# National Program 202: Soil Resource Management

**Assessment Team Meeting**
**February 1-2, 2005**
**Beltsville, Maryland**

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# Soil Resource Management National Program

**Overview:** Soil Resource Management is one of 22 National Programs within USDA-Agricultural Research Service (ARS). These National Programs are organized within four broad areas: Animal Production and Protection (APP); Natural Resources and Sustainable Agricultural Systems (NRSAS); Crop Production and Protection (CPP); and Nutrition, Food Safety/Quality (NFSQ). The Soil Resource Management National Program is part of NRSAS, but interaction also occurs with researchers in APP, CPP, and NFSQ. The National Program structure allows ARS to link scientists in laboratories around the country to address research problems of regional and national interest. Research in this National Program is conducted through 30 projects at 28 laboratories. The annual budget is approximately $23M and approximately 90 scientists are involved in the research.

Each National Program conducts a planning workshop to focus the research program by learning the problems and needs of customers, stakeholders and partners. These workshops help ensure that our research programs are relevant to the concerns of our constituents. Approximately 150 participants attended the planning workshop for this National Program including producers, commodity group representatives, public interest group representatives, scientists from universities, and scientists and administrators from ARS and other Federal and State agencies. The workshop participants felt that protecting, preserving, and enhancing the soil resource should be a key focus of this National Program. They believed that an overall understanding of soil properties and processes would allow development of soil management practices to ensure sustainable food, feed and fiber production while protecting the environment.

Based on input received at the planning workshop, research in the Soil Resource Management National Program was organized into five component areas: soil conservation and restoration, nutrient management, soil water, soil biology, and soil management systems. Teams of ARS scientists worked with members of the National Program Staff to develop an Action Plan that provided the framework for ARS research over a 5-year period. Each of the five components contained from three to five problem areas that required research. Groups of ARS scientists at each of the 28 laboratories wrote Project Plans that described the research they would conduct, the anticipated products or information to be generated by the research, roles and responsibilities of ARS scientists and their cooperators, and timelines and milestones to measure progress toward achieving the goals of the research. All the Project Plans were reviewed for scientific quality in December 2000 by a panel of experts in the field. ARS scientists used input from the panel to revise and improve their planned research.

The final stage in the cycle of an ARS National Program involves assessment of research that has been conducted. An expert panel is assembled to evaluate the impact of ARS research accomplishments and to offer suggestions for future ARS research direction and emphasis. Input from the expert panel and from interested parties at a planning workshop to be held February 22-23, 2005 in Dallas, Texas, will be used to develop the framework for ARS research over the next 5 years.

## Soil Conservation and Restoration Component

Soil is the major natural resource on which society depends for the production of food, feed, fiber, and wood products. 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 other soil physical, chemical, and biological properties and processes. Worldwide, erosion by water, wind, tillage, and irrigation remains a major cause of soil degradation and a primary environmental concern. Equipment traffic, grazing, and natural consolidation can cause soil compaction, which restricts root growth and movement of water, air, and chemicals. Poor land management can cause accelerated soil acidification and buildup of sodium and other soluble salts. Mining and industrial activities and improper use of municipal and industrial byproducts and animal manures can cause buildup of excess nutrients and toxic trace elements in soils. Degraded soils require restoration to support plant life and thus regain productivity. Land managers have means to remedy many of these conditions but the technologies are often too expensive, inefficient, or temporary. Effective and economically feasible methods are needed to control soil erosion, prevent soil compaction, and remediate soils degraded by soil erosion, compaction, or contamination.

Research within the Soil Conservation and Restoration Component of the Soil Resource Management National Program was conducted in three Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a planning workshop held at the start of the current five-year National Program cycle. The three Problem Areas are: (Problem Area 1) Erosion control practices, systems, and decision support tools are needed to protect our soil resources for future generations and to reduce the economic costs of soil erosion. (Problem Area 2) Methods are needed to measure, predict and ameliorate soil compaction. (Problem Area 3) Cost-effective methods are needed to remediate soils degraded by excess nutrients, salts, trace elements, and agricultural chemicals.

Soil conservation and restoration research is currently conducted by the following ARS locations: Ames, Iowa; Auburn, Alabama; Beltsville, Maryland; Bushland, Texas; Columbia, Missouri; Florence, South Carolina; Fresno, California; Ithaca, New York; Kimberly, Idaho; Lincoln, Nebraska; Lubbock, Texas; Mandan, North Dakota; Manhattan, Kansas; Morris, Minnesota; Oxford, Mississippi; Pendleton, Oregon; Pullman, Washington; Riverside, California; Saint Paul, Minnesota; Sidney, Montana; Temple, Texas; Tifton, Georgia; Watkinsville, Georgia; West Lafayette, Indiana.

## Soil Conservation and Restoration Component

**Problem Area 1:** Erosion control practices, systems, and decision support tools are needed to protect our soil resources for future generations and to reduce the economic costs of soil erosion.

**Background:** Soil erosion continues to be the principal threat to the long-term sustainability of American agriculture. It is estimated that over 2 billion tons of soil per year are lost from U.S. cropland because of rain- and wind-induced erosion. Erosion induced by irrigation, snowmelt, and tillage has not yet been estimated, but preliminary studies indicate that in affected regions the amount of soil loss per acre will rival that due to rain or wind. For several decades, the soil loss tolerance factor (T-value) has been used to assess rates of soil degradation from erosion. The T concept needs improvement to reflect current knowledge of soil formation plus the environmental and economic costs associated with off-site sediment. Prolonged exposure to wind-borne-particulates, including soil particulates, is suspected of causing health problems. Erosion models exist to predict off-site sediment delivery and atmospheric transport of soil particulates from agricultural areas, but need further technical refinement and improved user-friendliness. The economic costs associated with on-site crop productivity losses are debated but are undoubtedly important for long-term sustainability. One reason that on-site erosion loss estimates are controversial is the scientifically questionable assumption that soils eroding at less than the currently accepted "tolerance" limits are eroding at sustainable rates. Research must focus on integrated erosion control systems whose success is measured against soil erosion benchmarks that are scientifically sound and address the concerns of society. Estimates of soil erosion impacts need to include both on- and off-site erosional damage. Furthermore, on- and off-site damage evaluations need to be based on better scientific information regarding both short- and long-term impacts of erosion on crop productivity.

The goals of this research were:

Develop new, effective, and economical erosion control technologies, including strategies that use plants.

Develop economical approaches, methods, and technologies that lead to more accurate assessments of long-term soil erosion risks by rain, wind, tillage, snowmelt, and irrigation and capture information about erosional distributions on landscapes and in the atmosphere.

Develop a replacement for the T-value that incorporates current scientific knowledge about soil formation rates, sediment deposition and transport, and on- and off-site impacts.

Develop methods for determining tolerable erosion losses on a site-specific basis.

Establish more complete databases for erosion induced by irrigation, snowmelt, and tillage for use in model development; develop wind- and rain-induced erosion databases that include erosional distribution patterns; centralize erosion databases at appropriate locations for future use by erosion scientists.

Improve ARS erosion models (e.g., RUSLE, WEPP, RWEQ, WEPS) and continue development of the common, user-friendly, erosion model interface (MOSES), now underway.

Enhance the ability to predict the impact of management on erosion by rain, wind, irrigation, snowmelt, and tillage throughout the entire watershed and to predict the on- and off-site impacts of soil erosion.

**Accomplishments:**

**Development, testing, and deployment of practical, safe, economic and effective use of synthetic- and bio-polymers to prevent irrigation-induced erosion:** Irrigated agriculture is the highest yielding and most profitable agricultural sector, but because most is in arid environments with fragile soils, it is also vulnerable to erosion. Many conservation practices developed for rainfed conditions cannot meet the special constraints of irrigated farms, however, irrigation systems enable conservation options not possible under rainfed conditions. Since 1991 ARS scientists have investigated synthetic- and bio-polymer use to halt erosion. The most effective approach uses anionic polyacrylamide (PAM) formulations at very low application rates (one pound per acre per treated irrigation), usually resulting in seasonal applications of five to ten pounds per acre, with current PAM costs of about $2.50 per pound. Various bio-polymers are also effective, including natural or derived polymers of whey, starch, chitosan, polysaccharides and other sources. Bio-polymers are presently less effective than PAM but offer promise, especially for organic farms and as future alternatives to PAM as natural gas (the raw material for PAM) cost increases and availability declines. Erosion control is typically over 90%. Nutrients, pesticides, soil-borne microorganisms, weed seed and BOD in runoff are also greatly reduced, protecting receiving-water quality and reducing agri-chemical application needs. At low polymer application rates water infiltration is improved. High polymer application rates can be used to seal ditches and ponds to reduce seepage.

**Impact:** Polymer-based erosion control is used on about 2 million US acres of farmland and on construction sites. This versatile technology benefits farmers and all who require protection of surface water quality. Used knowledgeably polymers can increase water management options for irrigated farmers, conserve water and reduce nutrient leaching.

**Documentation:**


Sojka, R.E., R.D. Lentz, and D.T. Westermann. 1998. Water and erosion management with multiple applications of polyacrylamide in furrow irrigation. Soil Sci. Soc. Am. J. 62:1672-1680.

Orts, William J., Robert E. Sojka, Gregory M. Glenn, and Richard A. Gross. 1999. Preventing soil erosion with polymer additives. Polymer News 24:406-413.

Bjorneberg, D.L., and J.K. Aase. 2000. Multiple polyacrylamide applications for controlling sprinkler irrigation runoff and erosion. Applied Engineering in Agriculture 16(5):501-504.

Entry, J.A., and R.E. Sojka. 2000. The efficacy of polyacrylamide and related compounds to remove microorganisms and nutrients from animal wastewater. J. Environ. Qual. 29:1905-1914.

Lentz, R.D., and R.E. Sojka. 2000. Applying polymers to irrigation water: evaluating strategies for furrow erosion control. Trans. ASAE 43(6):1561-1568.
Entry, James A., R. E. Sojka, Maribeth Watwood, and Craig Ross. 2002. Polyacrylamide preparations for protection of water quality threatened by agricultural runoff contaminants. Environ. Pollut. 120:191-200.
Lentz, Rodrick D., Robert E. Sojka, and Bruce E. Mackey. 2002. Fate and efficacy of polyacrylamide applied in furrow irrigation: Full-advance and continuous treatments. J. Environ. Qual. 31:661-670.
Lentz, R.D., and D.L. Bjorneberg. 2003. Polyacrylamide and straw residue effects on irrigation furrow erosion and infiltration. J. Soil Water Conserv. 58(5):312-319.
Sojka, R.E., D.W. Morishita, J.A. Foerster, and M.J. Wille. 2003. Weed seed transport and weed establishment as affected by polyacrylamide in furrow-irrigated corn. J. Soil Water Conserv. 58(5):319-326.
Sojka, R.E., J. A. Entry, W J. Orts, D.W. Morishita, C.W. Ross, and D.J. Horne. 2003. Synthetic- and Bio-polymer use for runoff water quality management in irrigated agriculture. p. 3-130 - 3-136. In: M. Bruen (ed.) Proceedings of the 7th International Specialized Conference on Diffuse Pollution and Basin Management and 36th Scientific Meeting of the Estuarine and Coastal Sciences Association (ECSA), Dublin, Ireland. 17-22 Aug.

**Use of polyacrylamide (PAM) for erosion control in rainfed areas:** PAM has been used to reduce soil erosion, but the effectiveness of PAM for different soils and under different hydrologic conditions is yet to be quantified. Soil factors, such as clay and calcium contents and aggregate diameter were found to be most significant in affecting the PAM efficiency on rill erosion. PAM improved infiltration, which in turn decreased runoff and reduced erosion.

**Impact:** PAM can provide an alternative erosion control practice on critically eroding areas during vegetation establishment. This can save a large amount of soil from eroding, greatly reduce sediment loss, and potentially save millions of dollars in reconstruction costs.

**Documentation:**

Peterson, J.R., D.C. Flanagan, K.M. Robinson. 2003. Channel evolution and erosion in PAM-treated and untreated experimental waterways. Transactions of the American Society of Agricultural Engineers 46:1023-1031.
Peterson, J.R., D.C. Flanagan, J.K. Tishmack. 2002. PAM application method and electrolyte source effects on plot-scale runoff and erosion. Transactions of the American Society of Agricultural Engineers 45: 1859-1867.
Flanagan, D.C., K. Chaudhari, L.D. Norton. 2002. Polyacrylamide soil amendment effects on runoff and sediment yield on steep slopes: Part I. Simulated rainfall conditions. Transactions of the American Society of Agricultural Engineers 45 (5): 1327-1337.
Flanagan, D.C., K. Chaudhari, L.D. Norton. 2002. Polyacrylamide soil amendment effects on runoff and sediment yield on steep slopes: Part II. Natural rainfall conditions. Transactions of the American Society of Agricultural Engineers 45:1339-1351.
Peterson, J.R., D.C. Flanagan, J.K. Tishmack. 2002. Polyacrylamide and gypsiferous material effects on runoff and erosion under simulated rainfall. Transactions of the American Society of Agricultural Engineers 45: 1011-1019.

Flanagan, D.C., L.D. Norton, J.R. Peterson, K. Chaudhari. 2003. Using polyacrylamide to control erosion on agricultural and disturbed soils in rainfed areas. Journal of Soil and Water Conservation 58:301-311.

**Use of polyacrylamide in reducing crust formation and erosion:** Soil sealing on agricultural fields is a severe problem worldwide. The ensuing crust formation causes increased surface runoff and erosion, and decreased seedling emergence, resulting in on- and off-site problems affecting producers and communities. One possible soil sealing control measure is the application of polyacrylamide (PAM). PAM is a class of polymers, with varying characteristics that alter the properties of a given molecule. Researchers determined that a PAM polymer that has been partially hydrolyzed (20-30% of the amide groups replaced with hydroxyl groups) worked best in maintaining high infiltration rates in high clay soils when exposed to simulated rainfall. Sandy loams responded best to a moderately sized PAM molecule (12,000 molecular weight), regardless of the degree of hydrolysis. Poorly structured soils treated with PAM showed a three to five-fold increase in final infiltration rates, regardless of polymer configuration (20-40% hydrolysis, 6,000-18,000 molecular weight).

**Impact:** Soil crust formation and subsequent erosion can be reduced by a number of formulations of PAM. Producers, who want to include PAM as part of their management system, will be able to select the PAM molecular configuration most suited to their soil. The use of a PAM that has been selected for properties appropriate to a given soil can lead to saving soil, retaining fertility, and preventing pollution.

**Documentation**

Green, V.S., D.E. Stott, L.D. Norton and J.G. Graveel. 2000. Effect of polyacrylamide molecular weight and charge on infiltration under simulated rainfall. Soil Sci. Soc. Amer. J. 64:1786-1791.

Green, V.S., and D.E. Stott. 2001. Polyacrylamide: Use, effectiveness, and cost of a soil erosion control amendment. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds.). Sustaining the Global Farm - Selected papers from the 10th International Soil Conservation Organization Meeting, May 24-29, 1999, West Lafayette, IN. International Soil Conservation Organization in cooperation with the USDA and Purdue University, West Lafayette, IN. CD-ROM. USDA-ARS National Soil Erosion Laboratory, West Lafayette, IN. p. 384-389.

Green, V.S., D.E. Stott, J.G. Graveel, and L.D. Norton. 2004. Stability analysis of soil aggregates treated with anionic polyacrylamides of different molecular formulations. Soil Science 169:573-581.

**Use of soil amendments for erosion control:** Wind erosion degrades over 5 million ha of land worldwide each year. Control strategies are needed. Various types of amendments have been proposed to reduce wind erosion. We investigated the erosion control of tillage roughness, different densities of winter grain and frost-killed grain sorghum, post-harvest sorghum stubble, and surface applications of polycarylamide (PAM). Tillage roughness was very effective until rain smoothed the surface. Stubble was more effective at reducing wind erosion after rain but a combination of tillage and stubble was the most effective at controlling wind erosion. Though

PAM is reported to increase aggregation and reduce erosion, its application was not effective at controlling wind erosion or improving aggregate stability on these sandy soils.

**Impact:** A wide variety of different products and methods have been proposed to control wind erosion; however effectiveness needs to be accessed in lab and field studies before growers invest commit to using new methods. This research will assist growers, Cooperative Extension Personnel, and agricultural consultants in selecting the best management practices needed to control wind erosion using conventional dryland management practices.

**Documentation:**

Van Pelt, R.S., and T.M. Zobeck. 2004. Effects of polyacrylamide (PAM), cover crops, and crop residue management on wind erosion. Proc. of the 13$^{th}$ International Soil Conservation Organization Conference, July 2 – 9, 2004, Brisbane, Australia. 4 pp. (Proceedings on CD Rom).

**Grass hedges for erosion control:** Narrow strips of stiff, erect-growing grass are a biological erosion control practice that improves water quality by reducing sediment leaving fields. Hedges stop gully growth and keep fields farmable, work with conventional or reduced-tillage farming systems, and are suited to large as well as limited-resource farms. A team of ARS researchers (1) developed an equation relating depth of water flowing across a grass hedge to flow rate and vegetation characteristics; (2) determined the sediment trapping capacity of buffers under flume, plot, and field conditions; (3) demonstrated that hydraulic roughness of erect grass hedges was more important than width in buffering erosion due to the edge effects of enhanced growth, stem compression, and trapped residues; and (4) developed and validated a model that predicts hillslope evolution over time as a result of water erosion/deposition and tillage translocation processes. Based on this basic knowledge of the hydraulic and sediment trapping behavior of stiff-grass hedges, a national practice standard was drafted, field tested at a number of locations around the country, and officially adopted as an approved practice eligible for use in farm conservation plans and for cost sharing under NRCS' Environmental Quality Incentives Program (EQIP).

**Impact:** This research provided much of the basis for NRCS adding a national practice standard for Vegetative Barriers (Code 601) into its Field Office Technical Guide in March 2001 and for the assignment of conservation credit for grass strips within the Revised Universal Soil Loss Equation (RUSLE) so that producers get appropriate conservation credit for the adoption of buffer technology. Grass hedge technology has great potential worldwide as an inexpensive bio-technical alternative to structural measures for controlling ephemeral gullies and complements conservation tillage and residue management systems.

**Documentation:**

Dabney, S.M., D.C. Flanagan, D.C. Yoder, J. Zhu, and J. Douglas. 2001. Modeling temporal changes in erosion rates due to benching between vegetative barriers. *In:* Ascough, J.C., and D.C. Flanagan (eds.) Proceedings of the International Symposium on Soil Erosion Research for the 21st Century, 3-5 Jan 2001, Honolulu, HI. American Society of Agricultural Engineers, St. Joseph, MI. pp. 710-713.

Temple, D.M., and S.M. Dabney. 2001. Hydraulic performance testing of stiff grass hedges. Proceedings of the Seventh Interagency Sedimentation Conference 2:118-124.
Dabney, S.M. 2001. Tillage erosion: terrace relationships. Encyclopedia of Soil Science. Marcel Dekker, New York, NY pp. 1308-1310.
Jin, C.-X., S.M. Dabney, and M.J.M. Romkens. 2002. Trapped mulch increases sediment removal by vegetative filter strips: a flume study. Transactions of ASAE 45:929-939.
Dabney, S., F.D. Shields, Jr., D. Temple, A. Collison, and A. Simon. 2002. Layout and Establishment of Grass Hedges for Gully Control. Proceedings of the 12th Conference of the International Soil Conservation Organization. 26-31 May, Beijing, China. Volume III, p. 464-470.
Dabney, S.M. 2003. Erosion Control, Vegetative. Encyclopedia of Water Science. Marcel Dekker, New York, NY, pp. 209-213.
Zhu, J., S.M. Dabney, and D.C. Flanagan. 2003. Updating slope topography during erosion simulations with the water erosion prediction project model. Proceedings of the 10th Conference of the International Soil Conservation Organization. 23-27 May 1999. West Lafayette, IN pp. 882-887.

**Effectiveness of tree and grass species for erosion control in Kenya:** Soil erosion by water is a global problem and more so in the tropical regions due to the torrential nature of rainfall and highly erodible soils. ARS scientists from the National Soil Erosion Research Laboratory in collaboration with the CGIAR World Agroforestry Centre based in Nairobi, Kenya evaluated the effectiveness of various combinations of tree and grass species for erosion control and developed factors for the Revised Universal Soil Loss Equation (RUSLE) for Central Kenyan highland conditions. Calliandra-Napier grass combination hedges were found to be effective in controlling erosion on steep slopes while also providing N-rich fodder for on-farm animals. Using on-site field data and the RUSLE model, site-specific erosion hazards were identified in the test catchment for a wide array of cropping patterns and management practices. This work highlighted the severity of erosion in tropical highlands of east Africa and suggested possible intervention strategies such as terracing and the use of hedgerows.

**Impact:** Calliandra-Napier grass combination hedges are now used by small-scale farmers that use mixed farming systems in the Kenyan highland regions for erosion control. This should help preserve soil productivity in this region, and allow them to continue to feed their communities. RUSLE was adapted for Central Kenyan highland conditions, allowing local and regional land planners to target limited resources to the most erosive areas with erosion control measures tailored for the local conditions.

**Documentation:**

Angima, S.D., M.K. O'Neill, A.K., Omwega, and D.E. Stott. 2000. Use of tree/grass hedges for soil erosion control in the Central Kenyan Highlands. Journal of Soil and Water Conservation 55:478-482.
Angima, S.D., M.K. O'Neill, and D.E. Stott. 2001. On-farm assessment of contour hedges for soil and water conservation in Central Kenya. In: D.E. Stott, R.H. Mohtar and G.C. Steinhardt (eds.). Sustaining the Global Farm - Selected papers from the 10th International Soil Conservation Organization Meeting, May 24-29, 1999, West Lafayette,

IN. International Soil Conservation Organization in cooperation with the USDA and Purdue University, West Lafayette, IN. CD-ROM. USDA-ARS National Soil Erosion Laboratory, West Lafayette, IN. p.390-394.
Angima, S.D., D.E. Stott, M.K. O'Neill, C.K. Ong, and G.A. Weesies. 2002. Use of calliandra-Napier grass contour hedges to control erosion in central Kenya. Agriculture, Ecosystems and Environment 91:15-23.
Angima, S.D., D.E. Stott, M.K. O'Neill, C.K. Ong, and G.A. Weesies. 2003. Soil erosion prediction using RUSLE for central Kenyan Highland conditions. Agriculture, Ecosystems and Environment 97:295-308.

**Soil erosion from post-CRP lands:** Post-Conservation Reserve Program (CRP) land was evaluated for water erosion by ARS researchers. Runoff, erosion, and soil erodibility were measured on CRP under no-till (NT) and conventional-till (CT) crop production and CRP left in grass as permanent hayland (PH). Under the conditions of this study (4% land slope, loam soil), the cropped NT land had the same low erodibility as the annually hayed PH. The moderate pre-plant disk tillage of the CT raised erodibility 6-fold.

**Impact:** This information is of particular use in designing new management strategies for lands moving out of CRP. Since 1982, 10.7 million acres have been converted from CRP back to cultivation in the Northern Great Plains. These results show the importance of using no-till agricultural practices during such conversion to reduce on-site erodibility. This information is of great interest to soil conservationists, and demonstrates the value of a wheat-dominated continuous crop rotation combined with no-till management.

**Documentation:**

Merrill, S.D., C. Huang, T.M. Zobeck, and D.L. Tanaka. 2002. Use of the chain set for scale-sensitive erosion-relevant measurement of soil surface roughness. Proceedings 10th International Soil Conservation Organization Conference. CD-ROM.
Zheng, F., S.D. Merrill, C.H. Huang, D.L. Tanaka, F. Darboux, M.A. Liebig, and A.D. Halvorson. 2004. Runoff, soil erosion, and erodibility on Conservation Reserve Program Land under crop and hay production. Soil Sci. Soc. Am J. 68: 1332-1341. Log no. 138330

**Conservation benefits of large biomass soybeans:** Conventional soybeans produce much less crop residue than corn and many times fall below soil conservation targets. Large biomass soybeans produce more crop residues than conventional soybeans. Of the 60 million acres of soybeans planted in the U.S. yearly about 20 million of these are planted on highly erodible lands. In 2004 ARS scientists released a new large biomass multiple-use soybean ‘Tara’ (Plant Variety Protection Certificate #200300172 dated January 20, 2004). An exclusive license to market ‘Tara’ was granted to Southern States Cooperative Inc. The large biomass soybean variety produced levels of crop residue acceptable for soil conservation. The increased crop residue levels from ‘Tara’ were detectable using the advanced remote sensing techniques developed in this project.

**Impact:** Large biomass soybeans provide soybean producers with conservation benefits by reducing soil erosion and increasing carbon sequestration without sacrificing grain yields. In its first year of release 'Tara' has been increased to 850 bushels of foundation seed stocks with an estimated value of $750,000. "Tara" will provide increased crop residues for soil conservation to soybean farmers especially on highly erodible land.

**Documentation:**

Devine, T.E., and J.E. McMurtrey III. 2004. Registration of 'Tara' Soybean. Crop Science. 44:1020-1021.

Wu, S., Y.-C. Lu, J.E. McMurtrey, G. Weeies, T.E. Devine, and G.R Foster. 2004. Soil conservation benefits of large biomass soybean (LBS) for increasing crop residue cover. Journal of Sustainable Agriculture 24(1):107-128.

McMurtrey, J.E., C.S.T. Daughtry, T.E. Devine, and L.A. Corp. 2004. Spectral detection of crop residues for soil conservation from conventional and large biomass soybean. Agronomie (In press).

**Global change impact on erosion rates**: Expected changes in rainfall erosivity for the United States during the 21st century may have significant impacts on local and national soil conservation strategies. Results of climate change scenarios from two coupled Atmosphere-Ocean Global Climate Models were used to investigate the possible levels and patterns of change that might be expected over the 21st century. The results show cause for concern. Rainfall erosivity levels may be on the rise across much of the United States. Where rainfall amounts increase, erosion and runoff will increase at an even greater rate: the ratio of erosion increase to annual rainfall increase is on the order of 1.7. Even in cases where annual rainfall would decrease, system feedbacks related to decreased biomass production could lead to greater susceptibility of the soil to erode. Results also show how farmers' response to climate change can potentially exacerbate, or ameliorate, the changes in erosion rates expected. This will allow the United States to adjust predictions of erosion rates for purposes of conservation compliance relative to farm programs.

**Impact:** With climate change, rainfall erosivity levels may rise across much of the United States, leading to increased potential for erosion and runoff. The new coupled model, developed here, allows land managers and planners to adjust predictions of erosion rates for purposes of conservation compliance relative to farm programs.

**Documentation:**

Nearing, M.A. 2001. Impacts of climate change on erosivity in the United States: 2000- 2050. In: J.C. Ascough and D.C. Flanagan (eds.) Soil Erosion for the 21st Century. Proceedings of the International Symposium, January 3-5, 2001, Honolulu, Hawaii. 2001. pp. 268-270.

Nearing, M.A. 2001. Potential changes in rainfall erosivity in the US with climate change during the 21(st) century. Journal of Soil and Water Conservation 56: 229-232.

Pruski, F.F., and M.A. Nearing. 2002. Climate-induced change in erosion during the 21st century for eight US locations. Water Resources Research 38: Article No. 1298.

Pruski, F.F., and M.A. Nearing. 2002. Runoff and soil-loss responses to changes in precipitation: A computer simulation study. Journal of Soil and Water Conservation 57: 7-16.

Nearing, M.A., F.F. Pruski, and M.R. O'Neal. 2004. Expected climate change impacts on soil

erosion rates: A review. Journal of Soil and Water Conservation 59: 43-50.
Zhang, X.C., and M.A. Nearing. 2004. Downscaling monthly forecasts to simulate impacts of climate change on soil erosion and wheat production. Soil Science Society of America Journal 68: 1376-1385.

**Soil erosion from diverse crop residues:** The amount of soil coverage by crop residues was found to vary after spring seeding of various crops under no-till management. No-till assures that soil coverage in the erosion-vulnerable period right after seeding is fairly high if crop sequences contain small grain (wheat, barley), flax, and mustard family (canola, etc.) crops. However, if back-to-back sequences of pulses (soybean, dry pea, dry bean) or sunflower crops are grown, soil coverage levels approach the 30% level of marginal soil protection. Observations were made in years of average to above average rainfall; drought combined with back-to-back sequences of lower residue-producing crops will lead to unacceptably low levels of soil coverage and greatly increased soil erosion hazard.

**Impact:** The application of no-till agricultural systems incorporating a diversity of crop choices provides producers with alternatives in crop selection. This work provides needed information for these systems regarding the protection of our soil resource. Beneficiaries of this work are crop producers whose goal is to move from traditional wheat-fallow systems to sustainable diverse cropping systems.

**Documentation:**
Zobeck, T.M., T.W. Popham, E.L. Skidmore, J.A. Lamb, S.D. Merrill, M.J. Lindstrom, D.L. Mokma, and R.E. Yoder. 2003. Aggregate-mean diameter and wind-erodible soil predictions using dry aggregate-size distributions. Soil Sci. Soc. Am. J. 67:425-436.
Merrill, S. D., D. L. Tanaka, T. M. Zobeck, J. E. Stout, J. M. Krupinsky, and L. J. Hagen. 2004. Effects of tillage and fallowing on wind erosion in sunflower stubble land. *In* Proceedings of the 26th Sunflower Research Workshop Forum. Jan. 14-15th, 2004. National Sunflower Association, Bismarck, ND. Available: http://www.sunflowernsa.com.

**Soil roughness evolution on depressional storage and runoff initiation**: Soil roughness was analyzed and evaluated for depressional storage and runoff initiation. Maps made at various scales of soil surfaces exposed to a sequence of rainstorms showed a gradual decrease in roughness after each additional rainfall, and that all roughness scales were affected similarly. Also, there was a distinct topographic length that can be correlated to depressional storage capacity. The results also showed the sensitivity from a small change in microtopography to runoff initiation, indicating the need to define the soil surface geometry. To facilitate the measurement of soil roughness in the field, a new type of laser scanner was developed. The new laser scanner automatically digitizes surface topography at millimeter grids with sub-millimeter resolutions, producing data sets with 100 to 1000 times more detail and better quality than the traditional pin meter. Additionally, it was found that although increased roughness at low slopes decreased erosion, at high slopes, roughness could increase erosion due to the development of concentrated flow patterns.

**Impact:** Surface processes, such as depressional storage filling, runoff initiation and flow routing are affected by surface microtopography. The research showed the need to collect detailed topographic data (by using the laser scanning technology) and to perform topographic analysis in order to better understand the dynamic processes occurring on the surface. This is an area of research that has not been fully explored. The new laser scanner that was developed for this work produces finer detailed maps of the soil surface microtopography and is in use by many research groups around the world.

**Documentation:**

Darboux, F., and C.H. Huang. 2001. Contrasting effects of surface roughness on erosion and runoff. Soil Erosion Research for the 21st Century, Proceedings: 143-146.

Huang, C.; C. Gascuel-Odoux, and S. Cros-Cayot. 2002. Hillslope topographic and hydrologic effects on overland flow and erosion. Catena 46:177-188.

Darboux, F., and C.H. Huang. 2003. An instantaneous-profile laser scanner to measure soil surface microtopography. Soil Science Society of America Journal 67:92-99.

**Soil Ca:Mg ratio and its impact on soil structure and erodibility:** Calcium and magnesium, which are frequently added to soil as gypsum or lime amendments, may impact surface properties of soils. Research on the effect of exchangeable Ca and Mg on surface properties of soil clays to determine their effect on water sorption, and other properties was conducted by ARS scientists and university cooperators. The research showed that Mg amendments sorbed 25% more water than Ca systems in soil clays, and caused more dispersion. Field applications of Mg-containing liming materials will result in less available water and nitrogen for plants and therefore, may limit yields compared to high Ca liming materials and may increase the susceptibility of these soils to erosion by causing greater clay dispersion. Farmers and land-managers that have soil with poor infiltration may ameliorate the problem with applications of Ca-rich amendments.

**Impact:** Producers with poorly infiltrating soils can switch to using high calcium liming materials or other calcium-rich amendments such as byproducts from coal combustion. The resulting increases in infiltration will increase water availability to their crops, thereby improving yields.

**Documentation:**

Dontsova, K.M., and L.D. Norton. 2002. Clay dispersion, infiltration, and erosion as influenced by exchangeable Ca and Mg. Soil Science 167:184-193.

Zhang, X.C., and L.D. Norton. 2002. Effect of exchangeable Mg on saturated hydraulic conductivity, disaggregation and clay dispersion of disturbed soils. Journal of Hydrology 260:194-205.

Dontsova, K.M., L.D. Norton, C.T. Johnston, and J.M. Bigham. 2004. Influence of exchangeable cations on water adsorption by soil clays. Soil Science Society or America Journal, 68: 1218-1227.

**Cropping systems affect surface soil properties:** The effect of cropping systems on surface soil properties need to be documented because they affect wind and water erosion. Information on surface aggregation and roughness are used in wind and water erosion prediction equations that provide information to USDA NRCS programs. Distribution of aggregates on the soil surface was accurately and precisely described by the statistical Weibull distribution. In taking measurements, it was important that aggregate size distributions were determined using standard sieve sizes. Soil surface roughness differed with soils and tillage tools for most roughness measurements tested. Roughness could be classified into three general groups based on tillage tools. Ridging tools produced the greatest surface roughness while chisels, knife sweeps and cultivators produced the least surface roughness. Models were developed that estimated change in surface roughness with cumulative rainfall.

**Impact:** Accurate measurements of wind and water erosion are needed to determine the effects of conservation programs in the National Resources Inventory and to determine program compliance. Beneficiaries of this research will be Cooperative Extension Service personnel, NRCS, Technical Service Providers and other agricultural consultants developing and using models to estimate wind and water erosion.

**Documentation**:

Zobeck, T.M., and T.W. Popham. 2001. Cropping and Tillage Effects on Soil Roughness Indexes. Trans. ASAE 44(6):1527-1536.

Zobeck, T.M., T.W. Popham, E.L. Skidmore, S.D. Merrill, M.J. Lindstrom, D.L. Mokma, R.E. Yoder, and J.A. Lamb. 2003. Aggregate mean diameter and wind erodible soil predictions using dry aggregate-size distributions. Soil Sci. Soc. Am J. 67(2): 425-436.

**RUSLE2 development and implementation:** During the last 50 years, soil conservation planning and upland erosion control at the field scale almost exclusively depended on the Universal Soil Loss Equation (USLE). In the last 10 years, this technology, now named the Revised Universal Soil Loss Equation (RUSLE), was appreciably upgraded and additional data sets were incorporated to broaden its applicability. Recent findings, based upon a combination of rainfall simulator and natural rainfall-runoff studies showed that: (1) no-till improved surface soil quality, but this reduced runoff much more during summer months than during winter months when saturated subsoils limited infiltration, (2) resistance to sheet and rill erosion following tillage of long-term no-till areas was greater than predicted by RUSLE but this protection was lost within one year if crop residue cover was not reestablished, (3) tillage of no-till soil greatly increased the risk of concentrated-flow erosion if runoff was permitted to accumulate on long slopes, and (4) tillage erosion caused as much soil degradation as water erosion on sloping lands in the Mid-South.

**Impact:** The development of RUSLE2 technology as a conservation planning tool for soil erosion by water is of national importance. RUSLE2 is being implemented in all NRCS field offices and has been adopted by USDI-OSM (Office of Surface Mining) and by USDI-BLM (Bureau of Land Management) as well as other federal, state, and local agencies.

**Documentation:**

Dabney, S.M., R.L. Raper, L.D. Meyer, and C.E. Murphree. 2000. Management and subsurface

effects on runoff and sediment yield from small watersheds. Int. J. Sed. Res. 15(2):217-232.
Romkens, M.J., G. Govers, S.M. Dabney, and J.M. Bradford. 2002. Soil erosion by water and tillage. chapter in Methods of Soil Analysis, Part 4. Soil Science Society of America Monograph series. pp.1621-1662.
McGregor, K.C., R.F. Cullum, J.D. Schreiber, S.M. Dabney, G.V. Wilson, and J.R. Johnson. 2002. Development of Erosion control tillage systems for cotton, corn, soybean, and ryegrass. Mississippi Ag. and For. Expt. Sta. Research Report.
Wilson, G.V., K.C. McGregor, and S.M. Dabney. 2002. Effects of tillage and residue management on runoff and erosion. Mississippi Water Resources Research Conference Proceedings. pp. 164-175.
Wilson, G.V., S.M. Dabney, and K.C. McGregor. 2004. Tillage and residue effects on runoff and erosion dynamics. Transactions of ASAE 47(1):119-128.
Dabney, S.M., G.V. Wilson, K.C. McGregor, and G.R. Foster. 2004. History, residue, and tillage effects on erosion of loessial soil. Trans. ASAE 47(3):767-775.

**Unique theory and model requirements of irrigation-induced erosion:** Irrigation-induced soil erosion is affected by soil physical and chemical factors that exist in different combinations or intensities than with rain-induced erosion. ARS scientists found that factors unique to irrigation, such as instantaneous wetting of hot dry soil, soil and water salinity and sodicity, and systematic spatial variation in furrow water infiltration and runoff, variable water temperature affects and others affected erosion modeling parameters and the ability to accurately predict irrigation-induced erosion and infiltration using models and model parameters derived from rainfed conditions and processes used for describing rain-induced erosion. Many of the rain-derived model parameters are arrived at statistically from storm intensity and frequency factors, which bear no relationship to controlled repetitive irrigation events. Furrow irrigation, for example, has no splash component; due to infiltration along the furrow, water streams decrease downslope rather than increasing; water salinity and sodicity are often significantly different from rainwater and greatly affect soil detachment, dispersion, surface sealing and subsequent sediment transport, which ultimately govern infiltration, runoff and erosion.

**Impact:** These findings are providing the basis for improved predictive models, which will be used by conservationists, and land managers to better protect irrigated agriculture, which on average is the agricultural sector that is the highest yielding and most profitable per acre, yet also is the most vulnerable to erosion impairment.

**Documentation:**

Lehrsch, Gary A. 1998. Freeze-thaw cycles increase near-surface aggregate stability. Soil Sci. 163(1):63-70.
Bjorneberg, D.L., T.J. Trout, R.E. Sojka, and J.K. Aase. 1999. Evaluating WEPP-predicted infiltration, runoff, and soil erosion for furrow irrigation. Trans. ASAE 42(6):1733-1741.
Bjorneberg, D.L., D.C. Kincaid, R.D. Lentz, R.E. Sojka, and T.J. Trout. 2000. Unique aspects of modeling irrigation-induced soil erosion. Int. J. Sediment Res. 15(2):245-252.
Bjorneberg, D.L. 2001. Evaluating WEPP-predicted furrow irrigation erosion. p. 673-676. In: J.

C. Ascough, II, and D. C. Flanagan (ed.) Soil erosion research for the 21st Century. Proc. Int. Symp., Honolulu, HI. 3-5 Jan. 2001. ASAE, St. Joseph, MI.

Bjorneberg, D.L., R.E. Sojka, and J.K. Aase. 2002. Pre-wetting effect on furrow irrigation erosion: A field study. Trans. ASAE 45(3):717-722.

Kincaid, D.C. 2002. The WEPP model for runoff and erosion prediction under sprinkler irrigation. Trans. ASAE 45(1):67-72.

Strelkoff, Theodor S., and David L. Bjorneberg. 2002. Hydraulic modeling of irrigation-induced furrow erosion. p. 699-705. In: D. E. Stott, R. H. Mohtar and G. C. Steinhardt (eds). 2001. Sustaining the Global Farm. Proc. 10th International Soil Conservation Organization Meeting, May 24-29, 1999, Purdue Univ. and USDA-ARS National Soil Erosion Res. Lab., published on CD-ROM.

**Validation of wind erosion models:** Computer models predicting the effects of climate and soil management practices on wind erosion are commonly used by extension and regulatory agencies to determine compliance with public policy. The accuracy of these models has not previously been compared with actual wind erosion measurements from multiple locations and events. The Wind Erosion Equation (WEQ) that is used by the Natural Resources Conservation Service (NRCS) of the USDA and a proposed replacement model, the Revised Wind Erosion Equation (RWEQ) were tested using available weather data and soil conditions for six sites across the United States. In addition, the Wind Erosion Stochastic Simulator (WESS) subcomponent of the Environmental Policy Integrated Climate (EPIC) model was tested using weather data and soil conditions for 24 randomly chosen wind erosion events of varying magnitude observed at Big Spring, Texas during the period from 1989 to 1997. WEQ was found to be reasonably accurate for locations in eastern Colorado and western Kansas, but only predicted 53% of the observed erosion at Big Spring, Texas for 7 years of record. However, its accuracy could be greatly improved by varying the soil or climate factors outside of the table of commonly used values. WESS was found to be reasonably accurate for medium intensity events, but tended to over-estimate the erosion from low intensity events and under-estimate the erosion from high-intensity events. Over all, RWEQ was the most accurate model for all sites and events compared.

**Impact:** This study indicated that WEQ, the model currently used in the United States to make policy decisions, is in critical need of replacement or local calibration. The investigation also indicated that there may be problems with the algorithms used to predict erosion processes in field soils and that further research is necessary in the driving forces and resultant processes that control wind erosion rates.

**Documentation:**

Van Pelt, R.S., T.M. Zobeck, K.N. Potter, J.E. Stout, and T.M. Popham. 2004. Validation of the wind erosion stochastic simulator (WESS) and the revised wind erosion equation (RWEQ) for single events. Env. Modelling and Software 19:191-198.

Van Pelt, R.S., and T.M. Zobeck. 2004. Validation of the wind erosion equation (WEQ) for discrete periods. Env. Modelling and Software 19:199-203.

**Remote sensing crop residue cover:** Crop residues on the soil surface play significant roles in the surface energy balance, net primary productivity, nutrient cycling, and carbon sequestration.

Current methods of measuring crop residue cover are inadequate for objectively assessing many fields in a timely manner. Traditional remote sensing techniques have had difficulty discriminating crop residues from soils because as crop residues weather and decompose, they may be brighter or darker than the soil. An innovative remote sensing technique was developed based on a broad absorption band near 2100 nm that is present in crop residues but is absent in soils. The relative depth of this absorption feature, defined as the cellulose absorption index (CAI), is linearly related to crop residue cover for ground-based, aircraft, and satellite spectral data. Remotely sensed estimates of crop residue cover will allow local and regional assessments of the effectiveness of conservation practices.

**Impact:** This research will benefit farmers and NRCS by providing objective, quantitative assessments of crop residue cover. This information is also crucial for accurately monitoring the effectiveness of soil conservation practices at local and regional-scales.

**Documentation:**


Daughtry, C.S.T. 2001. Discriminating crop residues from soil by shortwave infrared reflectance. Agronomy Journal 93:125-131.

Barnes, E.M., K.A. Sudduth, J.W. Hummel, S.M., Lesch, D.L. Corwin, C. Yang, C.S.T. Daughtry, and W.C. Bausch. 2003. Remote - and ground-based sensor techniques to map soil properties. Photogrammetric Engineering and Remote Sensing 69:619-630.

Nagler, P.L., Y. Inoue, E.P. Glenn, A.L. Russ, and C.S.T. Daughtry. 2003. Cellulose absorption index (CAI) to quantify mixed soil-plant litter scenes, Remote Sensing of Environment 87:310-325.

Daughtry, C.S.T., E.R. Hunt Jr., and J.E. , McMurtrey III. 2004. Assessing crop residue cover by shortwave infrared reflectance. Remote Sensing of Environment 90:126-134.

## Soil Conservation and Restoration Component

**Problem Area 2:** Methods are needed to measure, predict and ameliorate soil compaction.

**Background:** Soil compaction reduces soil pore volume. This fundamental change within the soil may result from human or natural forces and produces numerous changes in soil properties and processes. Some of the changes are immediate, and others may not occur until years later. Changes in infiltration, soil surface crusting and sealing, soil erosion, root proliferation, weed infestation, root and crown diseases, nutrient cycling, soil aeration, resistance to rooting, water percolation and evaporation, soil structure, and chemical movement are only some of the impacts of soil compaction. Susceptibility to and impacts of compaction differ among major land resource areas of the U.S. Soils in transition from conventional tillage systems to reduced tillage systems are particularly susceptible to soil compaction, and this effect has site-specific significance. Effective preventive and remediation strategies for compaction are needed. Such strategies may consist of precise zones of tillage instead of the traditional full-field approaches, and/or more induced biological activity by use of cover crops, crop rotations, soil amendments, and alternative introduction of crop residues into the soil. Unique methods of tillage, including non-inversion tillage, which maintains large amounts of surface residue cover, may help alleviate soil compaction while allowing transition from conventional to conservation tillage systems.

The goals of this research were:

Develop a basic understanding of the effects of natural forces and management practices on the physical properties of compacted surface soils.

Determine methods of evaluating or diagnosing soil compaction, especially in areas not previously thought to be subject to severe soil compaction, e.g., irrigated fields, pastures.

Develop mechanical and nonmechanical methods to minimize soil compaction from machinery operations and grazing.

Create soil conditions more conducive to penetration of compacted layers by roots and seedlings through use of alternative cropping systems, cover crops, and soil amendments.

Develop improved technology to measure and ameliorate site-specific soil compaction with emphasis on reducing tillage energy requirements through improved management of soil properties.

**Accomplishments:**

**Selecting the best subsoilers for conservation tillage systems:** Selecting the best implement for eliminating compacted soil layers and producing optimum crop yields is mostly driven by implement cost. However, implements for deep tillage vary in their ability to maintain crop residues on the soil surface, which is extremely important for conservation tillage systems. Soil bin and field experiments were conducted which compared several deep tillage implements which are commonly used for soil compaction disruption. Results from this experiment showed that bentleg shanks maintained the highest amount of crop residue on the soil surface while not requiring additional force to disrupt compacted soil profiles.

**Impact:** Producers and their advisors including NRCS will benefit from the knowledge that deep tillage using bentleg shanks can be used to manage soil compaction while maintaining the maximum amount of crop residue on the soil surface

**Documentation**

Raper, R.L. 2002. Force requirements and soil disruption of straight and bentleg subsoilers for conservation tillage systems. ASAE Paper No. 02-1139. ASAE, St. Joseph, MI. 17 pp.

Raper, R.L. 2004. Selecting Subsoilers to Reduce Soil Compaction and Minimize Residue Burial. Proceedings of the 2004 CIGR International Conference, Beijing, China, 11-14 October.

**Using soil moisture to determine when to subsoil:** Breaking up compacted soil layers using tillage is necessary for many U.S. soils. However, the energy costs can be substantial. Also, tillage could result in excessive surface soil disruption that could unnecessarily expose bare soil to rainfall. A portable tillage profiler (PTP) using a laser scanner has been developed that allows field evaluations of aboveground and belowground tillage disruption to be obtained. An experiment was conducted to determine the energy requirements and the soil disturbance (as measured by the PTP) caused by two subsoilers, a straight shank and a "minimum-tillage" shank at four moisture contents in a Coastal Plains soil. The results showed that increased energy requirements and increased soil disturbance resulted from subsoiling at extremely dry conditions. A "minimum-tillage" shank required more energy than the straight shank but also caused more soil disturbance on the soil surface. Results indicate that producers wishing to subsoil to disrupt compacted soil layers should not operate at either extreme of soil moisture. Subsoiling in extremely wet soil conditions may lead to additional compaction due to vehicle traffic. Subsoiling in extremely dry soil conditions may increase energy requirements and surface disruption.

**Impact:** Though many producers believe that newer "minimum-tillage" shanks have similar draft requirements as older, straight shanks, this research indicates that even though the soil surface is disturbed less by these new shanks, they require additional horsepower. More importantly, producers are given information, which they can use to determine when to subsoil (from a soil moisture standpoint) to reduce horsepower requirements and minimally disrupt the soil surface.

**Documentation**

Raper, R.L., and T.E. Grift. 2002. Land laser: alternative measuring device records tillage effects. Resource Magazine, April.

Raper, R.L., and A.K. Sharma. 2002. Using soil moisture to determine when to subsoil. Proceedings of the 25th Annual Southern Conservation Tillage for Sustainable Agriculture, Auburn, AL. June 24-26.

Raper, R.L., T.E. Grift, and M.Z. Tekeste. 2004. A portable tillage profiler for measuring

subsoiling disruption. Transactions of ASAE 47(1): 23-27.
Raper, R.L., and A.K. Sharma. 2004. Soil moisture effects on energy requirements and soil disruption of subsoiling a coastal plains soil. Transactions of ASAE (In press).

**Tillage management of compacted soils:** Southeastern Coastal Plain soils have a number of interlinking problems that pose an environmental threat and cause poor yields: Compacted subsurface layers that restrict root growth and yield; erratic rainfall that leads to short-term droughts because sandy soils hold little water and the environment is hot; and intensive rainfall rates that leach nutrients out of the root zone and into the groundwater. These problems can be alleviated by non-inversion deep tillage that shatters compacted layers and promotes root growth so more water and nutrients will be available. Unfortunately deep tillage is not permanent because re-compaction, though incomplete, can be root limiting; and deep tillage often needs to be performed annually which is expensive in terms of energy, labor, and the need for large equipment. Relationships were developed that help explain the effect of compaction on yield; and, using these relationships, management systems were developed that can help alleviate compaction or circumvent deep tillage. For relatively complete loosening of the compacted subsurface layer in narrow row crop management, each 10 atmosphere decrease of soil strength increased corn yield 20 to 50 bushels per acre; similar relationships were found for soybean and corn. Even though most deep tillage is performed annually, residual effects of loosening persist for 6 years or more re-compacting slower with decreased rainfall amount. When producers are growing crops that respond to deep tillage, they can test soils for strength to determine whether or not deep tillage will boost yield enough to be beneficial. For different crops, deep tillage annually may not always be necessary. For example, for cotton planted in conventionally wide (38”) rows, annual deep tillage increased root growth but not yield, leading to the possibility that cotton growers could skip deep tillage for a year or two. When producers grow crops that do not respond to the deep tillage they can temporarily discontinue deep tillage, though they must be careful to maintain soil loose enough so that roots can scavenge nutrients before they enter the groundwater.

**Impact:** This work represents an advance in tillage management by helping explain how soils re-compact with rainfall, by quantifying potential yield increases when compaction is reduced in southeastern Coastal Plain soils, and by finding that not all crops may need annual deep tillage. These results can help producers and their advisors know when deep tillage will be advantageous and when it can be removed from the management system, saving time, energy, and wear and tear on machinery.

**Documentation:**

Busscher, W.J., J.R. Frederick, and P.J. Bauer. 2001. Effect of penetration resistance and timing of rain on grain yield of narrow-row corn in a coastal plain loamy sand. Soil and Tillage Research 63:15-24.
Busscher, W.J., P.J. Bauer, and J.R. Frederick. 2002. Recompaction of a coastal loamy sand after deep tillage as a function of subsequent cumulative rainfall. Soil and Tillage Research 68(1):49-57.
Bauer, P.J., J.R. Frederick, and W.J. Busscher. 2002. Tillage effect on nutrient stratification in narrow- and wide-row cropping systems. Soil and Tillage Research 66:175-182.

Busscher, W.J., and P.J. Bauer. 2003. Soil strength, cotton root growth and lint yield in a southeastern USA coastal loamy sand. Soil and Tillage Research 74(2):151-159.

**Management practices to minimize the effects of soil surface crusts on seedling emergence:** Many of the processes that define soil productivity are governed at the soil-atmosphere interface; however, raindrop impact and aggregate dispersion form a thin soil surface layer or crust that is less porous and less conductive than the underlying bulk soil. Soil crusts reduce infiltration, increase runoff and water erosion, and physically impede crop seedlings emergence. The effects of raindrop impact and surface soil geometry on crust formation, soil strength, and seedling emergence were quantified. Compared with intercepted drop impact conditions, normal drop impact reduced infiltration and formed thicker, stronger crusts that prevented seedling emergence and were unaffected by modified surface geometry. Intercepting raindrop impact using, for example, a residue mulch appeared to be one of the most effective management practices to prevent crust formation and increase seedling emergence.

**Impact:** The results of this research showed that soil management to retain residue cover on the soil surface to intercept crust forming raindrop impact was the appropriate choice for minimizing crust formation and improving seedling emergences. This information is relevant to agricultural producers and their advisors for implementing residue management practices that affect crop establishment and growth.

**Documentation:**

Baumhardt, R.L., P.W. Unger, and T.H Dao. 2004. Seedbed surface geometry effects on soil crusting and seedling emergence. Agron. J. 96:1112-1117.

Baumhardt, R.L., and R.C. Schwartz. 2004. Crusts. Encyclopedia of Soils in the Environment, Elsevier Science Ltd., NY (in press).

**Interpreting relationship of soil strength to bulk density and water content for better compaction management in Pacific Northwest soils:** Soil compaction can impede root penetration in the soil profile and reduce the yield and quality of many agricultural crops, but especially root crops, which are particularly important to irrigated farmers of the western US. There is only limited information on the fundamental relationships between soil strength, bulk density and water content for soils in general, but especially for the highly calcareous soils of the Pacific Northwest. Research showed that because of calcium carbonate cementation effects for the Portneuf soil, soil strength was far more affected by water content than bulk density over the typical range of bulk densities encountered in a cropped field. Also, the strength at a given water content was likely dependent upon whether the soil was in drying cycle or a wetting cycle, because of the time needed to dissolve calcium carbonate cementation between soil particles. The data of soil strength regressed against bulk density and water content was the first produced for the Portneuf soil.

**Impact:** This information showed the difficulty of assuring subsoiling benefit for highly calcareous soils with spring subsoiling. It also underscored the unreliability of sparse assessments of soil strength via bulk density sampling for determination of soil quality in calcareous Pacific Northwest soils.

**Documentation:**

Sojka, R.E. 1999. Physical aspects of soils of disturbed ground. Chapter 21, pp. 503-519. In: Ecosystems of the World 16: Ecosystems of Disturbed Ground.

Aase, J.K., D.L. Bjorneberg, and R.E. Sojka. 2001. Zone-subsoiling relationships to bulk density and cone index on a furrow-irrigated soil. Trans. ASAE 44(3):577-583.

Sojka, R.E., W.J. Busscher, and G.A. Lehrsch. 2001. In situ strength, bulk density, and water content relationships of a *durinodic xeric haplocalcid* soil. Soil Sci. 166(8):520-529.

**Incremental bulk density temporal changes due to management and climate:** Compaction is one of the major concerns facing farm managers today. Compaction measured as bulk density in 2 - cm depth increments showed differences over time under changing management practices. The temporal variability was greater than differences due to management. Crop yields were not affected by soil density, even beyond limits considered to impede crop growth. Soil fracture pathways allowed root growth, water infiltration, and gas exchange even when overall density was large.

**Impact:** This information is important to scientists and any one who makes recommendations to farm managers on whether compaction is impacting crop yield. The technique is useful to researchers who want to examine soil properties in smaller depth increments.

**Documentation**:

Logsdon, S.D., and Cambardella, C.A. 2000. Temporal changes in small depth-incremental soil bulk density. Soil Sci. Soc. Am. J. 64:710-714.

Logsdon, S.D., and D.L. Karlen. 2004. Bulk density as a soil quality indicator during conversion to no-tillage. Soil Tillage Res. 78:143-149.

**Freeze-thaw amelioration of compacted soils on military lands:** Military land-use planners must manage federal lands to meet the need for regular, realistic military training while also maintaining environmental quality. However, some military training may affect soil erodibility and runoff erosivity by compacting and rutting soil and damaging vegetation. In collaboration with Washington State University, USDA-ARS and the USACE Cold Regions Research and Engineering Lab (CRREL), the impacts of freeze-thaw cycles on soil erodibility and runoff erosivity of compacted and uncompacted soil on military training land was investigated. These studies a) established the magnitude of the differences between uncompacted soil and soil compacted by military tanks with emphasis on how surface topography of tank ruts change with time; b) how compacted soil characteristics, like soil bulk density, penetration resistance and steady-state infiltration rates change over winter, c) defined an appropriate means for measurement and characterization of patterns of soil freezing in compacted and uncompacted desert soil.

**Impact:** Understanding how soil freezing affects compacted soil aids in the design of more accurate erosion prediction models and provides information useful for minimizing environmental damage caused by military maneuvers. The results have implications for successful performance of the RUSLE and WEPP erosion prediction models. Further, the work helps support the goals of the U.S. Army at the Yakima Training Center by providing realistic high-quality training opportunities while minimizing environmental degradation. The information, data and methodologies derived from this work have been shared with Army Corps of Engineers scientists at CRREL engaged in related research

**Documentation:**

Gatto, L.W., J. J. Halvorson and D.K. McCool. 2001. Freeze-thaw-induced geomorphic and soil changes in vehicle ruts and natural rills, pp. 163-175. In J. Ehlen and Harmon, R. S. (eds.) The Environmental Legacy of Military Operations. Geological Society of America Reviews in Engineering Geology, v. XIV, Boulder, Colorado. 228 pp.

Gatto, L.W., J.J. Halvorson, D.K. McCool and Antonio J. Palazzo. 2001. Effects of Freeze-thaw cycling on soil erosion, pp. 29-55. In R.S. Harmon and Doe III, W.W.(eds.) Landscape Erosion and Evolution Modeling. Kluwer Academic/Plenum Publishers, New York, New York. 540 pp.

Halvorson, J.J., D. K. McCool, L. G. King and L.W. Gatto. 2001. Soil compaction and over-winter changes to tracked-vehicle ruts, Yakima Training Center, Washington. Journal of Terramechanics, 38:133-151.

Halvorson, J.J., L.W. Gatto and D.K. McCool. 2003. Overwinter changes to near-surface bulk density, penetration resistance and infiltration rates in compacted soil. Journal of Terramechanics,. 40:1-24.

**Moderate cattle grazing pressure of bermudagrass in summer does not compact surface soil relative to haying or conservation reserve:** Grazing of pastures by cattle has the potential to compact surface soil and increase water runoff and nutrient load into receiving bodies, because of the heavy burden imposed by the low surface area of cattle hooves. ARS scientists determined surface bulk density of pastures during 5 years under two grazing pressures, hayed, and unharvested bermudagrass management. Soil bulk density under grazing was lower at the soil surface than under hayed or unharvested management, but was greater immediately below the soil surface. Within the first 2 inches of soil, there was no difference in bulk density among management systems. Alleviation of compaction under grazed management was a result of enhanced soil organic matter, which helped buffer the impact of animal traffic.

**Impact:** Cattle producers and agricultural consultants will benefit from this information by helping them design sustainable production systems for restoring degraded soil, maintaining high productivity, and mitigating concerns of nutrient runoff from grazed pastures. These results impact several areas: (1) producers' views of how animals affect soil, (2) soil and water ecosystem modeling that characterizes the impact of grazing cattle, and (3) soil and water environmental policy designed to protect agricultural watersheds.

**Documentation:**

Franzluebbers, A.J., J.A. Stuedemann, H.H. Schomberg, and S.R.Wilkinson. 2000. Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA. Soil Biology and Biochemistry 32:469-478.

Franzluebbers, A.J., J.A. Stuedemann, and S.R. Wilkinson. 2001. Bermudagrass management in the Southern Piedmont USA: I. Soil and surface residue carbon and sulfur. Soil Science Society of America Journal 65:834-841.

**Tillage and soil compaction in structured soils:** Numerous studies have been conducted to evaluate soil compaction, but very few address the compaction thought to be caused by excessive or intensive rainfall. As a result, very little research information was available to help producers decide how to manage their soil resources after they had been flooded. Fear of soil compaction is also a primary reason given by many producers for not switching to no-tillage operations. In an on-farm study with 2-ha "plots," we found that pre-plant soil bulk density and cone penetration resistance throughout the growing season were significantly reduced by deep tillage, but neither corn nor soybean yields were increased. The net return for corn was $133/ha less with subsoiling and $104/ha less with chisel plowing than with no-tillage or the least amount of tillage needed to prepare a seedbed and ensure proper operation of the producer's planters. For soybean, moderate tillage (chisel plowing) returned $49/ha less than the shallow or no-tillage treatment. In another field-scale watershed study on deep loess soils in western Iowa, changes in soil bulk density and water content were measured at three landscape positions (summit, side-slope, and toe-slope) during the first 4 years of transition from disk-tillage to no-tillage. There were no significant differences among landscape positions or between the no-tillage fields and the long-term ridge-tillage field.

**Impact**: Producers, extension personnel, and crop consultants are the primary beneficiaries of this research. This research shows that compaction was not yield limiting on these soils and that money spent on subsoiling or chisel plowing clay loam soils, such as those upon which our study was conducted, to alleviate a perceived rain-induced soil compaction problem was essentially wasted. We recommend using the least amount of tillage necessary to prepare a seedbed for crops grown after soils have been flooded following intensive or extensive rainfall. It also shows that producers do not necessarily have to worry about increased compaction when changing from disk-tillage to no-tillage on deep-loess soils.

**Documentation**:
Heikens, K.E., D.L. Karlen, D.C. Erbach, H.M. Hanna, and J.H. Jensen. 1999. Tillage effects on previously flooded soils. J. Prod. Agric. 12:409-414.
Logsdon, S.D., and D.L. Karlen. 2004. Bulk density as a soil quality indicator during conversion to no-tillage. Soil Tillage Res. 78:131-142.

**Soil strain measurements reveal new information about soil compaction:** Vehicle traffic on soil occurs during crop production and this traffic often deforms and compacts the soil. Soil strain and compaction degrade soil by decreasing water infiltration and water holding capacity, and increasing runoff and erosion, resulting in increased crop production problems, decreased crop yields, and decreased profitability of farming systems. Soil compaction and displacement beneath an 18.4R38 radial-ply tractor drive tire were measured using soil strain transducers. The soil was an initially loose sandy loam soil and the tire was run at 10% travel reduction with a load of 25 kN at 110 kPa inflation pressure. Strain was determined in the vertical, longitudinal, and lateral directions at a depth of 220 mm. As the tire approached and passed over the strain transducers, the soil first compressed in the longitudinal direction, then elongated, and then compressed again. The soil was compressed in the vertical direction and elongated in the lateral direction. Mean natural strains of the soil following the tire pass were -0.2000 in the vertical direction, +0.1274 in the lateral direction, and -0.0265 in the longitudinal direction. The strain transducer data indicated the occurrence of plastic flow in the soil during one of the four replications. These results indicate the complex nature of soil movement beneath a tire during traffic and emphasize a shortcoming of soil bulk density data because soil deformation can occur during plastic flow while soil bulk density remains constant. These findings indicate that soil bulk density, which has often been used by researchers as a measure of soil compaction, does not always indicate soil displacement that occurs during traffic. This emphasizes the fact that soil strain typically occurs during traffic so connectivity of soil pores may be disrupted, thereby reducing water infiltration and water holding capacity, and increasing runoff and soil erosion, while initial and final soil bulk density information alone may not reflect this strain.

**Impact:** This work is important because it reveals the importance of soil strain transducers in providing soil displacement information that may not be shown by soil bulk density results. The information is relevant to manufacturers of tires, tracks, and vehicles that operate on soil, and to people conducting soil compaction research and technology transfer.

**Documentation:**

Way, T.R., D.C. Erbach, A.C. Bailey, E.C. Burt, and C.E. Johnson. 2000. Soil displacement beneath an agricultural tractor drive tire. Proc. 4th International Conference on Soil Dynamics, Adelaide, Australia, March 26-30, 2000. ISBN: 0-646-40961-1. pp 71-78.

Way, T.R., D.C. Erbach, A.C. Bailey, E.C. Burt, and C.E. Johnson. 2004. Soil displacement beneath an agricultural tractor drive tire. Journal of Terramechanics. (in press).

**Saving energy with site-specific subsoiling:** Soil compaction plagues many producers in the United States, particularly in the Southeast. Annual in-row tillage is necessary for many producers to alleviate their soil compaction problems and allow their plant roots to penetrate to depths sufficient to withstand short summer droughts. However, the cost of this annual tillage can be expensive. An experiment was conducted to determine if supplying tillage to the exact depth of compaction would maintain crop yields while reducing tillage costs. Results showed that site-specific tillage maintained corn and cotton yields while significantly reducing tillage power requirements and fuel costs. Improvements in technology necessary to map fields for soil compaction as well as development of implements that can adjust their tillage depth on-the-go should enable this concept to contribute to development of a more energy efficient food production system.

**Impact:** A CRADA with Deere and Company was created to investigate the concept of site-specific subsoiling. As a result of this CRADA, the research results were presented to several hundred producers at "Deere Days". Many producers are now conscious of their tillage depth and recognize the damaging effects that deeper than necessary tillage can have on future yields due to excessive soil compaction caused by vehicle traffic.

**Documentation**

Raper, R.L., D.W. Reeves, J.N. Shaw, E. vanSanten, P.L. Mask, and T. Grift. 2003. Reducing draft requirements and maintaining crop yields with site-specific tillage. Proceedings of the 16th ISTRO Conference, Brisbane, Australia, July 14-19. 6 pp.
Raper, R.L., D.W. Reeves, J.N. Shaw, E. VanSanten, and P.L. Mask. 2004. Site-specific subsoiling: benefits for Coastal Plains soils. Proceedings of the 26th Annual Southern Conservation Tillage for Sustainable Agriculture, Raleigh, NC. June 7-9, 2004.
Raper, R.L. Subsoiler shapes for site-specific tillage. 2005. Applied Engineering in Agriculture (In press).

**Development of an on-the-go soil compaction measurement system:** Compacted soil layers limit yield and reduce overall productivity of many Southeastern U.S. soils. A cooperative experiment was conducted on three Southeastern U.S. fields from Northern Mississippi. In this research, we determined that the depth of the soil compaction layer was extremely variable, especially in non-trafficked row middles where only natural compaction exists. We also found that conventional tillage moved this layer significantly closer to the soil surface and that the effect of vehicle traffic in a no-till field was minimal except for reducing the variation in the root-restricting layer. The time-consuming process of obtaining soil compaction measurements across a field with a soil cone penetrometer prompted the creation of a machine to measure soil compaction continuously. This invention is unique in that it is designed to be moved up and down in a cyclical manner as the field is sampled. An infinite number of depths are sampled and the depth to the root-restricting layer can be determined at specific sites within a field. Measuring soil compaction depth at these sites can be coupled with Global Positioning System (GPS) technology to create maps that could be used to adjust tillage depth. Using this device with site-specific tillage could potentially save the time required for sampling and processing.

**Impact:** This research study was the first to determine the approximate variation range of the natural hardpan layer that is found in Southern soils and how this variability is affected by vehicle traffic and tillage system. It also led to a patent on a method of measuring soil compaction continuously that will allow tillage depth to be adjusted to target depths of soil compaction rather than setting a uniform depth of tillage that may be either too deep wasting energy or too shallow ineffectively tilling the soil. The patent allows a single measurement transducer to be used across a field by adjusting tillage depth continuously. The successful implementation of this design will make the concept of site-specific subsoiling more feasible.

**Documentation**

Hall, H.E., R.L. Raper, T.E. Grift, and D.W. Reeves. 2000. Development of an on-the-fly mechanical impedance sensor and evaluation in a coastal plains soil. Proceedings of the 15th ISTRO Conference, Ft. Worth, TX. July 3-7.
Raper, R.L., E.B. Schwab, and S.M. Dabney. 2001. Measurement and variation of site-specific hardpans. ASAE Paper No. 01-1008. ASAE, St. Joseph, MI. 18 pp. (Technical handout).
Raper, R.L., and H.E. Hall. 2003. Soil strength measurement for site-specific agriculture. U.S. Patent #6647799. Nov. 18.

## Soil Conservation and Restoration Component

**Problem Area 3:** Cost-effective methods are needed to remediate soils degraded by excess nutrients, salts, trace elements, and agricultural chemicals.

**Background:** A combination of factors has caused some soils to become degraded, which has reduced yields, compromised food safety or marketability, and created environmental risks. Such factors include soil formation processes, geographical location, climate, cropping history, tillage practices, composition of fertilizers, soil amendments, irrigation water applied, and/or external contamination processes. The combinations of these effects have caused some soils to be historically degraded while many others have become impaired through human activities. Some soils have become impaired through accumulation of nutrients, salts, trace elements, or chemicals. In some cases, contaminated soils are severely poisonous to plants and remain barren decades after the contamination event occurred. Acidification of soils by mining activities or nitrogen fertilizer management practices can result in the release of toxic concentrations of trace elements. Irrigated soils are especially subject to salinization, rendering a loss in soil productivity. In any of these situations, remediation or restoration measures will be needed to improve soil productivity, protect human health, and/or prevent environmental degradation.

The goals of this research were:

Improve knowledge of soil degradation and contamination processes and sources to prevent problems with soil fertility, environmental hazards, and food safety.

Improve knowledge of the long-term fate and potential effects of soil contaminants

Identify soil properties that increase or decrease the risk potential from specific element contamination. Also identify cropping systems that affect the potential for reduced yield or food chain transfer of contaminants.

Develop methods for remediation of contaminated soils to reduce the potential risk of soil contaminants while minimizing restrictions to normal farming or ecosystem restoration.

Develop cost-effective methods to restore soils to a condition that can support a wide variety of plants

**Accomplishments:**

**Reducing soil phosphorus by addition of drinking water treatment byproducts:** Application of manure or other residuals with high levels of phosphorus (P) relative to other nutrients, especially nitrogen (N), or excessive additions have led to soils with high enough levels of P to require or benefit from remediation strategies. Water treatment residue rich in Al, a Fe-rich titanium ore processing byproduct, and alkaline calcium rich fluidized bed ash from coal combustion were tested at different rates on high P soils. At moderate rates the applied drinking water treatment residue was especially effective in lowering P solubility in water or in the Bray-

1 soil extraction. The Fe-rich byproduct was less effective than the drinking water byproduct. In another study a drinking water residual produced from addition of "polyhydroxy aluminum" was mixed with poultry litter and applied as fertilizer. Corn was grown for two seasons. Some reduction in water-soluble soil P was observed, and the corn yield was not reduced by this treatment. Additions of alum-treated drinking water residuals to sandy soils, commonly used for manure application, increased P retention 3 to 6 fold.

**Impact:** This research showed that water treatment byproducts are suitable soil amendments that can greatly increase soil P sorption capacity. Adoption of residuals as a chemical best management practice could turn a waste product into a useful agricultural amendment, thus providing benefit to both drinking water facilities, other industries and agriculture.

**Documentation:**

Novak, J.M. 2003. Utilization of water treatment residual to bind inorganic phosphorus. 7 pp. Proc. WEF/AWWA/CWEA Joint Residuals and Biosolids Management Cong., Feb. 19-22. Baltimore, MD. (CD-ROM).

Novak, J.M. and D.W. Watts. 2004. Increasing the P sorption capacity of SE Coastal Plain soils using water treatment residuals. Soil Sci. (in press)

Codling, E. E., R. L. Chaney and C. L. Mulchi. 2000. Use of aluminum- and iron-rich residues to immobilize phosphorus in poultry litter and litter-amended soils. J. Environ. Qual. 29:1924-1931.

**Effect of ferrihydrite on soil erodibility and on pollutant reductions in runoff:** Vast acreages of soils in the U. S. are susceptible to erosion losses that lead to the degradation of soil, water, and air quality. Ferrihydrite, an iron oxide sludge byproduct from water treatment plants, was evaluated, by ARS scientists and university cooperators from a number of locations, for its effectiveness at increasing soil aggregate resistance to wind and water erosion. This research demonstrated that the addition of ferrihydrite to soils improves the water stability of aggregates from acid soils, increases infiltration rates, and decreases surface runoff and soil loss from agricultural land. The research also demonstrated that ferrihydrite can reduce movement of phosphorus to surface waters.

**Impact:** These results demonstrate that ferrihydrite could be a low-cost soil amendment to reduce contamination of surface waters with sediment and phosphorus.

**Documentation:**

Rhoton, F.E., M.J.M Römkens, J.M., Bigham, T.M. Zobeck, and D.R. Upchurch. 2003. Ferrihydrite influence on infiltration, runoff, and soil loss. Soil Science Society of America Journal. 67:606-611.

Wilson, G.V., Rhoton, and F.E., Selim, H.M. 2004. Modeling the impact of ferrihydrite on adsorption-desorption of soil phosphorus. Soil Science. 169:271-282.

**Use of gypsum to decrease erosion and improve water quality:** Gypsum of varying types and quality are frequently added to soil as amendments. Greenhouse and lab research on the effect of gypsum additions on N and P losses in runoff and leachate, and NPK uptake in corn was conducted by ARS scientists and university cooperators. Gypsum significantly decreased soluble P, total P, ammonium and total N in runoff, as well as leachate P, and the surface transport of N & P, while a high Ca:Mg ratio reduced sediment bound P. Because P has been over applied in many production fields, producers concerned about the P level in their soil or about applying organic amendments will find gypsum a possible additive to prevent N and P losses to the environment.

**Impact:** The practical impact of this work is that gypsum amendments have the potential to improve water quality, but care should be taken with regard to phosphorus availability to corn.

**Documentation:**

Wallace, B.H., J.M. Reichert, L.F. Eltz, and L.D. Norton. 2001. Crust comparison on a Brazilian Typic Paleudalf with various amendments. For the Third International Conference on Land Degradation, Rio De Janeiro, Brazil. 17-21, September.

Wallace, B.H., J.M. Reichert, L.F. Eltz, and L.D. Norton. 2001. Conserving topsoil in Southern Brazil with polyacrylamide and gypsum. Soil Erosion for the 21st Century Symposium, Honolulu, HI. 2-5 January. pp. 183-186.

**Trace elements from poultry manure applied to pasture land accumulate differently depending upon harvest management:** Disposal of litter from chicken houses onto nearby agricultural land is a common practice, and can benefit farmers by supplying an organic form of fertilizer at a relatively low cost, but there is concern that trace elements may be accumulating in soil and possibly leading to toxicity levels in plants, animals, and human food supplies. ARS scientists determined the concentration of 12 trace elements in soil following 5 years of poultry litter application compared to commercial fertilizer application to a bermudagrass pasture. Soil did accumulate higher levels of copper, manganese, and zinc with poultry litter fertilization, but at levels not considered toxic and grazed pastures accumulated greater concentrations of trace elements than hayed fields, because feces from cattle returned elements to the soil.

**Impact:** Farmers and environmental organizations can benefit from this information to guide safe utilization of this vast manure resource in the southeastern USA. These results could impact decisions to supplement animal feeds with trace elements, producers' willingness to utilize poultry manure on their farm, and environmental regulations designed to protect water quality.

**Documentation:**

Franzluebbers, A.J., S.R. Wilkinson, and J.A. Stuedemann. 2004. Bermudagrass management in the Southern Piedmont USA: IX. Trace elements in soil with broiler litter application. Journal of Environmental Quality. 33:778-784.

**Phytoavailability of heavy metals in soils amended with manures, biosolids and composts:** ARS scientists conducted research to measure changes in metal adsorption and phytoavailability in soils amended with manures, biosolids and composts. Amended soils had higher Cd adsorption capacity than unamended or control soil from the same set of field plots. These soils were further examined to characterize whether the organic matter or mineral fraction of the amended soil had caused the increase. This was done to clarify whether biodegradation of the organic matter of organic amendments will cause an increase in phytoavailability of soil metals, a hypothesis called the "Time Bomb". The research indicated that the inorganic fraction of the amended soil controlled long-term metal adsorption. Both total and amorphous Fe and Mn oxides provided persistent increase in Cd adsorption by soils amended with biosolids. If Fe oxide in amended soils increases the specific adsorption of metals by soils, it could be useful to incorporate Fe from inexpensive by-products or ores into manures or biosolids for soil remediation.

**Impact:** These results offer important evidence that metals added in biosolids, manures and composts do not suddenly become more phytoavailable and comprise risk to soil fertility and human health. The "Time Bomb Hypothesis" was shown to be invalid. Biosolids amended with Fe oxides have been used to remediate trace element contaminated EPA "Superfund" sites.

**Documentation:**

Brown, S. L. and R. L. Chaney. 2000. Combining by-products to achieve specific soil amendment objectives. pp. 343-360. *In* Power, J. F. et al. (eds.) Land Application of Agricultural, Industrial and Municipal By-Products. SSSA Book Series No. 6. Soil Science Society of America, Madison, WI.

Hettiarachchi, G. M., J. A. Ryan, R. L. Chaney and C. M. La Fleur. 2003. Sorption and desorption of cadmium by different fractions of biosolids-amended soils. J. Environ. Qual. 32:1684-1693.

**Tailor-made remediation mixtures of biosolids and alkaline by-products:** Soils contaminated by mining and smelting activities often become barren and severely eroded when soil acidity is combined with Zn, Cu or Ni contamination. Some sites also are contaminated with Pb, a risk to animals and humans that ingest soil. Several Superfund sites (> 1000 ha) have remained barren for over 30 years indicating that active remediation practices are required. A method was developed and tested based on an understanding of soil metal risks, the role of Fe and Mn oxides in adsorbing metals in biosolids-amended soils, and the ability of added phosphate to cause formation of Pb pyromorphite (a compound of Pb with very low bioavailability to animals). "Tailor-Made Remediation Mixtures" of biosolids and alkaline by-products were developed to bind toxic metals on Fe and Mn oxide surfaces. This approach was first demonstrated at the Palmerton, PA, Superfund site on an urban garden with a high level of Zn. This approach was then tested on Zn-Pb-smelter slag in Katowice, Poland using biosolids and byproduct limestone. The test was so successful that the industry has contracted to obtain all local biosolids and is doing soil remediation where facilities had remained barren for many years. Mixtures of biosolids and wood ash were used to remediate Zn phytotoxic soils at the Bunker Hill, ID Superfund site. By mixing and surface applying the biosolids-wood ash mixture, and surface application of seed after ammonia release had slowed, all soils tested were readily revegetated. Biosolids from 4 cities were shown to be effective. Simple application of chemical fertilizer and limestone with seed did not yield persistent revegetation. The organic matter in the biosolids improves soil structure and water infiltration and storage capacity; and the biosolids inoculates the soil with diverse microbes needed for good soil fertility. Further, biodegradation of the biosolids organic matter allows alkalinity to leach down the soil profile much more rapidly than limestone without organics. This approach also was successful on severely acidic and Zn phytotoxic mine waste sites. Manure and composts could be used instead of the biosolids to make the remediation mixtures.

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**Impact:** A method that utilizes biosolids and alkaline byproducts has been shown to be highly effective in remediating contaminated soils. Furthermore, this method is much more cost effective than other options commonly used. The "tailor-made" remediation mixtures approach has been designated a Presumptive Remedy for remediation of metal contaminated soils by the U.S. EPA. The cost savings are at least 100 times that of the currently used practice of soil removal and replacement, which costs $1M per acre-foot. There are over 50,000 sites nationwide that could benefit from this *in-situ* remediation procedure using tailor-made biosolid or manure mixtures or composts.

**Documentation:**


Brown, S.L., R.L. Chaney, M. Sprenger and H. Compton. 2002. Soil remediation using biosolids: Soil-plant-animal pathway. BioCycle 43(6):41-44.

Brown, S.L., C.L. Henry, R.L. Chaney, H. Compton and P.S. DeVolder. 2003. Using municipal biosolids in combination with other residuals to restore metal-contaminated mining areas. Plant Soil 249:203-215.

Brown, S.L., R.L. Chaney, J.G. Hallfrisch, Q. Xue, J.A. Ryan and W.R. Berti. 2004. Use of soil amendments to reduce the bioavailability of lead, zinc and cadmium *in situ*. J. Environ. Qual. (in press).

Chaney, R.L., S.L. Brown, Y-M. Li, J.S. Angle, T.I. Stuczynski, W.L. Daniels, C.L. Henry, G. Siebielec, M. Malik, J.A. Ryan and H. Compton. 2002. Progress in risk assessment for soil metals, and in-situ remediation and phytoextraction of metals from hazardous contaminated soils. In Proc. US-EPA Conf. "Phytoremediation: State of the Science." *May 1-2, 2000, Boston, MA.* Published on the web at http://www.epa.gov/ORD/NRMRL/Pubs/625R01011b/625R01011bchap14.pdf. [ARS-119548]

Li, Y-M., R.L. Chaney, G. Siebielec and B.A. Kershner. 2000. Response of four turfgrass cultivars to limestone and biosolids compost amendment of a zinc and cadmium contaminated soil at Palmerton, PA. J. Environ. Qual. 29:1440-1447.

Stuczynski, T.I., W.L. Daniels, F. Pistelok, K. Pantuck, R.L. Chaney and G. Siebielec, 2000. Application of sludges for remediation of contaminated soil environment. pp. 227-242. In M.J. Wilson and B. Maliszewska-Kordybabh (eds). Soil Quality in Relation To Sustainable Development of Agriculture and Environmental Security in Central and Eastern Europe. (October 13-17, 1997. Pulawy, Poland). Kluwer Academic Publ., Dordrecht.


**Biosolid treatments to decrease the bioavailability of lead in soil:** Pb contamination at mine and smelter sites, or in urban soils (from paint and automotive emissions) comprise a risk to wildlife or children by soil ingestion. Our earlier research had shown that certain biosolids composts rich in Fe could strongly reduce the absorption of Pb from soil fed to rats. Further tests were conducted and Fe and P were clearly important in Pb inactivation. In cooperation with US-

EPA and others, we tested different phosphate amendments and high-Fe biosolids compost for inactivation of Pb in soils at an abandoned mine site near Joplin, MO. A three-year field test was conducted during which the bioavailable fraction of soil Pb was measured by chemical extractions or feeding tests. After 3 years, a human feeding test was conducted to test how well phosphate reduced soil Pb bioavailability, which was reduced by 69%. The human test used stable isotopes of Pb in the contaminated soil. This approach was extended to urban soils in the inner-city area of Baltimore, MD. High Fe composted biosolids permitted for use on lawns and gardens was applied at about 200 t/ha including 10% limestone added to the compost. Before application, lawns were compacted and poorly vegetated; in that condition, one is advised to remediate or remove soils with over 400 mg Pb/kg. Where the compost was incorporated, lawn grass grew strongly, reducing soil transfer and Pb bioavailability; vegetated soils with up to 1200 mg Pb/kg do not require removal or further remediation. This approach could be used to reduce soil Pb risk to urban children at low cost.

**Impact:** A low cost effective method for the remediation of lead contaminated soils using composted biosolids is available for use by industry and EPA. This method can alleviate the potential for lead poisoning in animals and humans.

**Documentation**:


Brown, S.L., R.L. Chaney, J.G. Hallfrisch and Q. Xue. 2003. Effect of biosolids processing on the bioavailability of lead in urban soils. J. Environ. Qual. 32:100-108.

Brown, S.L., R.L. Chaney and D.M. Hill. 2003. Biosolids compost reduces lead bioavailability in urban soils. BioCycle 44(6):20-24.

Farfel, M.R., A.O. Orlova, R.L.,Chaney, S. J. Lees, C. Rohde and P.J. Ashley. 2004. Biosolids application for reducing urban soil lead hazards. Sci. Total Environ. (in press).

Ryan, J.A., W.R. Berti, S.L. Brown, S.W. Casteel, R.L. Chaney, M. Doolan, P. Grevatt, J.G. Hallfrisch, M. Maddaloni and D. Mosby. 2004. Reducing children's risk from soil lead: Summary of a field experiment. Environ. Sci. Technol. 38:18A-24A.


**Efficient reclamation of saline-sodic soils**: Increasing use of low quality waters for irrigation means that reclamation, consisting of leaching or use of amendments, will be very important to maintain the productivity of irrigated lands. Reclamation practices are currently based on generalized guidelines that insure adequate reclamation in almost all instances. These guidelines do not consider important site-specific factors, and thus overestimate water and amendment requirements in most instances. We evaluated the capability of the UNSATCHEM model to predict leaching and reclamation of a saline-sodic field in Coachella Valley. The model well predicted the measured electrical conductivity and SAR (sodium adsorption ratio) of the soil water with depth after application of gypsum and leaching water. The model was also used as a management tool to evaluate both the impact of green manuring on the quantity of gypsum required, suggesting that the quantity of gypsum could have been greatly reduced, and the depth of gypsum placement and its relation to quantity of water required to achieve specified reclamation goals. These tools can be utilized for development of cost optimized site specific reclamation practices, reducing water and quantities of reclamation amendments. The UNSATCHEM model was also modified to consider boron adsorption and desorption. The model was applied to the problem of supplemental irrigation with a high boron containing water and management practices were evaluated for minimizing crop losses from boron toxicity, with different results for sandy and high clay soils.

**Impact**: The UNSATCHEM model is applicable to reclamation of saline sodic soils, developing site specific reclamation plans that can be optimized for factors such as cost, quantity of water, or type of reclamation and amendment placement depth. Farmers and irrigation districts will benefit from this research. A user friendly version of the model was developed and is to be distributed world-wide by FAO.

**Documentation:**

Lebron, I., M.G. Schaap, and D.L. Suarez. 1999. Saturated hydraulic conductivity as affected by pore size and pore geometry in soils with variable chemical composition. Water Resources Research. 35(10):3149-3158.

Suarez, D.L. 2001. Sodic soil reclamation: Model and field study. Australian Journal of Soil Research. 39:1225-1246.

Lebron, I., D.L. Suarez, and M.G. Schaap. 2002. Soil pore size and geometry as a result of aggregate size distribution and chemical composition. Soil Science. 167(3):165-172.

Lebron, I., D.L. Suarez, and T. Yoshida. 2002. Gypsum effect on the aggregate size and geometry of three sodic soils under reclamation. Soil Sci. Soc. Am. J. 66(1):92-98.

Suarez, D.L. 2002. Evaluation of management practices for use of low quality waters for irrigation: Model simulations. In: Proceedings, Meeting of the International Union of Soil Scientists, August 14-21, 2002, Bangkok, Thailand. Symposium no. 34. 1096:1-8.

Suarez, D.L. 2002. Reclamation of saline soils. In: Proceedings of International Symposium on the Environmental Sound Reclamation and Agricultural Advanced Utilization of Land. September 9-13, 2002, Seoul Korea. pp. 36-52.

Suarez, D.L. 2004. Predicting soil and water chemistry in and below the root zone of agricultural lands: Major ions, nutrients and toxic ions. In: Proceedings of U.S. Federal Interagency Workshop entitled "Conceptual model development for subsurface reactive transport modeling of inorganic contaminant, radionuclides and nutrients". Albuquerque, NM. April 20-22, 2004. pp. 93-96.

Suarez, D.L. 2004. Chemistry of salt-affected soils. In: D.L. Sparks (ed.) Chemical Processes in Soils, a Soil Science Society of America Book Series Special Publication. Madison, WI. (In press).

**Salinity assessment for leaching, Lower Colorado River Region:** The leaching of accumulated salts from agricultural fields is a long standing management practice implemented by many growers in the arid Southwestern US. While some degree of leaching must be maintained to ensure viable crop production and sustainable agricultural systems, excessive leaching can lead to many negative side effects (depletion of soil nutrients, need for excessive drainage water disposal, non-beneficial water use, etc.). Since up to 30% of a farm's annual water application is used in yearly leaching events, optimizing such leaching processes is clearly important. Research was initiated by ARS to use intensive conductivity survey data and limited soil samples for designing optimal leaching plans with the goal of efficient salinity control and minimal water use. Leaching design software was developed that optimizes the spatial distribution of water application amounts based on the expected differences in spatial leaching efficiency and the desired target salinity level. Field leaching trials were conducted in the summer of 2003 in order to test both the precision leaching concept and new software program. Three field leaching projects were undertaken where calibrated electrical conductivity ($EC_a$) survey data were collected prior to and after completion of the leaching process. In each field, the calibrated $EC_a$ survey data were effectively used to (i) accurately diagnose the pre-leaching, spatial salinity conditions, and (ii) suggest improved leaching implementation strategies for use in each field. Although a full implementation of these improved strategies was not possible due to technical constraints, the acquired pre- and post-leaching sample data definitively indicated that the leaching efficiency could have been increased from 30% to 70% by adjusting the proposed leaching process in light of baseline survey information. Specifically, the calibrated EC survey data can be used to identify and isolate high saline zones and/or specific sub-regions in a field suffering from inadequate drainage.

**Impact:** This work demonstrates and validates the "precision leaching strategy" concept and shows that such strategies are indeed feasible, when good baseline survey data is available. Such strategies offer the potential for greater leaching efficiency and significant water savings, provided that cost-effective techniques can be identified for effectively adjusting and controlling the spatial water application rate across the field. Precision leaching software has been developed and incorporated into the Salinity Laboratory assessment software package (ESAP) and will be made available to all software users by the end of 2004. These improved leaching techniques and new software module will aid the US Bureau of Reclamation, lower Colorado region water districts, and individual landowners and/or growers managing salt-effected farmland.

**Documentation:**

Lesch, S.M., D.L. Corwin, and D.L. Suarez. 2004. Final progress report (part B): Field study report for ARS/USBR project # 60-5310-2-337 (June 21, 2004). USDA-ARS George E. Brown Jr. Salinity Laboratory, Riverside, CA, 128 pp.

## Nutrient Management Component

Both organic and inorganic nutrient pools are important to the productivity, sustainability, and potential off-site environmental impacts associated with soil resource management. Soil nutrient management depends heavily on soil chemical, physical, and biological properties and processes; and environmental and management factors further influence nutrient cycling. Fertilizer use-efficiency is commonly less than 50% in many agricultural systems, and application of excessive amounts of fertilizer contributes to agriculture being the largest non-point source of pollution to surface and groundwater. Nutrients not used by plants may leach into groundwater or be transported in runoff or sediment to surface waters. In surface and groundwater, excessive concentrations of nutrients can make these water resources unacceptable for drinking, lead to nutrient enrichment known as eutrophication, sustain microorganisms from human or animal wastes, deplete oxygen, or cause blooms of aquatic organisms that produce toxins. Research is needed to understand nutrient fate and transformations in soil so management practices can be developed for sustainable production while protecting soil, water and air. In North America, soil organic matter has declined 30 to 60% in some soils since the land was first cultivated. Management practices to enhance soil carbon sequestration and improvement of soil properties and processes as a result of carbon sequestration are important topics of investigation in this program component.

Research within the Nutrient Management Component of the Soil Resource Management National Program was conducted in four Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a planning workshop held at the start of the current five-year National Program cycle. The four Problem Areas are: (Problem Area 4) Management practices are needed for more effective use of inorganic and organic nutrients in sustainable crop production systems. (Problem Area 5) A greater understanding is needed of the physical, chemical and biological processes involved in transformation, interaction and fate of nutrients in soil-plant-microbe-climatic systems. (Problem Area 6) Management practices need to be developed that minimize the potential for nutrient losses to ground and surface waters while maintaining or improving desirable soil characteristics. (Problem Area 7) More information is needed about management practices that enhance soil carbon sequestration, and the influence of changes in soil carbon levels on soil properties and processes.

Nutrient management research is currently conducted by the following ARS locations : Akron, Colorado; Ames, Iowa; Auburn, Alabama; Beltsville, Maryland; Florence, South Carolina; Fort Collins, Colorado; Kimberly, Idaho; Lincoln, Nebraska; Mandan, North Dakota; Morris, Minnesota; Pendleton, Oregon; Pullman, Washington; Riverside, California; Saint Paul, Minnesota; Temple, Texas; Tifton, Georgia; University Park, Pennsylvania; Watkinsville, Georgia; and West Lafayette, Indiana.

## Nutrient Management Component

**Problem Area 4:** Management practices are needed for more effective use of inorganic and organic nutrients in sustainable crop production systems.

**Background:** Plant-available nutrients applied at the proper time and in adequate amounts can optimize crop quality and crop production. Nutrients applied improperly, at the wrong time or in forms that become available to plants at the wrong time, may fail to meet crop needs and pose a threat to the environment. Important sources of nutrients for growing plants include dissolution of nutrients from inorganic minerals, mineralization of soil organic matter, nutrient release from decomposing plant residue, nutrients present in precipitation and irrigation water, nitrogen fixing crops, field-applied fertilizers, and animal manure. Tillage, soil amendments, lime, irrigation timing and amount, as well as inorganic fertilizer form, placement, application timing, and nitrification inhibitors all influence the supply, retention, and availability of nutrients to a crop. Research will be needed to develop management practices, assessment tools and decision aids to help producers provide needed nutrients more efficiently.

The goals of this research were:

Improve understanding of the effects of management practices and their interaction on nutrient availability from organic and inorganic nutrient sources.

Develop predictive relationships for determining site-specific fertilizer needs based on soil process-level knowledge of nutrient cycling and plant use efficiency.

Develop soil nutrient management practices that are economically and environmentally sound and sustainable and efficient in meeting crop nutrient needs and increasing productivity.

**Accomplishments:**

**Nitrogen management in vegetable production areas:** Elevated levels of nitrate-N ($NO_3$-N) are present in groundwater in the Arkansas River valley in Colorado where vegetables are grown in rotation with corn, alfalfa, soybean, sorghum, and wheat. Shallow rooted vegetable crops often receive high rates of N fertilizer (> 224 kilograms N per hectare) to assure high yield and quality. Fertilizer N-use efficiency by onion was only 15%. Corn following onion in rotation recovered another 24% of the fertilizer N applied to onion. Fertilizer N was leached below the root zone of both crops during the first growing season. Minimal response of corn to N fertilization was obtained following alfalfa and watermelon in rotation. Average 4-yr corn grain yields were near maximum with 88 kilograms N per hectare per year, with an average N fertilizer use efficiency of 50% at the smallest fertilizer N rate and 30% at the highest N rate based on grain N removal. A minimal amount (60 to 90 kilograms N per hectare) of N fertilizer may be needed to optimize grain and silage corn yields in the Arkansas Valley in rotation with vegetable crops and alfalfa; this is expected to reduce $NO_3$-N contamination of groundwater. Crop consultants, Extension Agents, and USDA-NRCS personnel benefit from this information in advising vegetable and corn growers on N application in the lower Arkansas River Valley.

**Impact:** Reducing N application rates reduces the amount of fertilizer N entering the shallow ground water system in this area. Farmers, Extension Agents, and USDA-NRCS personnel are enlightened regarding the level of residual N in these soils and the minimal amount of N fertilizer required for good corn yields following vegetable crops in this area.

**Documentation:**

Halvorson, A., C. Reule, F. Schweissing, and M. Bartolo. 2001. Nitrogen management projects on corn and onion at AVRC. pp. 11-14. *In :* 2000 Research Reports, Arkansas Valley Research Center, Colorado State University Agricultural Experiment Station Technical Report TR01-9. Colorado State University. Fort Collins, Colorado.

Halvorson, A.D., R.F. Follett, M.E. Bartolo, and F.C. Schweissing. 2002. Nitrogen fertilizer use efficiency of furrow-irrigated onion and corn. Agronomy Journal. 94:442-449.

Halvorson, A.D., F. Schweissing, and C. Reule. 2002. Nitrogen fertilization of irrigated corn in a high residual soil N environment in the Arkansas River Valley. *In :* Proceedings of 2002 Great Plains Soil Fertility Conference. Denver, CO, March 5-6, 2002. Kansas State University, Manhattan, KS and Potash and Phosphate Institute, Brookings, SD. 9:138-142.

Halvorson, A., F. Schweissing, and C. Reule. 2002. Nitrogen fertilization of irrigated corn at AVRC. pp. 14-18. *In :* Colorado State University Agricultural Experiment Station Technical Report TR02-8. Colorado State University, Fort Collins, Colorado.

Bartolo, M., O. Doss, A. Halvorson, R. Follett, and J. Davis. 2002. Onion fertility trial. pp. 51-52. *In :* Colorado State University Agricultural Experiment Station Technical Report TR02-8. Colorado State University. Fort Collins, Colorado.

Halvorson, A, F. Schweissing, and C. Reule. 2003. Nitrogen Fertilization of Irrigated Corn Following Alfalfa and Watermelon at AVRC. p. 13-18. *In :* Colorado State University Agricultural Experiment Station Technical Report TR03-8. Colorado State University. Fort Collins, Colorado.

Halvorson, A.D., Schweissing, F., Bartolo, M., Reule, C.A. 2004. Irrigated corn response to nitrogen fertilization in the Colorado Arkansas Valley. *In :* Proceedings of 2004 Great Plains Soil Fertility Conference. Denver, CO, March 2-3, 2004. Kansas State University, Manhattan, KS and Potash and Phosphate Institute, Brookings, SD. 10:157-163.

**Tillage system and fertilizer N application rate and timing effect corn yields in the Texas Blackland Prairie:** Tillage systems and fertilizer application practices are an essential part of production agriculture; however, movement of sediment and nutrients into waterways from these agricultural operations is thought to be a contributor to nutrient enrichment of downstream water bodies and the Gulf of Mexico. Research was conducted on the development and evaluation of soil tillage and soil fertility management techniques, for both agronomic and environmental consequences. In wet years, corn grain yields and N uptake were increased with N application up to168 kg N $ha^{-1}$ (150 lbs per acre). Application of fertilizer N in the fall reduced yields 30% when compared with fertilizer application at planting. The greatest yields were observed with the no tillage system, with large differences observed between no tillage and the other tillage systems in low rainfall years. Application of fertilizer in the fall results in lost yield potential and conservation tillage may be the most reliable production system in the Texas Blackland Prairie.

This research aids crop producers with both agronomic decisions and environmental concerns regarding crop production practices.

**Impact :** Knowledge for development of soil fertilizer and soil tillage management programs that are both cost efficient and environmentally beneficial has been developed and provided to crop producers and their advisors.

**Documentation:**

Torbert, H.A., K.N. Potter, and J.E. Morrison, Jr. 2001. Tillage system, fertilizer nitrogen rate and timing effect on corn yields in the Texas Blackland Prairie. Agronomy Journal 93:1119-1124.

Bronson, K.F., J.D. Booker, R.J. Lascano, H.A. Torbert, and A.B. Onken. 2001. Irrigated cotton lint yields as affected by phosphorus fertilizer and landscape position. Communications in Soil Science and Plant Analysis. 32:1959-1967.

Gerik, T. J., R.G. Lemon, A. H. Abrameit, M.L. McFarland, J. T. Cothren, D.R. Krieg, H. Torbert, and J. E. Morrison, Jr. 2001. Improving the crop water supply : A key to increasing dryland cotton yields. p. 10-15. *In :* Proceedings of the National Conservation Tillage Cotton & Rice Conference. January 30-31, 2001. Houston, Texas.

Torbert, H.A., K.N. Potter, K.N. and J.E. Morrison, Jr. 2001. Tillage systems and N fertilizer practices effect on corn yields in the Texas Blackland Prairie. p. 61. *In :* Proceedings of the Twenty-fourth Annual Southern Conservation Tillage Conference for Sustainable Agriculture. J. Stiegler, *ed*. July 9-11, 2001. Oklahoma City, Oklahoma.

Harman, W.L., T. Gerik, H.A. Torbert, and K.N. Potter. 2003. Agronomic and economic implications of conservation tillage and ultra-narrow row cropping systems. p. 11-13. *In:* National Conservation Tillage Cotton and Rice Conference. Jan. 23-24, 2003. Houston, Texas.

**Improving nitrogen fertilizer use efficiency in deficit-irrigation systems for cotton :** Water and nitrogen are major constraints to cotton production in the Southern High Plains of Texas. Nitrogen management has not changed with improved irrigation delivery systems. As a result, some over-fertilization of N occurs, as evidenced by rising groundwater levels of $NO_3^-$, or farmers fail to optimize N fertilizer placement. In-season monitoring of plant N status by spectral reflectance and chlorophyll meter measurements were tested as in-season N decision aids for irrigated cotton near Lubbock, Texas. Less N was required when N application was directed by in-season monitoring. Basing N applications on in-season monitoring reduced N application rates in low yielding seasons and matched the yield potential in high-yielding seasons. As cost of production is reduced and nitrate leaching minimized farmers, consumers and the environment benefit.

**Impact :** Adoption of these practices will decrease on-farm costs, increase cotton production and decrease nitrate leaching.

**Documentation:**

Mosier, A.R., and Z.L. Zhu. 2000. Changes in patterns of fertilizer nitrogen use in Asia and its

consequences for $N_2O$ emissions from agricultural systems. Nutrient Cycling in Agroecosystems. 57:107-117.
Mosier, A.R., M.A. Bleken, P. Chaiwanakupt, E.C. Ellis, J. R. Freney, R.B. Howarth, P. A. Matson, K. Minami, R. Naylor, K.N. Weeks and Z.L. Zhu. 2001. Policy implications of human-accelerated nitrogen cycling. Biogeochemistry. 52:281-320.
Shoji, S., J. Delgado, A. Mosier and Y. Miura. 2001. Use of control release fertilizers and nitrification inhibitors to increase nitrogen use efficiency and to conserve air and water quality. Communications in Soil Science and Plant Analysis. 32:1051-1070.
Mosier, A.R. 2002. Environmental challenges associated with needed increases in global nitrogen fixation. Nutrient Cycling in Agroecosystems. 63:101-116.
Chua, T.T, K.F. Bronson, J.D. Booker, J.W. Keeling, A.R. Mosier, J.P. Bordovsky, R.J. Lascano, C.J. Green and E. Segarra. 2003. In-season nitrogen status sensing in irrigated cotton : I. Yields and nitrogen-15 recovery. Soil Science Society of America Journal. 67:1428-1438.
Phongpan, S. and A.R. Mosier. 2003. Effect of crop residue management on nitrogen dynamics and balance in a lowland rice cropping system. Nutrient Cycling in Agroecosystems 66:133-142.
Phongpan, S. and A.R. Mosier. 2003. Effect of rice straw management on nitrogen balance and residual effect of urea-N in an annual lowland rice cropping sequence. Biology and Fertility of Soils. 37:102-107.

**Nutrient placement in reduced tillage systems:** Delayed warming of the soil reduces uptake of non-mobile soil nutrients and slows seed germination/early crop growth, which in turn allows a competitive edge to weeds and insect pests. Information is needed on the optimal N-P-K fertilizer placement for improved crop growth and yield with no-tillage and ridge-tillage. We demonstrated that: 1) compared with conventional tillage, corn grown under ridge-till had improved tolerance to corn rootworm larval feeding and that grain yield and soil condition were not greatly different under ridge-till, 2) that synergistic effects of soil fertility/crop growth and yield benefits associated with crop rotation were less pronounced as the level of agrochemical inputs increased, and 3) more net N was mineralized from soil under rotations that included legumes especially if the plots did not receive N fertilizer. Further, increased rotation complexity and reduced agrochemical inputs encouraged a greater abundance and diversity of beneficial insects. Crop producers benefited with information on economically competitive systems that conserve the natural resource.

**Impact :** Guidelines on the optimal placement of fertilizers under no-till conditions and encouragement to adapt these high-residue soil-conserving systems to their operations were provided to producers. Information on the benefits of ridge-tillage in terms of pest tolerance, grain yield, and soil condition was developed. This work was featured in grower meetings organized by the Nebraska Cooperative Extension Service in 2001.

**Documentation:**

Riedell, W.E., D.L. Beck, T.E. Schumacher. 2000. Corn response to starter fertilizer in an irrigated no-till system. Agronomy Journal. 92:316-320.

Riedell, W. E., D. L. Beck and T. E. Schumacher. 2000. Should K be used on high K-testing soils? Fluid Journal. 8:14-17.
Riedell, W. E., and T. E. Schumacher. 2003. Transport of water and nutrients in plants. In : Agricultural Sciences, R. Lal, ed. *In* Encyclopedia of Life Support Systems (EOLSS). Developed under the auspices of the UNESCO, Eolss Publishers, Oxford, UK. (http://www.eolss.net).
Osborne, S. L., J. S. Schepers, and M. R. Schlemmer. 2004. Detecting nitrogen and phosphorus stress in corn using multi-spectral imagery. Communications in Soil Science and Plant Analysis. 35:505-516.

**Improved anhydrous ammonia application technology:** Excessive application of ammonia fertilizer is attributed to farmers compensating for the poor application uniformity of current equipment. In cooperation with ISU engineers and industry, we developed a new manifold that produces much more even distribution of anhydrous ammonia across the tool bar. Farmers will benefit by adoption of this technology through reduce N fertilizer application rates and reduced fertilizer costs. The public benefits through improved water quality.

**Impact :** Efficiency of anhydrous ammonia applications to agricultural lands has been advanced. This innovative product received an AE50 award by the American Society of Agricultural Engineers.

**Documentation:**

Hanna, H. M., M. L.White, P.M. Boyd, T.S. Colvin, J.L. Baker. 2001. Improving the uniformity of anhydrous ammonia application. Iowa State University Extension Pamphlet PM-1875.
Hanna, H.M., M.L.White, T.S. Colvin, J.L. Baker. 2002. Anhydrous ammonia distribution during field application. Applied Engineering in Agriculture. 18(4): 443-451.
Boyd, P. M., H. M. Hanna, J. L. Baker, T. S. Colvin. 2002. Field evaluation of anhydrous ammonia manifold performance and variability. American Society of Agricultural Engineers. paper No 02-1039.

**Nitrogen mineralization/immobilization:** Synchronization of nitrogen release from soil and uptake by plants can increase N use efficiency. Agricultural management practices that include innovative manure management strategies, manure composting, and the use of cover crops, and green manures can improve N-use efficiency. In a laboratory experiment to evaluate the effect of compost processing and maturity on soil N cycling, we measured net C and N mineralization in soil (without plants) amended with dried swine manure compost. The dominance of apparent net N immobilization throughout the incubation period was not correlated with C mineralization or substrate C/N ratio. In field plots, fresh or composted swine hoop house manure applied to corn (in a corn-soybean rotation) in the spring or fall gave the following results: 1) N-supply efficiency was greatest for fall-applied composted swine hoop house manure and least for spring-applied fresh swine hoop house manure, 2) corn grown with composted swine manure was larger and produced more grain than corn grown with fresh swine manure, 3) cumulative net N mineralization (0-20cm) in fresh and compost amended soils did not differ, and 4) weed species differed in their responses to compost and manure amendments. Corn grain producers benefit because composted manures supply plant nutrients and enhance soil quality. Swine producers benefit from methods developed for composting reduces manure volume and improved ease of handling. Scientists benefit because the studies have filled knowledge gaps relating to N-use efficiency.

**Impact :** ARS scientists have been invited to give presentations of this work by producers, university, and industry groups in Iowa, Wisconsin, Kansas and Minnesota. These results lead to better manure and nutrient management.

**Documentation:**

Malpassi, R.N., T.C. Kaspar, T.B. Parkin, C.A. Cambardella, and N.A. Nubel. 2000. Oat and rye root decomposition effects on nitrogen mineralization. Soil Science Society America Journal. 64:208-215.

Parkin, T.B., T.C. Kaspar, and C.A. Cambardella. 2002. Oat plant effects on net nitrogen mineralization. Plant and Soil. 243:187-195.

Cambardella, C.A., T.L. Richard, and A.E. Russell. 2003. Compost mineralization in soil as a function of composting process conditions. European Journal of Soil Biology. 39:117-127.

Loecke, T.D., M. Liebman, C.A. Cambardella, and T.L. Richard. 2004. Timing of application and composting affect corn (*Zea mays* L.) yield response to solid swine (*Sus scropfa* L.) manure. Agronomy Journal. 96:214-223.

Loecke, T. D., M. Liebman, C.A. Cambardella, and T.L. Richard. 2004. Growth responses of corn (*Zea mays* L.) to composted and fresh solid swine (*Sus scrufa* L.) manure. Crop Science. 44:177-184.

Liebman, M., F.D. Menalled, D.D. Buhler, T.L Richard, D.N. Sundberg, C.A. Cambardella, and K.A. Kohler. 2004. Impacts of composted swine manure on weed and corn nutrient uptake, growth, and seed production. Weed Science. 52:365- 375.

Singer, J.W., K.A. Kohler, M. Liebman, T.L. Richard, C.A. Cambardella, and D.D. Buhler. 2005. Tillage and Compost Affect Yield of Corn, Soybean, and Wheat and Soil Concentrations of Organic Matter, Phosphorus, and Potassium. Agronomy Journal. (Accepted for publication June 2004).

Karlen, D.L., C.A. Cambardella, and R.S. Kanwar. 2005. Challenges of managing liquid swine manure. Applied Engineering in Agriculture. (Accepted for publication June 9, 2004).


**Improving N supply in low-input systems:** In southeastern Brazil, in an area dominated by subsistence farming, the development of sustainable land management requires the integration of crops with trees. Low-input farmers in tropical regions of the world primarily use residues of previous crops as well as leaves of neighboring trees to supply nitrogen and other nutrients to current crops. ARS scientists and Brazilian cooperators determined the effectiveness of mixing leaves of different species on decomposition rates and nutrient release. Nitrogen mineralization rates of most residues showed potential to supply the nutrient needs of a crop of corn. This information will enable low-input farmers to improve the nitrogen supply to their crops.

**Impact :** This research demonstrates that mixing leaves of a number of species, rather than relying on a single source, improves the nitrogen status of the next crop. This also provides a use for trees planted for erosion control, thereby reducing the chance that farmers will destroy trees to provide more space for cash crops.

**Documentation:**

Mendonça, E.S., and D.E. Stott. 2003. Characteristics and decomposition pattern of pruning residues from a shaded coffee system in southeastern Brazil. Agroforestry Systems. 57:117-125.

**Nitrogen fixation in an endangered clover species**: The survival of Running Buffalo Clover, an endangered plant species native to the eastern U.S., is uncertain, because little is known about management practices to enhance growth. Running Buffalo Clover does not fix nitrogen from the atmosphere as is characteristic of most clovers and may be a contributing factor for its demise. However, close cutting management does not damage Running Buffalo Clover stands. Scientists benefit through knowledge that efforts to enhance survival should be directed towards insertion of nitrogen fixing genes into the species. The general public, who are interested in plant species as a natural resource, benefits from this research because they know how to manage clover sites.

**Impact**: Chances for the survival of the endangered running buffalo clover species may be increased.

**Documentation**:

Morris, D.R., V.C. Baligar, T.M. Schuler, and P.J. Harmon. 2002. Biological nitrogen fixation and habitat of running buffalo clover. Journal of Plant Nutrition. 25:735-746.

**Remotely sensed leaf N content:** Site-specific nitrogen (N) management depends on identifying the spatial variation in leaf chlorophyll concentration and applying appropriate amounts of N fertilizer to optimize crop yield and minimize fertilizer loss to the environment. Reflectance and fluorescence spectra of corn leaves and canopies with a wide range of leaf chlorophyll concentrations were acquired and analyzed. Selected pairs of spectral vegetation indices were linearly related to leaf chlorophyll and leaf N concentrations without the confounding problems of variations in background reflectance and leaf area index. Natural fluorescence emissions of plant canopies in sunlight provided additional unique information related to the crop's physiological condition and carbon fixation. Effective remote sensing tools for improved management of N fertilizer will reduce the environmental impact of crop fertilization and benefit both crop producers and the general public.

**Impact:** A means of remotely assessing crop nitrogen status in the presence of factors affecting crop reflectance has been developed.

**Documentation:**

Daughtry, C.S. T., C.L. Walthall, M.S. Kim, E.B. De Colstoun, and J.E. McMurtrey. 2001. Estimating corn leaf chlorophyll status from leaf and canopy reflectance. Remote Sensing of Environment. 74:229-239.

Kim, M.S., J.E. McMurtrey, C.L. Mulchi, C.S.T. Daughtry, E.W. Chappelle, and Y.R. Chen. 2001. Steady-state multispectral fluorescence imaging for plant leaves. Applied Optics.

40:157-166.
McMurtrey, J.E., P.C. Doraiswamy, A.S. Stern and L.A. Corp. 2001. Indices for detecting nitrogen level needs for site-specific management in field corn. Proceedings of the Third International Conference on Geospatial Information in Agriculture and Forestry. Denver, Colorado. CD-ROM pp. 1-7
Corp, L.A., J.E. McMurtrey, E.M. Middleton, C.L. Mulchi, E.W. Chappelle, and C.S. T.Daughtry. 2003. Fluorescence sensing systems: In vivo detection of biophysical variations in field corn due to nitrogen supply. Remote Sensing of Environment. 86:470-479.
Pinter, P.J., J.L. Hatfield, J.S. Schepers, E.M. Barnes, M.S. Moran, C.S.T. Daughtry, and D.R. Upchurch. 2003. Remote sensing for crop management. Photogrammetric Engineering and Remote Sensing. 69:647-664.

**Alternative remote sensing platforms for crop management:** Remote sensing of nitrogen status in corn is limited by sensor spatial resolution, timeliness of data delivery, and expense of airborne and satellite-borne data. Imagery from unmanned, radio-controlled model aircraft was acquired over 3 years and related to ground data on biomass and nitrogen requirements of corn. Relative differences in growth and nitrogen content were clearly distinguished in the imagery from commercial digital cameras. These images had higher spatial resolution, shorter delivery time (<1 day), and significantly lower cost than current satellite or airborne imagery for monitoring small fields. Farmers, crop scouts, and crop consultants benefit through improved labor efficiency in determining crop nitrogen status.

**Impact:** Significant improvement in labor efficiency has been obtained with development of alternative remote sensing systems for site-specific nitrogen fertilizer management.

**Documentation:**

Hunt, Jr., E.R., Daughtry, C.S.T., McMurtrey, J.E., Walthall, C.L., Baker, J.A., Schroeder, J.C., and Liang, S. 2002. Comparison of remote sensing imagery for nitrogen management. Sixth International Conference on Precision Agriculture Proceedings. CD-ROM.
Hunt, Jr., E.R., Daughtry, C.S.T., Walthall, C.L., McMurtrey, III, J.E., and Dulaney, W.P. 2003. Remote sensing using radio-controlled model aircraft and airborne sensors for nutrient management. pp. 197-205. *In:* Digital Imaging and Spectral Techniques : Applications to Precision Agriculture and Crop Physiology. T. VanToai, D. Major, M. McDonald, J. Schepers, and L. Tarpley, *eds*. ASA Special Publication Number 66, Madison, Wisconsin.

**Benefits from and limitations to land application of animal manures are summarized:** Under-utilization or inefficient use of manure wastes a valuable resource. ARS scientists and university cooperators from a number of locations compiled relevant information on the benefits from and limitations to effective use of manure via land application. Manure is an excellent source of major plant nutrients and land application can improve soil physical, chemical, and biological properties, reduce soil erosion and water runoff, and mitigate greenhouse gas emission by sequestering carbon in soil, but limitations to greater use of manure include potential water quality problems with runoff, uncertainty associated with nutrient availability, high transportation and handling costs, and public perception or odor issues. Improved technical information, made available to the public, permits implementation of solutions that alleviate environmental, social, and political concerns with land application of animal manures. This information enables agricultural consultants and environmental organizations to foster development of land application systems for animal manures that are efficient and environmentally sensitive.

**Impact :** Producers are guided in grazing land management and consultants are provided an informational database from which to formulate best management practices. The knowledge developed enables environmental trading of greenhouse gas credits and guides environmental polices designed to mitigate greenhouse gas emissions and protect soil, water, and air quality.

**Documentation:**

Risse, L.M., M. L. Cabrera, A.J. Franzluebbers, J.W. Gaskin, J.E. Gilley, R. Killorn, D.E. Radcliffe, W.E. Tollner, and H. Zhang. 2001. Chapter 7. Land application of manure for beneficial reuse. p. 7.1-7.46. *In :* White Papers on Animal Agriculture and the Environment. National Center for Manure and Animal Waste Management. Summary available at : http://www.cals.ncsu.edu/waste_mgt/natlcenter/papers.htm, accessed and verified August 19, 2004.

**Soil, plant, and manure analyses improve nutrient management :** Implementing routine soil, plant, and manure analyses helps producers achieve and maintain an optimum supply of available plant nutrients without increasing the risk for unintended offsite environmental degradation. A series of studies demonstrated that (1) chlorophyll measurements between plant growth stages V9 and V12 were useful for assessing the N status of corn plants and their response to various tillage and N fertilizer management treatments; (2) stratification in soil-test P and K was not a production issue for central Iowa soils if overall soil-test levels were adequate; (3) additional research is needed to evaluate the merits of the basic cation saturation ratio (BCSR) philosophy for soil-test interpretation; and (4) developing a local manure nutrient database is essential for improved nutrient use efficiency with swine manure. Producers, crop consultants, and persons using surface and groundwater resources for recreation, drinking water, or other uses are the primary beneficiaries of this research.

**Impact:** Specific recommendations are provided on a) timing of leaf chlorophyll measurements to optimize N management for corn, b) how to improve nutrient management when liquid swine manure is the primary nutrient source for corn production, and c) a 5-year assessment of expected soil-test changes when using a diversified crop rotation, ridge-tillage, and nutrients supplied by a mixture of organic amendments.

**Documentation:**

Siambi, M.M., D.L. Karlen, and R.M. Shibles. 1999. Chlorophyll meter assessments of corn response to nitrogen management practices. Journal of the Iowa Academy of Science. 106:34-39.

Karlen, D.L., K.A. Kohler, D.A. Laird, R.L. Thompson, and D.D. Buhler. 2002. Soil-test dynamics throughout a five-year “Thompson farm” rotation in Iowa. American Journal of

Alternative Agriculture 17:9-17.

Karlen, D.L., C.A. Cambardella, C.A., and R.S. Kanwar. 2005. Challenges of managing liquid swine manure. Applied Engineering In Agriculture. (Accepted 06/09/2004).

**Anaerobically digested dairy manure by-product as fertilizer for corn:** Anaerobic digestion of animal manures can exceed the energy needs of a 60-cow dairy farm in the form of methane, and the by-product manure can be applied to crops as fertilizer. The by-product manure was more effective in acid than in alkaline soil for increasing growth of corn in early vegetative growth stages and was similar or better than most inorganic nitrogen fertilizers tested. This information is important to producers and consumers because it indicates U.S. energy can be conserved, not only through the generation of methane, but by using by-product manure to offset lime and inorganic nitrogen fertilizer applications.

**Impact:** These findings demonstrate an economic benefit for producers both from the energy produced and the byproduct manure from the anaerobic digestion process.

**Documentation:**

Morris, D.R. and D.J. Lathwell. 2004. Anaerobically digested dairy manure as fertilizer for maize in acid and alkaline soils. Communications in Soil Science and Plant Analysis. 35:1757-1771.

**Isolate those elements, using the resin-extraction technique, that limit crop yield:** Plants respond to the entire suite of readily available elements in the soil either directly or indirectly, but scientists were without a means of assessing that suite until recently. Using resin extractors designed, tested, and patented by ARS, 20 to 30 elements can be assayed in a single extraction and subsequently analyzed by inductively coupled plasma methods. A survey of the Barnes, Buse, Langhei, and Svea soils, all closely associated in the Northern Great Plains, shows that soils lying adjacent to each other in the landscape can be quantitatively distinguished by their suite of resin extractable elements. Conventional methods of soil testing found almost no differences between soils and could provide no insights to improving resource use efficiencies. Coupled with earlier observations that maize hybrids and soybean and wheat varieties were differentially sensitive to various resin extractable elements or complex combinations of elements, the results provide a foundation for investigations of precision agriculture and plant genetics. Crop breeders now have a soil-testing tool available that will identify potential genetic responses and enable crop producers to improve the precision of fertilizer management. Conventional methods of soil testing found almost no differences between the soils surveyed and could provide no insights to improving resource use efficiencies.

**Impact:**

Scientists are now able to obtain multiple assays of reactive soil nutrients and toxic elements in a single extraction in which the assay results correlate with genetic response. Crop breeders are aided by the ability to determine the nature of the environment and the elements that are likely to affect crop yield.

**Documentation:**

Olness, A.E., Palmquist, D., Rinke, J.L. 2001. Ionic ratios and crop performance: Effects of interactions amongst vanadium, phosphorus, magnesium and calcium on soybean yield. Journal of Agronomy and Crop Science. 187:47-52.

Olness, A.E. 2001. Using resin-extraction of soil nutrients for genotype selection and fertility management. p. 738-739. *In :* Plant Nutrition: Food security and sustainability of sgro-ecosystems through basic and applied research. Horst, W.J., et al., *eds*. Kluwer Academic Publishers.

Olness, A.E., Kunze, B., Lieser, M., Weiser, H., Rinke, J.L. 2002. Precision chemical analysis of soils to support precision management decisions. Proceedings Seventeenth World Congress of Soil Science. Paper #125. 8 p. Aug. 13-18, 2002. Bangkok, Thailand. CD-ROM

Olness, A.E., Archer, D.W., Gesch, R.W., Rinke, J.L. 2002. Resin-extractable phosphorus, vanadium, calcium and magnesium as factors in maize (Zea mays L.) yield. Journal of Agronomy and Crop Science. 188:94-101.

Olness, A.E., Lieser, M., Kunze, B., Weiser, H., Rinke, J. 2002. Assessing active inorganic chemical variability of soils and resin extraction. Abstracts Sixth International Conference on Precision Agriculture and Other Precision Resources Management. July 14-19, 2002. Richfield, Minnesota. p.19.

Olness, A.E., Lieser, M., Weiser, H., Kunze, B., Rinke, J.L. 2003. Four northern great plains soils : Their unique chemical signatures. Soil and Water Conservation Symposium. Minnesota Academy of Science. CD-ROM. April 25, 2003. St. Paul, Minnesota.

Olness, A.E., Weiser, H., Kunze, B., Lieser, M., Rinke, J.L. 2004. Differentiation of four northern Great Plains soils using resin extraction. Canadian Journal of Soil Science. 84:31-42.

**Identification of a single dominant gene controlling susceptibility to zinc deficiency in common bean :** Zinc deficiency occurs in many varieties of bean (*Phaeseolus vulgaris* L.) in production regions in the U.S. ARS scientists evaluated the inheritance of susceptibility to zinc deficiency in the common bean in collaboration with university cooperators. Field and greenhouse studies showed that a single dominant gene controls susceptibility to zinc deficiency in common bean. Bean breeders benefit through identification of a single dominant gene that addresses zinc deficiency. Farmers with zinc deficient soils benefit through development of zinc efficient cultivars.

**Impact :** This knowledge aids transfer of zinc deficiency-resistance to new bean genotypes. Producers can avoid planting susceptible genotypes on soils with low zinc availability.

**Documentation:**

Singh, S.P., and D.T. Westermann. 2002. A single dominant gene controlling resistance to soil zinc deficiency in common bean. Crop Science. 42:1071-1074.

# Nutrient Management Component

**Problem Area 5:** A greater understanding is needed of the physical, chemical and biological processes involved in transformation, interaction and fate of nutrients in soil-plant-microbe-climate systems.

**Background:** Plant nutrients occur in soil in many different organic and inorganic forms. Availability of some nutrients requires complex chemical and biological transformations via processes that depend on soil physical, chemical, and biological properties. In addition, the availability and use of some essential nutrients can be impaired by the availability or uptake of nonessential or toxic elements present in some soils. Plant nutrients can be stored in the soil, lost from the soil to water and air, or removed from the soil by harvested plants. Nutrients can be returned to the soil as plant residue, animal urine or feces, ions dissolved in irrigation water or precipitation, or as fertilizer inputs. A better understanding is needed of the physical, chemical, and biological processes that transform nutrients contained in organic and inorganic complexes into forms available to plants. This understanding is needed to insure that all nutrient sources are used efficiently and to minimize potential negative environmental impacts. Soil biota both provide for and compete with plants for nutrients. More process-level information is needed to clarify the role of soil biota in nutrient cycling and nutrient movement throughout the soil profile and in the soil surrounding plant roots. In addition, the role of plant structure, physiology, and biochemistry in nutrient acquisition must be understood to optimize nutrient management across cropping systems, fertilizer formulations, nutrient reaction modifications, soil amendments, and climates.

The goals of this research were:

Integrate understanding of the effects of physical, chemical, and biological factors in soil nutrient cycling processes as related to crop performance, plant nutrient use-efficiency, and environmental quality.

Develop methodologies to quantify the availability and effect of nonessential elements on plant nutrient use-efficiency and yield.

Develop new methodologies to identify and characterize soil microbial populations and their nutrient cycling activities, and develop management practices that optimize the amount and timing of nutrients made available by soil microorganisms.

Quantify effects of fertilizer and organic byproduct additions to soil on nutrient transformations and fate of nutrients in different soils and climatic zones.

Quantify the effect of ammonia-based nitrogen fertilizers on soil acidification and aluminum, calcium, and manganese chemistries; and quantify the loss of pH buffering capacity when ammonia-based nitrogen fertilizers are used in semi-arid and arid soils containing inorganic carbon in the form of carbonates and bicarbonates.

**Accomplishments:**

**Phosphorus extractabilities in semi-arid region soils:** Manure and synthetic fertilizers vary in their contributions to soluble and extractable forms of P when applied to soils. Knowledge of these source and soil-dependent effects is required for planning fertilizer applications so that soil test P values remain below threshold levels. Selected soils of the Southern High Plains were amended with fed cattle manures, composted manure, and inorganic fertilizers at five rates and incubated under controlled conditions to evaluate P source and soil effects on P extractability. The increase in extractable P in soils amended with manures and synthetic fertilizers varied considerably with respect to P source, incubation time, extractant, and soil characteristics. Changes in water extractable P per unit increase in agronomic soil test P (for example, Mehlich 3 and $NaHCO_3$) averaged 105 percent greater for a soluble fertilizer as compared to composted and scraped manure amended soils. This information aids State and Federal Agencies developing and implementing phosphorus P indices and assessment tools.

**Impact :** Knowledge of the shortcomings of current methods improves state and federal agencies abilities to develop and implement P indices and assessments. Short-term P-source dependent relationships limit the use of agronomic soil extractants to make correct inferences about water extractable P and dissolved P in runoff.

**Documentation:**

Schwartz, R.C., R.L. Baumhardt, and T.H. Dao. 2002. Tillage and beef cattle manure effects on soil nitrogen in a dryland rotation. Vol. 9, pp. 66-71. *In:* Great Plains Soil Fertility Conference Proceedings. March 5-6, 2002. Denver, Colorado.

Schwartz, R.C. 2004. Phosphorus extractability from soils amended with stockpiled and composted cattle manure. Final Report Submitted to Texas Cattleman Feeders Association. USDA-ARS Conservation and Production Laboratory, Experiment Station Publication. 44 pp. Bushland, Texas.

Cole, N.A., R.C. Schwartz, and R.W. Todd. 2004. Assimilation vs. accumulation of macro- and micro-nutrients in soils: relations to livestock feeding operations. p. 36-54. *In:* Proceedings of the Combined Animal, Dairy, and Poultry Science Workshop, Joint Animal, Dairy, and Poultry Science Association Annual Meeting. R. Reynnells, *ed*. July 26, 2004. St. Louis, Missouri.

**Root exudates and phosphorus availability:** An understanding of phosphorus release kinetics and the compounds involved is needed to develop and improve soil management options to establish, grow, and maintain high quality forages. Organic acids in root exudates can enhance phosphorus availability. Two methods to identify and quantify twelve aliphatic and eleven aromatic organic acids in the rhizosphere, using chromatographic methods with UV/Vis detection, were developed. Both methods are simple, fast and reliable for the analysis of the most common aliphatic and aromatic organic acids found in root exudates. These two methods are been used in the identification of organic acids in the rhizosphere of chicory (*Cichorium intybus* L.), grown in soils with different rates of phosphorus. Scientists benefit from this information to better understand the processes affecting plant-available phosphorus in marginal, low-nutrient soils.

**Impact :** Tools to identify and quantify aliphatic and aromatic organic acids in root exudates were developed and knowledge on the effect of root exudates on phosphorus availability was generated. Development and/or improvement of soil management practices to overcome nutrient limitations, especially plant-available phosphorus in marginal, low-nutrient soils is enabled.

**Documentation:**

Gonzalez, J.M. and D.A. Laird. 2003. Carbon sequestration in clay mineral fractions from $^{14}C$-labeled plant residues. Soil Science Society of America Journal. 67:1715-1720.

Gonzalez, J.M. and D.A. Laird. 2004. Role of smectites and Al-substituted goethites on the catalytic condensation of arginine and glucose. Clays and Clay Minerals. 52:445-452.

**Plant-soil interactions and phosphorus uptake by plants:** Significant additional knowledge of the interaction of plant and soil parameters in phosphorus (P) uptake is needed to support the improvement of P uptake from soils with low available-P. Research with six mycorrhizal isolates (VAM) and five soils demonstrated that there were specific interaction patterns between soils and VAM, with no one VAM being “best” with all, or even most, of the soils. The complexity of these interactions is further complicated by differential plant cultivar by VAM interaction as measured by P uptake effectiveness. Measurements of root length and specific root length (SRL - length per unit mass) shows that there were cultivar specific adaptations to different levels of P, different acid soils and different mycorrhizal VAM. Subsequent analyses demonstrated that the basis for plant SRL differences between P levels, soil types and mycorrhizal VAM, was in increasing and/or decreasing the length of specific root diameter classes amongst roots less than 0.5 mm diameter. These fine, rapid-turnover roots provide plants with the ability to move P absorbing surface areas to the most available P. Scientists benefit from knowledge of the nature of interactions between soil, VAM and plant genotypes. The root knowledge is especially useful for scientists in further clarifying nutrient uptake functionality and plant soil interactions. The interaction methodology and knowledge also aids plant breeders and agronomists in development of specific cultivars and recommendations for their use.

**Impact:** Techniques have been developed to identify optimal cultivar/VAM/soil combinations for specific agricultural areas. The knowledge and techniques developed are applicable to a wide range of nutrient forms. These techniques aid further characterization of the functional type of root needed in a given soil nutrient niche at a given time to optimize adaptation and ultimately nutrient uptake.

**Documentation:**

Paolillo, D.J., and R.W. Zobel. 2002. The formation of adventitious roots on root axes is a widespread occurrence in field-grown dicotyledonous plants American Journal of Botany. 89:1361-1372.

Zobel, R.W. 2003. Fine roots – discarding flawed assumptions. New Phytologist. 160:276-280.

Zobel, R.W. 2003. Sensitivity analysis of computer-based diameter measurement from digital images Crop Science. 43:583-591.

Ritchey, K.D., R.W. Zobel, and D.J. Snuffer. 2004. Nutrient Film Technique to Evaluate Clipping Height Effects on Orchardgrass Shoot Biomass Production and Root Dynamics. Vol 13. pp. 424-428 *In :* Proceedings of the 2004 Conference of the American Forage and Grasslands Council. June 12-16, 2004. Roanoke VA

**Pasture management impacts on near-surface soil properties:** Appalachian pasture management practices change soil biological, chemical and physical properties and information is needed to understand the effects of management variables such as grazing intensity and pasture establishment on the magnitude and spatial distribution of important reservoirs of soil organic matter, biogeochemical processes and ultimately forage productivity. Concentrations of soil C, N, and dissolved inorganic orthophosphate were greatest at the surface of continuously-grazed pastures relative to non-grazed or rotationally-grazed pastures. Concentrations of dissolved unreactive phosphorus increased with depth and were correlated to concentrations of dissolved organic carbon. Surface-applied calcium sources caused soil changes, even 6 years after application. These changes were localized in the surface inch of soil and yields were more closely correlated with properties of soil collected from the surface inch than from greater soil depths. Appalachian hill land producers, USDA-NRCS, EPA, researchers and extension agents at public and private institutions, US-AID, FAS-ICD and industry benefit from these findings.

**Impact:** A better understanding of the close relationship between soil surface conditions, soil quality, and water quality has been provided to conservationists. Pasture management guidance has been created for livestock producers.

**Documentation:**

Ritchey, K.D.,D.P. Belesky, J.J. Halvorson, and J.D. Snuffer. 2002. Soil properties and clover establishment 6 years after surface application of Ca-rich by-products. Abstracts of the Annual Meetings of the American Society of Agronomy Society. Oct. 21-25, 2002. Indianapolis, Indiana. CD-ROM

Ritchey, K.D., D.P. Belesky, J.J. Halvorson, and J. D. Snuffer. 2002. Soil properties and clover establishment 6 years after surface application of Ca-rich by-products. Abstracts of the Annual Meetings of the American Society of Agronomy Society. Oct. 21-25, 2002. Indianapolis, Indiana. CD-ROM

Alloush, G.A., D.G. Boyer, D. P. Belesky, and J.J. Halvorson. 2003. Phosphorus mobility in a karst landscape under pasture grazing system. Agronomie. 23:593-600.

Ritchey, K.D., D.P. Belesky, and J.J. Halvorson. 2005. Soil properties and clover establishment 6 years after surface application of Ca-rich by-products. Agronomy Journal. (Accepted 07/07/04).

**Impact of elevated $CO_2$ on soil fertility:** Information regarding the impact of global change on future agriculture production is critical. One concern is in regard to the potential change in soil quality and soil fertility. Soil C storage was found to be sensitive to soil nitrogen dynamics and the decomposition of plant material grown under elevated $CO_2$ depended on plant specie and indigenous soil properties. Fertilizer N application in grain sorghum was unaffected by elevated $CO_2$ level. While elevated $CO_2$ may enhance crop production and change N status in plant tissue, changes to soil N fertilizer application practices may not be needed. This research aids decision makers working on global change policy issues. The scientific community benefits from recommendations and hypotheses for future $CO_2$/climate change research.

**Impact:** Understanding of the potential impact of elevated $CO_2$ on soil C and N cycling and the potential impact on soil fertility in future agriculture production has been enhanced.

**Documentation:**

Torbert, H.A., S.A. Prior, and H.H. Rogers. 2001. Effect of elevated $CO_2$ and temperature on soil C and N cycling. p. 309-315. *In :* R. M. Rees, B. C. Ball, C. D. Campbell, and C. A. Watson, *eds.* Sustainable management of soil organic matter. CABI Publishing, UK.

Prior, S.A., H.A. Torbert, G.B. Runion, and H.H. Rogers. 2003. Implications of elevated $CO_2$-induced changes in agroecosystem productivity. Journal of Crop Production. 8:217-244.

Prior, S.A., H.A. Torbert, G.B. Runion, and H.H. Rogers. 2003. Implications of elevated $CO_2$-induced changes in agroecosystem productivity. p 217-244. *In :* S. Anil, *ed.* Cropping Systems: Trends and Advances. Food Products Press, An Imprint of The Haworth Press, Binghamton, NY.

Prior, S.A., G.B. Runion, H.A. Torbert, H.H. Rogers, and D.W. Reeves. 2003. Effects of elevated $CO_2$ on biomass production and C sequestration : Conventional and conservation cropping systems. p. 943-948. *In :* Soil Management for Sustainability, Proceedings of Sixteenth International Conference of the International Soil Tillage Research Organization. University of Queensland. Brisbane, Australia.

Torbert, H.A., S.A. Prior, H.H. Rogers, and G.B. Runion. 2004. Elevated atmospheric $CO_2$ effect on nitrogen fertilization in grain sorghum and soybean. Field Crops Research 88:47-57.

Prior, S.A., G.B. Runion, H.A. Torbert, and H.H. Rogers. 2004. Elevated atmospheric $CO_2$ in agroecosystems : Soil physical properties. Soil Science. 169:434-439.

Prior S.A., H.A. Torbert, G.B. Runion, and H.H. Rogers. 2004. Elevated atmospheric $CO_2$ in agroecosystems : Residue decomposition in the field. Environmental Management 33:Supplement 1 S344-S354.

**Linkage between soil respiration and nitrogen mineralization:** The linkage between soil respiration and nitrogen mineralization is incompletely developed. Soil respiration is linked to organic matter decomposition and nitrogen availability. To understand this relationship, laboratory and field studies were conducted. Roots of living plants stimulated decomposition of organic matter and nitrogen mineralization. Field measurement techniques were developed that showed temperature, time of measurement, and frequency of measurement influenced estimates of cumulative respiration. Scientists have been aided through recognition of complex interactions between plants and soil microbial respiration and soil nitrogen dynamics.

**Impact:** Better estimates of cumulative soil respiration and the impact of plants on decomposition provide a basis for devising better estimates of nitrogen mineralization and nitrogen fertilizer requirements.

**Documentation:**

Malpassi, R.N., T.C. Kaspar, T.B. Parkin, C.A. Cambardella, and N.A. Nubel. 2000. Oat and rye root decomposition effects on nitrogen mineralization. Soil Science Society of America Journal. 64:208-215.

Parkin, T., T.C. Kaspar, and C.A. Cambardella. 2002. Oat plant effects on net nitrogen

mineralization. Plant and Soil. 243:187-195.
Parkin, T. B., and T.C. Kaspar. 2003. Temperature controls on diurnal carbon dioxide flux: Implications for estimating soil carbon loss. Soil Science Society of America Journal. 67:1763-1772.
Parkin, T.B., and T.C. Kaspar. 2003. Temporal variability of soil CO2 flux : Effect of sampling frequency on cumulative carbon loss estimates. Soil Science Society of America Journal. 68:1234-1241.

**Verification of a model simulation of the dynamics of N and 15 N in the soil-plant biosystem:** Optimal crop residue management information is needed to coordinate soil resource protection and nutrient cycling. Research was conducted to verify the capability of the NCSWAP/NCSOIL model to simulate the dynamics of nitrogen (N) and 15N in the soil-plant system. The model was used to obtain information about variables that cannot be measured and was calibrated against measured N concentrations in corn and soil and 15N enrichment data obtained from a long-term field experiment located at Rosemount, Minnesota. Corn roots released 24% of total N uptake. This loss was mitigated by the recycling of 14% of rhizodeposition-N into corn by maturity. 15N enrichment in corn and soil was greater for the 20 than the 200 kg N $ha^{-1}$ treatment. This resulted from the rapid N mineralization-immobilization turnover that channeled N through the inorganic N pool whose 15N enrichment was fixed yearly to that of the fertilizer. Tracer N enrichment decreased more rapidly in corn than in soil from 1986 to 1992 when tracer N was no longer added with the fertilizer, and by 1992, 15N was localized in the stable pool and flushed from the more labile pools. Scientists are aided in estimating effects of managed plant residue decomposition.

**Impact:** This information should be useful in the development of decision support tools to manage carbon and nitrogen in the soil.

**Documentation:**
Molina, J.A.E., C.E. Clapp, D.R. Linden, R.R. Allmaras, M.F. Layese, R.H. Dowdy, and H. H. Cheng. 2001. Incorporation of corn (*Zea mays* L.) carbon from roots and rhizodeposition into soil organic matter. Soil Biology and Biochemistry. 33:83-92.
Molina, J.A.E., C.E. Clapp, R.R. Allmaras, and M.F. Layese. 2004. Simulation of nitrogen rhizodeposition and assimilation back into corn (*Zea mays* L.) roots. Soil Biology and Biochemistry. 36:(accepted 7/20/04).

**Soil wetting and drying effects on C and N dynamics are revealed**: A minimum amount of useful information about carbon (C) and nitrogen (N) dynamics during the drying period and within a few hours of rewetting is available in literature due to the traditional drying technique used. As soil was exposed to more dry-wet (DW) cycles (total of 4 cycles), the C mineralization rate at the end of each drying cycle was reduced by 16%, 23%, and 47% for cycle 2, 3, and 4, respectively, compared with the first drying cycle. The continuous reduction in C mineralization rate indicates that the repeated DW cycles affect the available substrate and the microbial activity. Net N mineralization was significantly less for the DW, compared with the constant water content (CWC) treatment. A reduction in mineralized N was observed during the first 24 h after each rewetting period. This reduction in mineralized N could be caused by to increased microbial activity after rewetting the dry soil, resulting in N immobilization. In general, soil inorganic N significantly decrease in DW treatments compared with CWC treatment by 7, 10, 12, and 15 µg N $g^{-1}$ soil at the end of cycle 1, cycle 2, cycle 3, and cycle 4, respectively. Significant increase in microbial biomass N (MBM-N) was observed with DW cycles, compared with CWC at cycle 3 and cycle 4, which indicate that more inorganic N was assimilated by soil microorganisms. Research scientists developing baseline information about soil quality indicators and how to accurately measure them are the primary beneficiaries of this research.

**Impact:** A new technique that simulates *in situ* drying and rewetting cycles was developed and demonstrated to provide better information regarding soil C and N dynamics.

**Documentation:**
Mikha, M.M., Charles W. Rice, and George A. Milliken. 2005. Carbon and nitrogen mineralization as affected by drying and wetting cycles. Soil Biology and Biochemistry (accepted 08/18/2004)

**Iron chelate photodegradation alters both fertilizer formulation and plant physiology:** Iron chelates like ferric ethylenediaminetetraacetic acid (FeEDTA) and ferric diethylenetriaminepentaacetic acid (FeDTPA) incorporated into commercially-produced soluble fertilizers are vulnerable to photodegradation when exposed to ultria-violet or blue-spectrum radiation; conditions that would occur if a fertilizer stock solution in a translucent stock tank were exposed to sunlight. We found that exposure to ultraviolet or blue-spectrum light altered the ratio of soluble iron to other soluble micronutrient metals (manganese, copper, and zinc) in iron chelates. Photodegraded iron chelate-containing nutrient/fertilizer solution used in crop production causes greater root ferric reductase activity and greater rhizosphere acidification, iron deficiency, and manganese in ornamental bedding crops and vegetables. Horticultural producers benefit by knowledge of factors affecting stability of iron supplements.

**Impact:** Growers changed management practices related to fertilizer stock solution storage and fertilizer manufacturers changed fertilizer formulations. The practical consequences of both the vulnerability of FeDTPA to photodegradation and adverse response of crops to degraded Fe-chelates were demonstrated.

**Documentation:**
Albano, J.P. and W.B. Miller. 2001. Photodegradation of FeDTPA in nutrientsolutions. I. Effects of irradiance, wavelength, and temperature. HortScience. 36:313-316.
Albano, J.P. and W.B. Miller. 2001. Photodegradation of FeDTPA in nutrient solutions. II. Effects on root physiology and foliar Fe and Mn levels in marigold. HortScience. 36:317-320.
Albano, J.P. and W. B. Miller. 2001. Ferric ethylenediaminetetraacetic acid (FeEDTA) in commercially produced soluble fertilizers. HortTechnology. 11:265-267.
Albano, J.P. and W.B. Miller. 2003. Ferric ethylenediaminetetraacetic acid (FeEDTA) in a commercially produced soluble fertilizer affects iron uptake in tomato. HortTechnology. 13:289-292.

**Soil and crop management to improve forage mineral balances for better animal health and production:** Cattle production is adversely impacted when mineral nutrient imbalances or toxic phytochemicals occur in pasture, range or forage feeds. The linkage of several animal maladies to nutrient imbalances or accumulation of toxic phytochemicals was determined across a range of forage, range, and pasture species, including relationships involving selenium contents, potassium and magnesium ratios, and sulfur compounds by ARS scientists from a number of locations and university cooperators. Soil and grazing management practices as well as development and introduction of new forage cultivars was accomplished to optimize animal intake of desirable components and diminish uptake of potentially toxic components. Animal producers and the meat consuming public significantly benefit by reducing the incidence of grass tetany, selenium toxicosis and several related or similar maladies.

**Impact:** Knowledge of complex nutrient ratios and their effects is expected to reduce losses in animal production by more than $400 million annually.

**Documentation:**


Ajwa, H.A., G.S. Bañuelos, and H.F. Mayland. 1998. Selenium uptake by plants from soils amended with inorganic and organic materials. Journal of Environmental Quality 27:1218-1227.

Bañuelos, G.S., and H.F. Mayland. 2000. Absorption and distribution of selenium in animals consuming canola grown for selenium phytoremediation. Ecotoxicology and Environmental Safety. 46:322-328.

Asay, K.H., H.F. Mayland, P.G. Jefferson, J.D. Berdahl, J.F. Karn, and B.L. Waldron. 2001. Parent-progeny relationships and genotype X environment effects for factors associated with grass tetany and forage quality in Russian Wildrye. Crop Science. 41:1478-1484.

Jefferson, P.G., H.F. Mayland, K.H. Asay, and J.D. Berdahl. 2001. Variation in mineral concentration and grass tetany potential among Russian Wildrye accessions. Crop Science. 41:543-548.

Mayland, H.F. and G.E. Shewmaker. 2001. Animal health problems caused by silicon and other mineral imbalances. Journal of Range Management. 54:441-446.

Mayland, Henry F. and Juley L. Hankins. 2001. Mineral imbalances and animal health : A management puzzle. Station Bulletin 73. Idaho Forestry, Wildlife and Range Experiment Station. Moscow, Idaho.

Panter, K.E., H.F. Mayland, D.R. Gardner, and G.E. Shewmaker. 2001. Beef cattle losses after grazing *Lupinus argenteus* (Silvery Lupine). Vetinary and Human Toxicology. 43:279-282.

Sabreen, S., S. Saiga, M. Tsuiki, and H.F. Mayland. 2002. Plant tissues suitable for individual selection of Mg in tall fescue. pp. 316-317. *In :* Proceedings of the Japan Grassland Science Meeting. 21-23 September. Fukuoka, Japan.

Sleper, D.A., H.F. Mayland, R.J. Crawford, Jr., G.E. Shewmaker, and M.D. Massie. 2002. Registration of HiMag Tall Fescue Germplasm. Crop Science. 42:318-319.

Shewmaker, G.E., D.A. Johnson, H.F. Mayland, S.A. Martin, and S.B. Hansen. 2004. Elemental uptake in relation to root characteristics of tall fescue. Communications in Soil Science and Plant Analysis. 35:1339-1355.

**Models for cell-surface electrical effects required for a quantitative resolution of plant-ion interactions:** A comprehensive view of cell-surface electrical effects is required for an understanding of plant-ion interactions. These interactions include plant acquisition of essential nutrients or harmful pollutants, plant intoxication by ions, and the alleviation of intoxication by ameliorative ions. Electrostatic models with newly evaluated parameter values now enable the computation of electrical potentials, ion activities, and ion binding in plant cell walls and at plasma membrane surfaces. Electrostatic effects influence ion transport phenomena. Cell-surface ion activities inserted into nonlinear equations successfully resolved multiple toxic and ameliorative effects observed in multi-ion systems. Examples include separate and interacting effects of Na, Ca, and K in salinity toxicity and Al, H, Ca, and Mg in acidic soil toxicity. The effectiveness of Ca in the alleviation of mineral toxicities (including intoxication by Al, Na, H, Cu, etc.) is now understood in terms of three mechanisms : *Mechanism I,* electrostatic displacement of cell-surface toxicants; *Mechanism II,* replacement of toxicant-induced Ca-displacement required at the cell surface; and *Mechanism III*, collective ameliorative effect of Ca beyond *Mechanisms I* and *II*. *Mechanism III* plays an important role in Na toxicity, a significant but lesser role in H toxicity, and no role in Al toxicity. Some ions, Al and H in particular, sometimes enhance and sometimes inhibit root elongation, and the cause of these effects is now clear from electrostatic principles. Enhancement occurs when a toxicant ion (for example, Al) displaces another toxicant ion (for example, H) and when this effect outweighs the usual intoxicating effect of the ameliorative ion (that is, Al). Beneficiaries of these studies include agricultural scientists and advisors and anyone with a need to understand the mechanisms of plant-ion interactions.

**Impact :** The concepts and the models developed in these studies are increasingly being incorporated into the world scientific literature dealing with plant-ion interactions. It is now widely recognized that plant-ion interactions must be interpreted in terms of cell-surface ion activities, which differ significantly from ion activities in bulk-phase rooting media. Thus, plant responses to ions usually correlate well with cell-surface ion activities and often correlate poorly with bulk-phase activities.

**Documentation:**

Kinraide, T.B. 2001. Ion fluxes considered in terms of membrane-surface electrical potentials. Australian Journal of Plant Physiology. 28:605-616.

Kinraide, T.B. 2003. The controlling influence of cell-surface electrical potential on the uptake and toxicity of selenate ($SeO_4^{2-}$). Physiologia Plantarum. 117:64-71.

Kinraide, T.B. 2003. Toxicity factors in acidic soils: attempts to evaluate separately the toxic effects of excessive $Al^{3+}$ and $H^+$ and insufficient $Ca^{2+}$ and $Mg^{2+}$ upon root elongation. European Journal of Soil Science. 54: 323-333.

Shomer, I., A. Novacky, S. Pike, U. Yermiyahu, and T.B. Kinraide. 2003. Electrical potentials of plant cell walls in response to the ionic environment. Plant Physiology. 133:411-422.

Pedler, J.F., T.B. Kinraide, and D.R. Parker. 2004. Zinc rhizotoxicity in wheat and radish is alleviated by micromolar levels of magnesium and potassium in solution culture. Plant and Soil. 259:191-199.

Kinraide, T.B., J.F. Pedler, and D.R. Parker. 2004. Relative effectiveness of calcium and magnesium in the alleviation of rhizotoxicity in wheat induced by copper, zinc,

aluminum, sodium, and low pH. Plant and Soil 259:201-208.
Kinraide, T.B. 2005. Possible influence of cell walls upon ion concentrations at plasma membrane surfaces. Toward a comprehensive view of cell-surface electrical effects upon ion uptake, intoxication, and amelioration. Plant Physiology. 136: (accepted 04/16/04).

# Nutrient Management Component

**Problem Area 6:** Management practices need to be developed that minimize the potential for nutrient losses to ground and surface waters while maintaining or improving desirable soil characteristics.

**Background:**
The application of plant nutrients as fertilizer, manure, or compost is necessary for profitable production of crops. Prior to the 1950s, most plant nutrients were "mined" from the soil by the crop, symbiotically fixed by nutrient-fixing crops, or recycled as applied animal manures or crop residues. Since then, greater use of concentrated chemical fertilizers and specialized farming operations have evolved, significantly reducing nutrient recycling on many farms. As a general rule in agriculture, nutrients in the harvested crop are removed from the farm. In modern farming systems, an additional imbalance occurs when chemical fertilizers are applied in predominately crop-producing areas, and harvested products are transported to concentrated animal producing areas in other regions of the country. The subsequent accumulation of manure nutrients can lead to excessive amounts of soil nitrogen, phosphorus, and potassium, increasing the risk of degradation of ground and surface waters. To address eutrophication and other problems caused by excessive nutrient export from agricultural lands, many state regulatory agencies require producers to develop nutrient management plans. Most of the current nutrient management data at the field and farm scales are not linked to transport mechanisms that control nutrient export to surface or ground water. Consequently, nutrient management plans developed with such data may not achieve the desired reduction in nitrogen and phosphorus export and may cause an undue burden on already financially strapped producers.

The goals of this research were:

Develop nutrient management systems that minimize the loss of nutrients to ground and surface waters while maintaining the necessary food, feed, and fiber production and a profitable agricultural economy.

Develop site-specific nutrient management based on soil properties and regional hydrology to retain and efficiently utilize nutrients.

Provide scientific information for action agencies developing a phosphorus index for use by producers, regulators, and consultants in developing nutrient management plans; for action agencies determining TMDLs for environmental protection; and for conservation organizations and producers in developing fertilizer, manure, and conservation practices (e.g., grassed waterways, vegetation buffer strips) for nutrient loss mitigation.

**Accomplishments:**

**Nitrate leaching and economic analysis package (NLEAP) computer model:** Proper management of N in agricultural systems while understanding its transport and transformations is becoming increasingly important to agricultural producers and to modern society. A book that included the Nitrate Leaching and Economic Analysis Package (NLEAP) computer model has been developed. Both the book and the NLEAP model have been used worldwide, but updates and explanations of how to use the model in special situations and unique applications have been needed. The NLEAP model was updated, a new updated NLEAP model was delivered to the Natural Resources Conservation Service (NRCS), and updated publications are planned. The NRCS benefits and through their technical guidance to farmers, the general public will have cleaner drinking water and the environment in general will benefit by less overloading with fixed nitrogen.

**Impact:** An improved model (NLEAP) has been developed and released to NRCS for use by that agency and the public. An overview of N management, directed at minimizing impacts of N fertilizer on human health and the environment has been provided to the public. Methods for use of non-radioactive isotopes have been developed to track N transport and transformations in the environment.

**Documentation:**

Delgado, J.A., Ronald F. Follett, and Marvin J. Shaffer. 2000. Simulation of nitrate-nitrogen dynamics for cropping systems with different rooting depths. Soil Science Society of America Journal. 64:1050-1054.

Delgado, J.A., R.J. Ristau, M.A. Dillon, R.F. Follett, M.J. Shaffer, H.R. Duke, R.R. Riggenbach, R.T. Sparks, A. Thompson, L.M. Kawanabe, A. Stuebbe, A. Kunigi, and K. Thompson. 2001. Use of Innovative Tools to Increase Nitrogen Use Efficiency and Protect Environmental Quality in Crop Rotations. Communications in Soil Sci. Plant Analysis. 32:1321-1354.

Follett, R.F. and J.L. Hatfield. 2001. Nitrogen in the environment, sources, problems, and management. *In :* Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection : Proceedings of the second International Nitrogen Conference on Science and Policy. http:// www.thescientificworld. com/publications/NitrogenToC.asp. Dec 27, 2001.

Shaffer, M.J. and J.A. Delgado. 2001. Chapter 15. Field techniques for modeling nitrogen management. pp. 391-411. *In :* Follett et al., *eds*. Nitrogen in the Environment : Sources, Problems, and Management. Elsevier Science Publishers. The Netherlands.

Shaffer, M.J., B.J. Newton, and C.M. Gross. 2001. An internet-based simulation model for nitrogen management in agricultural settings. The Scientific World 1:728-736.

Follett, R.F. and J.L. Hatfield. 2001. Nitrogen in the environment, sources, problems, and management. In Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection : Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World 1:920-926

Follett, R.F. 2001. Nitrogen Transformation and Transport Processes. pp. 17-44. *In :* R.F. Follett and J. Hatfield, *eds.* 2001. Nitrogen in the Environment; Sources, Problems, and Solutions. Elsevier Science Publishers. The Netherlands.

Follett, R.F. and J.A. Delgado. 2002. Nitrogen fate and transport in agricultural systems. Journal of Soil and Water Conservation. 57:402-408.

Delgado, J.A. and R.F. Follett. 2002. Carbon and nutrient cycles. Journal of Soil and Water Conservation. 57:455-464.

Shaffer, M.J. and R. Flynn. 2004. Installation of Internet NLEAP on a Windows XP machine. Manual. Colorado State University, Fort Collins, Colorado. Flynn, R. 2004. NLEAP ARCIMS Data Setup. Manual, Colorado State University, Fort Collins, Colorado.

**Improved model for N management:** More rapid tools are needed for the assessment of nitrate leaching and improved N management. Over forty fields across various farms in south central Colorado were monitored. At each one of these sites data from soils, crops, precipitation, and management was collected. At some of these locations specific N management studies were installed and monitored with small plots located within the farmers fields. Over five hundred model simulations were conducted. A new version of the Nitrogen Leaching Economic Analysis Package (NLEAP) was developed that simulates cropping sequences with different rooting depths. A unique geographic information system (GIS) NLEAP database for south central Colorado (over 2000 center irrigated pivot irrigation systems) was developed which allowed evaluation of the effects of variability in soil type and cropping systems on N use efficiencies and nitrate leaching across the whole region. After combining the new NLEAP program with advanced GIS software, the programs were tested for N management on a regional basis. The model and publications about best management practices are being used by farmers, USDA-NRCS personnel, and CSU extension personnel.

**Impact:** NLEAP-GIS, a powerful and useful tool for evaluation of precision conservation practices, identifies areas sensitive to nitrate leaching losses. NLEAP version 1.2 was listed as one of the Best Management Practices for the Cooperative Extension Service, Colorado State University, and Best Management Practices Bulletin. Regional scale evaluations are being used to evaluate a new generation of the nitrate leaching indices. This work has led to the publication of a research editorial about the need for a revised Nitrate Leaching Index. This information has contributed to the formation of a national working group composed of NRCS and state universities to develop a new generation of the nitrate leaching index. ARS scientists were invited to conduct national and international presentations and to cooperate in similar studies conducted at other regional locations.

**Documentation:**

Delgado, J.A., R.F. Follett, and M.J. Shaffer. 2000. Simulation of $NO_3^-$-N dynamics for cropping systems with different rooting depths. Soil Science Society of America Journal. 64:1050-1054.

Shaffer, M.J., and J.A. Delgado. 2001. Field techniques for modeling nitrogen management. pp. 391- 411. *In :* R.F. Follett and J. Hatfield, *eds.* 2001. Nitrogen in the Environment; Sources, Problems, and Solutions. Elsevier Science Publishers. The Netherlands.

Hall, M.D., M.J. Shaffer, R.M. Waskom, and J.A. Delgado. 2001. Regional nitrate leaching variability: What makes a difference in Northeastern Colorado? Journal of the American Water Resources Association. 37:139-150.

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Delgado, J.A., W. Colon, W. Bausch, D. Wright, D. Westfall, M. Dillon, A. Thompson-Johns,

M. Shaffer, K. Thompson, H. Duke, R. Follett, and L. Olivieri. 2002. Use of innovative tools to increase nitrogen use efficiency and protect environmental quality for temperate and tropical regions. Stormwater 3:48-56.
Shaffer, M.J., and J.A. Delgado. 2002. Essentials of a National Nitrate Leaching Index Assessment Tool. Journal of Soil and Water Conservation. 57:327-335.
Delgado, J.A. 2002. Quantifying the Loss Mechanisms of Nitrogen. Journal of Soil and Water Conservation. 57:389-398.
Schleicher, T.D., W.C. Bausch, and J.A. Delgado. 2003. Low Ground Cover Filtering to Improve Reliability of NRI Corn N Status Classification. Transactions of American Society of Agricultural Engineers. 46:1707-1711.
Delgado, J.A., and Alva, A.K., A. Fares, S. Paramasivam, D. Mattos, Jr., K. Sajwan. 2004. Numerical Modeling to Study the Fate of Nitrogen in Cropping Systems and Best Management Case Studies. *In :* Enhancing the Efficiency of Nitrogen Utilization in Crops.A. Basra and S. Goyal, eds. Haworth's Food Products Press, Binghamton, New York. (Accepted 9/22/03).
Van Es, H.M., and J.A. Delgado. 2004. Nitrate Leaching Index. Encyclopedia Soil Science. Markel and Decker. New York, NY. (Accepted 12/9/03).

**Use of a pre-sidedress soil test to reduce N loss:** Nitrate lost from tile drains into surface waters has led to serious surface-water-quality problems and has been implicated in the expansion of the northern Gulf of Mexico's hypoxic zone. Much of the Midwest Cornbelt is underlain with subsurface drains, or "tiles," that remove excess water from the soil and permit large-scale production of corn and soybean. In collaboration with eight farmers, the impact of adopting a pre-sidedress soil test and sidedressing with nitrogen fertilizer on water quality on a 1000-acre watershed was evaluated. After 4 years, nitrate concentrations in water leaving the treated watershed were reduced by more than 30% compared to control watersheds, although nitrate concentrations still occasionally exceeded the U.S. Environmental Protection Agency's standard for maximum contaminant level for drinking water. Corn yields were maintained within the treated watershed, but the pre-sidedress soil test resulted in an overall reduction in the nitrogen fertilizer applied. Scientists benefit because the studies have filled knowledge gaps related to the relationship of N fertilizer management, crop yield, and $NO_3$ concentrations and leaching loads in streams and rivers. Land managers benefit because the results will help guide the implementation of alternative N management strategies in corn production systems. Society benefits because wide-scale adoption of this N management strategy could reduce $NO_3$ concentrations in rivers and streams.

**Impact :** A N-fertilizer management practice has been demonstrated to reduce nitrate concentrations in rivers and streams draining cultivated cropland without reducing crop yields.

**Documentation :**

Dinnes, D.L., Karlen, D.L., Jaynes, D.B., Kaspar, T.C., Hatfield, J.L., Colvin, T.C., and Cambardella, C.A. 2002. Nitrogen Management Strategies to Reduce Nitrate Leaching in Tile-Drained Midwestern Soils. Agronomy Journal. 95:153-171.
Tomer, M.D., Meek, D.W., Jaynes, D.B., and Hatfield, J.L. 2003. Evaluation of Nitrate Nitrogen Fluxes from a Tile-Drained Watershed in Central Iowa. Journal of Environmental

Quality. 32:642-653.
Jaynes, D.B., Dinnes, D.L., Meek, D.W., Karlen, D.L., Cambardella, C.A., and Colvin, T.S. 2004. Using the Late Spring Nitrate Test to Reduce Nitrate Loss within a Watershed. Journal of Environmental Quality. 33:669-677.

**Knowledge of subsurface hydrology dramatically improves nitrogen management:** Excessive application of nitrogen to crops results in loss of nitrate to surface and subsurface water with potentially detrimental impacts on neighboring ecosystems. Effective nitrogen management depends on identifying soil and hydrologic parameters that govern crop growth and yield. A new protocol reduced nitrogen inputs while enhancing crop yield by nearly 50% on a small 4.2 ha watershed relative to adjacent watersheds. This protocol uses information on subsurface hydrology gleaned from ground-penetrating radar, digital elevation maps, and the spatial distribution of yields as a function of climate. The agricultural community benefits from development of a tool for precision management of nitrogen while maintaining crop productivity. The public benefits from diminished nitrate concentrations in water supplies.

**Impact :** Off-site environmental impact of nitrogen fertilization of agricultural crops has been reduced through development of new technology and information.

**Documentation:**

Gish, T.J., W.P. Dulaney, K.-J.S. Kung, C.S.T. Daughtry, J.A. Doolittle, and P.T. Miller. 2002. Evaluating use of ground-penetrating radar for identifying subsurface flow pathways. Soil Science Society of America Journal. 66:1620-1629.
Gish, T.J., C.L. Walthall, C.S.T. Daughtry, and K.-J.S. Kung. 2004. Using soil moisture and spatial yield patterns to confirm subsurface flow pathways. Journal of Environmental Quality. (Accepted 08/24/04).
Gish, T.J., C.S.T. Daughtry, C.L. Walthall, and K.-J.S. Kung. 2004. Quantifying the impact of hydrology on corn grain yield using ground-penetrating radar. pp. 493-496. *In :* Proceedings of the 10$^{th}$ International Conference on Ground-Penetrating Radar. June 21-24, 2004. Delft, The Netherlands.

**Nitrogen management in soils with tile drainage:** Nitrogen, an essential plant nutrient, can be very difficult to manage in tile-drained soils because of the increased potential for its loss to surface water through the drainage network. Long-term field research shows that nitrate loss increases with annual tile drainage volume. Use of the late spring nitrate test as a fertilizer management strategy reduced nitrate loss through tile drainage by 25% compared to a single pre-plant N application. Using liquid swine manure as the N source resulted in greater residual soil nitrate than the commercial fertilizer because of difficulties in predicting the amount of N that would actually become available to corn plants. We found less residual soil nitrate following soybean when no-tillage was used than with chisel plowing. Producers, crop consultants, and persons using surface and groundwater resources for recreation, drinking water, or other uses were the primary beneficiaries of this research.

**Impact:** These plot-scale studies demonstrate that improved N management results in sustainable crop yields without having adverse effects on subsurface drainage water or the receiving water bodies into which this water is discharged.

**Documentation**:

Bakhsh, A., R.S. Kanwar, D.L. Karlen, C.A. Cambardella, T.S. Colvin, T.B. Moorman, and T.B. Bailey. 2000. Tillage and nitrogen management effects on crop yield and residual soil nitrate. Transactions of the American Society of Agricultural Engineers. 43:1589-1595.

Bakhsh, A., R.S. Kanwar, D.L. Karlen, C.A. Cambardella, C.A., T. Bailey, T.B. Moorman, and T.S. Colvin. 2001. N-Management and crop rotation effects on yield and residual soil nitrate levels. Soil Science. 166:530-538.

Bakhsh, A., R.S. Kanwar, T.B. Bailey, C.A. Cambardella, D.L. Karlen, and T.S. Colvin. 2002. Cropping system effects on NO3-N loss with subsurface drainage water. Transactions of the American Society of Agricultural Engineers. 45:1789-1797.

**Nitrogen leaching in tile drained corn production systems:** Agriculture has been linked to chemical contamination of surface- and ground-water in the upper Midwest but the controlling agronomic and hydrologic factors are poorly understood. Yields and $NO_3$ concentrations in tile water leaving a producer's field in Iowa were measured in an area where three N fertilizer rates (the farmer's typical rate and 2/3 and 1/3 of this rate) were used on corn in a corn - soybean rotation. All rates of added N fertilizer increased $NO_3$ concentrations in tile drainage and these concentrations exceeded the 10-ppm maximum contaminant level set by EPA for drinking water at some point in the season. Yields, soil $NO_{3,}$ water flow, and $NO_3$ concentrations in tile drain water were measured in production-scale corn-soybean research plots in NE Iowa where fertilizer N was applied using pre-sidedress N test to guide rates compared with a single pre-plant application. Late-spring N management resulted in 25% lower N leaching loads and 13% higher corn grain yield compared to single pre-plant N application. Scientists benefit because the studies have filled knowledge gaps related to the relationship of N fertilizer management, crop yield and $NO_3$ concentrations and leaching loads in tile-drain water. Land managers benefit because the results will help guide the implementation of alternative N management strategies in corn production systems.

**Impact:** The results were immediately applied by an ARS research team to design a watershed-scale study of alternative N management strategies and surface water in central Iowa. The information was also used by a CAD/ARS research team in the design of a watershed-scale study of crop rotation and ground-water quality in southwest Iowa.

**Documentation:**

Bakhsh, A., R.S. Kanwar, D.L. Karlen, C.A. Cambardella, T.S. Colvin, T.B. Moorman. 2000. Tillage and nitrogen management effects on crop yield and residual soil nitrate. Transactions of American Society of Agricultural Engineers. 43:1589-1595.

Jaynes, D.B., Colvin, T.S., Karlen, D.L., Cambardella, C.A., and Meek, D.W. 2001. Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate. Journal of Environmental Quality. 30:1305-1314.

Bakhsh, A., R.S. Kanwar, D.L. Karlen, C.A. Cambardella, T.B. Bailey, T.B. Moorman, and T.S. Colvin. 2001. N-Management and crop rotation effects on yield and residual soil nitrate

levels. Soil Science 161 : 530-538.
Bakhsh, A., R.S. Kanwar, T.B. Bailey, C. A. Cambardella, D.L. Karlen, and T.S. Colvin. 2002. Cropping system effects on $NO_3$-N loss with subsurface drainage water. Transactions of American Society of Agricultural Engineers. 45:1789-1797.

**Cover crops reduce drainage nitrate leaching:** Lack of an off-season crop to take up water and nitrogen can result in increased nitrate leaching. Drainage and nitrate leaching were measured from large undisturbed soil blocks planted to a corn/soybean rotation with cover crops (oat or rye) interplanted late summer into soybean. Cover crops reduced drainage and nitrate loss compared with a control without cover crops. Reduced nitrate contamination in water benefits the public and those involved in water treatment. The results aid scientists and conservationists working with post season cover crops to reduce nitrate leaching within a corn/soybean rotation.

**Impact:** Off-season cover crops are useful for reducing nitrogen loss.

**Documentation:**
Logsdon, S.D., T.C. Kaspar, D.W. Meek, and J.H. Prueger. 2002. Nitrate leaching as influenced by cover crops in large soil monoliths. Agronomy Journal. 94:807-814.

**Cover crops to reduce N loss in the Northern Corn Belt:** Effluent from agricultural drainage tiles is a significant source of nitrate contamination of surface waters. Additionally, erosion from fields planted to a corn-soybean rotation continues to contaminate surface waters with sediment. Management systems to grow small grain cover crops in a corn-soybean rotation in the upper Midwest were developed. Subsequent studies showed that small grain cover crops significantly reduced rill and inter-rill erosion, increased water infiltration, and reduced nitrate leaching in this rotation. This research shows that small grain cover crops can be used in a corn-soybean rotation in the upper Midwest to reduce nitrate and sediment contamination of surface waters.

**Impact:** Crop producers have been provided with a means of reducing nitrate concentrations and nitrogen loads in surface waters in the Corn belt through use of cover crops.

**Documentation:**
Johnson, T.J., T.C. Kaspar, K. A. Kohler, S. J. Corak, and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. Journal of Soil and Water Conservation. 53:276-279.
Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. Journal of Soil and Water Conservation. 56:160-164.
Logsdon, S.D., T. C. Kaspar, D.W. Meek, and J.H. Prueger. 2002. Nitrate leaching as influenced by cover crops in large soil monoliths. Agronomy Journal. 94:807-814.

**Winter cover crops and deeper rooted rotations are being used to control nitrate leaching and soil erosion:** Nitrate leaching and soil erosion by wind are crop production hazards in Colorado. Winter cover crops (WCC) and deeper rooted crops protect groundwater by mining residual soil $NO_3$-N from the soil profile and by recovering $NO_3$-N from water used for irrigation. Deeper rooted crops, such as small grains, contribute to the protection of water quality by scavenging residual soil $NO_3$-N and sequestering large amounts of N into particulate organic matter. Rotations using these crops contribute to the sequestration of 7 to 20 kg N per year in the soil organic matter from applied fertilizer. Potential benefits from the implementation of Best Management Practices and recommended cropping systems that contribute to mine $NO_3^-$-N from underground water and increased N use efficiencies were demonstrated. WCC conserve soil quality by reducing potential wind erosion from vegetables by an average of 28.3 Megagrams per hectare per year. Farmers are benefiting from these BMPs that preserve the soil, soil organic matter, and nutrients at the site. Additionally, the airborne soil is not being transferred off-site reducing the potential impact of dust transferred to cities and town areas.

**Impact:** Recommended Best Management Practices that account for N budgets have a conservative estimated savings of $2.1 million dollars for south central Colorado farmers. Colorado State University Extension and USDA-NRCS are recommending the return of crop residue from winter cover crops and small grain rotations to increase soil organic matter sequestration and to improve soil quality levels for the south central Colorado region. ARS scientists were invited to conduct several national and international presentations and to cooperate in similar studies conducted at other regional locations. South central Colorado farmers are using these WCC on about 50 % of the 2430 ha and by implementing these BMPs 192,000 Megagrams of top soil, 2.2 million kilograms of soil organic matter, 119,000 kilograms of N and 21,000 kilograms of $P_2O_5$ were saved across the agricultural region. This retention is higher since these WCC are also implemented in 10 to 15 % of the area used for potatoes.

**Documentation:**

Delgado, J.A. 2000. Control of Nitrogen Transformations to Increase Nitrogen-Use Efficiency and Protect Environmental Quality. Journal of Erosion Control. 7:68-75.

Castellanos, J.Z., S. Villalobos, J.A. Delgado, J. Muñoz-Ramos, A. Sosa, P. Vargas, I. Lazcano, E. Alvarez-Sanchez, S.A. Enriquez. 2001. Use of best management practices to increase nitrogen use efficiency and protect environmental quality in a broccoli-corn rotation of Central Mexico. Communications in Soil Science and Plant Analysis. 32:1265-1292.

Delgado, J.A., R.R. Riggenbach, R.T. Sparks, M.A. Dillon, L.M. Kawanabe, and R.J. Ristau. 2001. Evaluation of nitrate-nitrogen transport in a potato-barley rotation. Soil Science Society of America Journal. 65:878-883.

Delgado, J.A. 2002. Keeping our soil in place with the right crop rotation for conservation of soil and water quality. Journal of Erosion Control. 8:50-55.

Follett, R.F. and J.A. Delgado**.** 2002. Nitrogen fate and transport in agricultural systems. Journal of Soil and Water Conservation. 57:402-408.

Meisinger, J.J. and J.A. Delgado. 2002. Principles for managing nitrogen leaching. Journal of Soil and Water Conservation. 57:485-498.

Delgado, J.A., and R.F. Follett. 2002. Carbon and Nutrient Cycles. Journal of Soil and Water Conservation. 57:455-464.

Delgado, J.A., W. Reeves, and R. Follett. 2004. Winter Cover Crops. Encyclopedia of Soil Science. Markel and Decker, New York, NY. (Accepted 12/9/03).

Delgado, J.**.,** M.A. Dillon, R.T. Sparks, and R.F. Follett. 2004. Tracing the fate of $^{15}N$ in a small-grain potato rotation to improve accountability of N budgets. Journal of Soil Water

Conservation. (Accepted 12/10/03).
Al-Sheikh, A., J.A. Delgado, K. Barbarick, R. Sparks, M. Dillon, Y. Qian, and G. Cardon. 2004. Effects of Potato-Grain Rotations on Soil Erosion, Carbon Dynamics and Properties of Rangeland Sandy Soils. Journal of Soil Tillage Research. (Accepted 12/12/03).

**Pasture management to reduce N loss:** Grazing is economically important and a prevalent land use throughout the Appalachian region, but high nitrogen inputs can negatively impact groundwater quality. Some current nitrogen rates for pastures are excessive for maintenance of acceptable water quality, but good management practices reduce high levels of nitrogen in groundwater. Without nitrogen fertilizer application, a rotational grazing or haying system reduces nitrogen in groundwater to acceptable levels. Nitrogen application levels should be kept to 100 lbs per acre annually and should include manure, purchased fertilizer, feed**,** and legume contributions. Legumes are the recommended primary source of N for pastures, especially with highly permeable soils. Strategically timed nitrogen applications to pastures in the Appalachian region overcome summer slump or stockpile forage nitrogen deficits in the autumn. Beneficiaries of this work are producers who graze livestock, NRCS, and policy makers.

**Impact:** These results contributed to NRCS grazing management guidelines in the Appalachian region.

**Documentation.**

Owens, L.B., R.W. Van Keuren, and W.M. Edwards. 2003. Non-nitrogen nutrient inputs and outputs for fertilized pastures in silt loam soils in four small Ohio watershed. Agriculture Ecosystems and Environment. 97:117-130.
Owens, L.B., and J.V. Bonta. 2004. Reduction of nitrate leaching with haying or grazing and omission of nitrogen fertilizer. Journal of Environmental Quality. 33:1230-1237.

**Development of the P Index to reduce the risk of phosphorus loss from agricultural fields :** Soil management can reduce the risk of phosphorus (P) loss in runoff from agricultural fields. In response to mounting water quality concerns, many states developed guidelines for land application of P, soil management, and farm and watershed management, based on the potential for P loss in agricultural runoff. These actions have been spurred, in part, by a federal initiative in which the USDA and EPA created a joint strategy to implement Comprehensive Nutrient Management Plans (CNMPs) on all Animal Feeding Operations (AFOs) by 2008, which consider both agronomic and environmental impacts of applied P. To address this need, ARS, NRCS, and University soil scientists led the development and refinement of a P Index to rank the vulnerability of fields to P loss in runoff and identify those at greatest risk for loss. ARS research showed most of the P exported (>80%) from agricultural watersheds comes from only a small area of land (<20%) during a limited number of storms. The overall significance of implementing the P Index is seen in terms of its' impact on Concentrated Animal Feeding Operations (CAFOs). According to the EPA, today 15,500 CAFOs, which represent only 7% of AFOs in the U.S., produce 60% of all manure generated by AFOs. The P Index also serves as an educational tool that aids interaction between planners and farmers, helps elucidate implications of management decisions for water quality, and identifies and prioritizes alternative management options available to land users, thereby providing flexibility in developing remedial strategies.

**Impact:** The NRCS adopted the P Index in 47 states as the basis for their CMNPs to target P-based nutrient management planning. Workshops, fact sheets, and on-site demonstration programs were developed by ARS, NRCS, and Extension personnel to train field agents and farm advisors on the use of the P Index in writing nutrient management plans. Over 2000 field agents and nutrient management consultants across the U.S. have received training in the use of the P Index. By better targeting resources to the largest operations and areas at greatest risk of water quality impairment, CNMP strategies that include the P Indexing approach have an estimated cost to the CAFO industry of $355 million rather than the $980 million per year without the P Index. This approach is estimated to reduce P loadings in water by 56 million pounds annually and reduces sediment released by over 2.1 billion pounds from CAFOs to the environment. Economic benefits of this approach are estimated at $204 to $355 million and include increased recreational use of waters, greater shellfish harvest, fewer fish kills, lesser drinking water treatment costs, and reduced loss of livestock to disease. Soil scientists from ARS have also worked with overseas researchers and advisors to aid adaptation and implementation of the P Indexing approach to targeted nutrient management in Australia, Brazil, Finland, Ireland, New Zealand, Norway, and United Kingdom. Wide spread adoption and use of the P Index is resulting in the first significant reduction in the threat to water quality from non point sources of P.

**Documentation:**


Gburek, W.J., A.N. Sharpley, and G.J. Folmar. 2000. Critical areas of phosphorus export from agricultural watersheds. pp. 83-104. *In :* Agriculture and Phosphorus Management : The Chesapeake Bay. A. Sharpley, *ed*. Lewis Publishers. New York, NY.

Gburek, W.J., A.N. Sharpley, L. Heathwaite, and G.J. Folmar. 2000. Phosphorus management at the watershed scale : A modification of the phosphorus index. Journal of Environmental Quality. 29:130-144.

Heathwaite, L., A.N. Sharpley, and W.J. Gburek. 2000. A conceptual approach for integrating phosphorus and nitrogen management at watershed scales. Journal of Environmental Quality. 29:158-166.

Sharpley, A.N., R.W. McDowell, J.L. Weld, and P.J.A. Kleinman. 2001. Assessing site vulnerability to phosphorus loss in an agricultural watershed. Journal of Environmental Quality. 30:2026-2036.

Weld, J.L., A.N. Sharpley, D.B. Beegle, and W.J. Gburek. 2001. Identifying critical source areas of phosphorus export from agricultural watersheds. Nutrient Cycling in Agroecosystems. 59 :29-38.

Coale, F.J., J.T. Sims, and A.B. Leytem**.** 2002. Accelerated deployment of an agricultural nutrient management tool : the Maryland Phosphorus Site Index. Journal of Environmental Quality. 31:1471-1476.

Kleinman, P.J.A., A.N. Sharpley, B.G. Moyer and G.F. Elwinger. 2002. Effect of mineral and manure phosphorus sources on runoff phosphorus. Journal of Environmental Quality. 31:2026-2033.

Kleinman, P.J. A., A.N. Sharpley, A.M. Wolf, D.B. Beegle, and P.A. Moore, Jr. 2002. Measuring water-extractable phosphorus in manure as an indicator of phosphorus runoff. Soil Science Society of America Journal. 66:2009-2015.

McDowell, R.W., A.N. Sharpley and P.J.A. Kleinman. 2002. Integrating phosphorus and nitrogen decision management at watershed scales. Journal of the American Water Resources Association. 38 :479-491.
Heathwaite, A.L., A.N. Sharpley, and M. Bechmann. 2003. Conceptual basis for a decision support framework to assess phosphorus loss at the field scale across Europe. Journal of Soil Science and Plant Nutrition. 166:447-458.
Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.L. Gburek, P.A. Moore, and G. Mullins 2003. Development of phosphorus indices for nutrient management planning strategies in the U.S. Journal of Soil and Water Conservation. 58:137-152.

**Relationship of soil test phosphorus to runoff phosphorus in calcareous and non-calcareous soils:** Movement of nutrients into waterways from confined animal feeding operations (CAFO) is thought to be the cause of recent outbreaks of organisms that have caused fish kills and human illnesses. A linear relationship between soil test P level and P losses in runoff was found over the range of soil tests examined. Significant differences exist in the potential for runoff losses of P (at the same concentration of soil test P) between different soil types within the same watershed. Calcareous soil types contributed lesser concentrations of soluble P compared to more acidic soil types. A potential exists to group classes of soil types for their soil P loss potential. These differences, properly described, are useful in refining tools such as the P index for manure management. This research aids decision makers working on policy issues as they relate to waste management programs.

**Impact:** Knowledge for development of a soil phosphorus index for manure management CAFOs has been acquired.

**Documentation:**

Torbert, H.A., T.C. Daniel, J.L. Lemunyon. and R.M. Jones. 2002. Relationship of soil test phosphorus to runoff phosphorus in calcareous and noncalcareous soils. Journal of Environmental Quality. 31:1380-1387.
Harmel, R.D., P. B. DeLaune, B. E. Haggard, K.W. King, C.W. Richardson, P.A. Moore, Jr., and H.A Torbert. 2002. Initial evaluation of a phosphorus index on pasture and cropland watersheds in Texas. Paper No. 02-2075. *In :* American Society of Agricultural Engineers, Chicago, IL, July 28-31, 2002.
Torbert, H.A., T.C. Daniel, J.L. Lemunyon, and R.M. Jones. 2003. Relationship of soil test phosphorus to runoff phosphorus in calcareous soils. pp. 18-22. *In :* Ag Professional. October 2003.
Torbert, H.A., and K.N. Potter. 2004. Fertility management effects on runoff losses of phosphorus. p. 220-234. *In :* W.L. Hall, and W.P. Robarge, eds. Environmental Impact of Fertilizer Products on Soil, Air, & Water. Washington DC.

**Quantifying phosphorus availability and potential losses in the Pacific Northwest:** In the Pacific Northwest the combination of high phosphorus fertilization requirements for high value crops, poorly understood phosphorus dynamics in the highly calcareous soils, rapid growth in concentrated animal production, and promotion of phosphorus transport to surface and groundwater by irrigation seepage and return flows has made understanding the chemical dynamics of phosphorus loss in these systems a high priority. ARS scientists developed new, more accurate, rapid phosphorus characterization techniques for calcareous Pacific Northwest soils and for animal manure sources to aid estimation of P availability and potential losses from irrigated arid zone crop and animal agricultural systems. These techniques, essential steps for development of reliable phosphorus indices for Pacific Northwest soils, help guide management decisions to optimize crop and animal phosphorus supplementation while protecting surface and groundwater quality. Farmers and animal producers benefit by optimizing P fertilization and supplementation requirements, thereby reducing input costs. The public and environment benefit by enabling protection of surface and groundwater resources from excess P levels that lead to harmful algal blooms and impairment of use. These findings have important economic and quality of life benefits for the public at large living in the Pacific Northwest.

**Impact:** A major obstacle to improved management manure has been overcome through development of analytical techniques and new knowledge.

**Documentation:**

Robbins, C.W., D.T. Westermann, and L.L. Freeborn. 1999. Phosphorus forms and extractability from three sources in a recently exposed calcareous subsoil. Soil Science Society of America Journal. 63:1717-1724.

Turner, B.L., and I.D. McKelvie. 2002. A novel technique for the pre-concentration and extraction of inositol hexakisphosphate from soil extracts with determination by phosphorus-31 nuclear magnetic resonance. Journal of Environmental Quality. 31:466-470.

Leytem, A.B., and R.L. Mikkelsen. 2003. Separation of soil organic phosphorus compounds using reverse-phase ion-pair chromatography. Communications in Soil Science and Plant Analysis. 34:1393-1406.

Leytem, A.B. and D.T. Westermann. 2003. Phosphate sorption by Pacific Northwest calcareous soils. Soil Science. 168:368-375.

Turner, B.L. and V. Rayboy. 2003. Phosphorus cycle. pp. 329-334. *In :* E. Geller, *ed*. McGraw-Hill Yearbook of Science & Technology, McGraw-Hill, Inc., New York.

Turner, B.L., N. Mahieu, and L.M. Condron. 2003. Phosphorus-31 nuclear magnetic resonance spectral assignments of phosphorus compounds in soil NaOH-EDTA extracts. Soil Science Society of America Journal. 67:497-510.

Turner, B.L., B.J. Cade-Menun, and D.T. Westermann. 2003. Organic phosphorus composition and potential bioavailability in semi-arid arable soils of the Western United States. Soil Science Society of America Journal. 67:1168-1179.

Leytem, A.B., J.T. Sims, and F.J. Coale. 2004. Determination of phosphorus source coefficients for organic phosphorus sources : Laboratory studies. Journal of Environmental Quality. 33:380-388.

Turner, B.L. 2004. Optimizing phosphorus characterization in animal manures by solution phosphorus-31 nuclear magnetic resonance spectroscopy. Journal of Environmental Quality. 33:757-766.

Turner, B.L, and A.E. Richardson. 2004. Identification of scyllo-inositol phosphates in soil by solution phosphorus-31 nuclear magnetic resonance spectroscopy. Soil Science Society of America Journal. 68:802-808.

**Understanding forms of phosphorus to minimize phosphorus losses:** Phosphorus losses via surface runoff and erosion primarily depend on the kind and form of manures applied, on surface soil characteristics, and on conservation practices such as cover crops and vegetative buffer strips. The magnitude of P losses, however, is also highly dependent on the kind and form P in the applied manures and the conservation practices implemented. Specifically, the release of P from manure depends upon its chemical form and its solubility, but current analytical methods for P can produce misleading and unpredictable results. A method to differentiate organic and inorganic forms of P in manures using solid state 31P NMR was developed. NMR differentiates the slow release organic form of P, which is mainly heavy-metal, bound, from inorganic forms, which are generally fast release. A long-term field study was established in 2001 to assess P runoff from poultry manure applied to eight relatively large-sized corn plots with and without vegetative buffers. The largest reductions in dissolved phosphorous in runoff occurred from plots with 8-m vegetative filters and no poultry manure application on the lower 16 m of the plot areas compared to the plots without vegetative filters and with P application on the entire plot area. This field research provided an assessment of the grass-buffer influence and the loss of orthophosphate (soluble-P) in runoff for the mid-Atlantic region. Findings from the newly developed NMR methodology help scientists and investigators interested in developing a more realistic quantitative "cause and effects" relationships between soluble P component within manure matrix and the effective P concentration/amount found in surface water bodies adjacent to sites of manure applications. If proven effective, this treatment will be adopted as a best management practice in Maryland for controlling P runoff.

**Impact :** The new NMR analytical method offers an advantage over current methods because the heavy metal interferences with P-NMR analysis of manures has been diminished, and insoluble P species are more directly differentiated. A scientific basis has been provided for weighting factors with respect to the influence of vegetative filters and manure applications in the overall P-index estimations.

**Documentation:**

Dao, T., and W.F. Schmidt. 2001. Ca (II) amendment effects on phytate-phosphorus hydrolysis. Abstracts of the Annual Meetings of the American Society of Agronomy. Oct. 21-25, 2001. Charlotte, North Carolina. CD ROM.

Heighton-Davies, L., R.L. Siefert, and W.F. Schmidt. 2004. Availability of Phytic Acid Complexes of Ferric and Ferrous Iron to Enzymatic Dephosphoralation by *Aspergillus ficcum*. Abstracts of the American Society of Limnology and Oceanography Summer Meeting. June 13-18, 2004. Savannah, Georgia.

**Fertilizer placement effects on profile P distribution:** A need exists to improve the efficiency of fertilizer P use in agricultural crops. We found that most P applied in liquid form to the soil surface moves into the profile. This knowledge provides both producers and the fertilizer industry a management tool for P fertilizer applications that are effective and have minimal impact on the environment.

**Impact:** Solution P fertilizers can be applied to the soil surface without increasing P losses in surface runoff.

**Documentation:**

Kovar, J.L. 2002. Agronomic principles of fertilizer placement. *In :* P.J. Prosser, Jr., *ed.* Proceedings Fertilizer Industry Roundtable. Charleston, SC. October, 28-30. CD-ROM.Kovar, J.L. 2003. Searching for more effective corn starters in conservation-till. Fluid Journal. 11:8-11.

Kovar, J. L. 2004. Starter composition and hybrid selection affect early growth and yield of corn. pp. 131-141. *In :* Fluid focus : We can do it. L. S. Murphy, *ed*. Proc. Fluid Fertilizer Foundation Research Symposium, Scottsdale, Arizona. February 22-24, 2004. Fluid Fertilizer Foundation. Manhattan, KS.

Kovar, J.L., P.D. Schroeder, and K.L. Washburn, Jr. 2004. Positional availability of phosphorus from surface fertilizer bands. p. 271-276. *In :* A.J. Schlegel, *ed.* Proceedings of the Great Plains Soil Fertizer Conference. March 2-3, 2004. Denver, Colorado. Kansas State University. Manhattan, Kansas.

**Grazing of bermudagrass by cattle improves soil-plant nutrient cycling and prevents losses to the environment :** Loss of nutrients through leaching and surface runoff is both an immediate economic loss to farm producers, as well as a long-term economic burden for society. Scientists determined (a) soil-profile accumulation of inorganic nitrogen and (b) surface-soil accumulation of nitrogen, phosphorus, potassium, and other nutrient cations during 5 years of inorganic and organic fertilizer application to bermudagrass pastures. They found little evidence of leaching of inorganic nitrogen suggesting that well-managed pastures with high nitrogen input can increase soil fertility and therefore pose little risk to groundwater contamination. Accumulation of phosphorus occurred with poultry manure application, but at levels not considered threatening to surface runoff contamination due to concomitant increases in surface organic matter. Poultry manure was an excellent nutrient source for pastures and its application along with cattle grazing resulted in greater surface-soil nutrient cycling that was viewed as beneficial to high pasture productivity. However, continued application of poultry manure at high levels could pose a threat to water quality should water runoff from pastures increase. Cattle producers, agricultural consultants, and environmental organizations benefit from this information through design of sustainable grazing systems in the southeastern USA that increase productivity, while reducing costs of inputs and protecting soil and water quality.

**Impact :** Nutrient recommendations in pastures, modeling of nutrient cycles in pasture ecosystems, and environmental policies designed to protect surface and ground water quality in agricultural landscapes have been advanced through this research.

**Documentation:**

Schomberg, H.H., A.J. Franzluebbers, J.A. Stuedemann, S.R. Wilkinson. 2000. Nutrient distribution in grazed endophyte infected tall fescue pastures. Abstracts of the Annual Meetings of the American Society of Agronomy. Nov. 6-10, 2000. Minneapolis, Minnesota. p. 82.

Franzluebbers, A.J., and J.A. Stuedemann. 2001. Bermudagrass management in the Southern Piedmont U.S. IV. Soil-surface nitrogen pools. The ScientificWorld. 1(S2):673-681.

Franzluebbers, A.J., J.A. Stuedemann. 2001. Soil nitrogen pools under bermudagrass management in the Southern Piedmont USA. *In :* Second International Nitrogen Conference. October 14-18, 2001. Potomac, Maryland.

Franzluebbers, A.J., J.A. Stuedemann, and S.R.Wilkinson. 2002. Bermudagrass management in the Southern Piedmont USA. II. Soil phosphorus. Soil Science Society of America Journal. 66:291-298.

Franzluebbers, A.J., J. A. Stuedemann. 2002. Soil C, N, and P from poultry manure on grazed and ungrazed bermudagrass in the southeastern USA. *In :* World Congress of Soil Science Proceedings. August 14-21, 2002. Bangkok, Thailand. CD-ROM. 10 p.

Franzluebbers, A.J., and J.A. Stuedemann. 2003. Bermudagrass management in the Southern Piedmont USA. VI. Soil-profile inorganic N. Journal of Environmental Quality. 32:1316-1322.

Franzluebbers, A.J., S.R. Wilkinson, and J.A. Stuedemann. 2004. Bermudagrass management in the Southern Piedmont USA : VIII. Soil pH and nutrient cations. Agronomy Journal. (Accepted 04/14/04).

# Nutrient Management Component

**Problem Area 7**: More information is needed about management practices that enhance soil carbon sequestration, and the influence of changes in soil carbon levels on soil properties and processes.

**Background:**
Plants, residues, and soils constitute the largest pools for carbon in terrestrial systems. Changes in the carbon content of these pools affect physical, chemical, and biological processes in soils. Management decisions such as tillage intensity, fertilizer form and amount, cropping intensity, and water management affect carbon dynamics. Future productivity and environmental quality will require a better understanding of the effect of various management practices on carbon dynamics and of carbon content on various soil functions. Because of the importance of soil organic matter as a nutrient pool and its beneficial influence on other soil properties (greater soil aggregation, improved water infiltration, higher water holding capacity, etc.), soil organic matter transformations are an important part of nutrient management. In addition, there has been a growing interest in increasing carbon sequestration in soil to offset the increase of the atmospheric greenhouse gas, carbon dioxide. Management practices are needed that facilitate the accumulation of soil organic matter.

The goals of this research were:

Identify and develop management practices that maintain or increase organic matter in residue and soil.

Determine the extent and relative importance of inorganic and organic carbon sources on overall carbon storage in soils within management systems and on a national basis.

Develop management practices that provide sufficient nitrogen, phosphorus, and sulfur to meet plant needs and that allow for the accumulation of organic matter without jeopardizing environmental quality.

Determine the effect of organic and inorganic carbon on soil physical, chemical, and biological properties.

**Accomplishments:**

**Assessments of soil carbon stocks for policy makers:** A major requirement for meaningful participation in international climate change activities and meetings is continuous inventory of sources and sinks for greenhouse gases in the US. Working procedures were developed to conduct inventories of soil carbon stocks. Now, in collaboration with others, inventories of the soil carbon stocks on agricultural lands are conducted annually. These inventories, formerly provided to the Environmental Protection Agency (EPA; the agency responsible for reporting all green house gases for the US), were independently released by USDA for the years 1999 to 2001. We summarized potential to increase soil carbon stocks and developed several publications to specifically address issues that aid the focus on programs and practices related to soil carbon sequestration in the United States. We provided information concerning the stability of soil carbon sequestration as soil organic carbon and related this stability to past climate to bring understanding to the impact of long-term climate on soil C stocks. These inventories indicate that mineral soils alone in 2001 resulted in a net $CO_2$ flux from agricultural soils of -59.1 Tg $CO_2$ equivalents per year; this is equivalent to the sequestration of 16 Tg of organic carbon in soil annually. Adjustment for $CO_2$ flux from organic soils and from the liming of agricultural soils results in a net overall flux for all agricultural soils of –15.2 Tg $CO_2$ equivalents per year. Other researchers, the public, and US policy makers in USDA and US State Department benefit from this research.

**Impact:** This work served a major role in justifying soil as an important sink for atmospheric carbon dioxide. It provided USDA, Department of State, and members of congress with a perspective on soil carbon. This work recently supported development of legislation concerning possible carbon trading that indicates the growing awareness of the US Congress to the importance of agriculture and soil carbon sequestration. This work is leading to improvement of methods for greenhouse gas inventories for agriculture for use in future inventory reports.

**Documentation:**


Eve, M.D., K. Paustian, and R. Follett. 2000. A. U.S. inventory of agricultural soil carbon at local to national scales. *In :* Problems, Prospects, and Needs for Research. Proceedings of the fourth International Conference on Integrating Geographic Information Systems and Environmental Modeling. B. Parks, K. M. Clark, and M. P. Crane, *eds*. Sep 2-8, 2000. Boulder, Colorado. University of Colorado-Boulder, Cooperative Institute for Research in Environmental Science. CD-ROM.

Eve, M.D., K. Paustian, R. Follett, and E.T. Elliott. 2000. A national inventory of changes in soil carbon from National Resources Inventory data. pp. 593-610. *In :* Assessment Methods for Soil Carbon. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, *eds*. Lewis Publishers, Boca Raton, Florida. 696 p.

Eve, M.D., K. Paustian, R. Follett, and E.T. Elliott. 2001. A preliminary $CO_2$ inventory for U.S. cropland soils. pp. 51-65. *In :* Soil Carbon Sequestration and the Greenhouse Effect. R. Lal and K. McSweeny, *eds*. Soil Science Society of America Special Publication Number 57, Madison, Wisconsin. 236 p.

Kimble, J.M., L.R. Everett, R. Follett, and R. Lal. 2002. Carbon sequestration and the integration of science, farming, and policy. pp. 3-11. *In :* Agricultural Practices and Policies for Carbon Sequestration. J. M. Kimble, R. Lal, and R. F. Follett, *eds.* CRC Press. Boca Raton, Florida. 512 p.

Kimble, J. M., R. Lal, and R.F. Follett. 2002. Agricultural practices and policy options for carbon sequestration : what we know and where we need to go. pp. 495-501. *In :* Agricultural Practices and Policies for Carbon Sequestration. J. Kimble, R. Lal, and R.F. Follett, *eds.* CRC Press. Boca Raton, Florida. 512 p.

Eve, M.D., M. Sperow, K. Howerton, K. Paustian, and R.F. Follett. 2002. Predicted impact of management changes on soil carbon stocks for each agricultural region of the conterminous United States. Journal of Soil and Water Conservation. 57:196-204.

Lal, R., R.F. Follett, and J.M. Kimble. 2003. Achieving soil carbon sequestration in the U.S.: A

challenge to the policy makers. Soil Science 168:827-845.
Eve, M.D., M. Sperow, K. Paustian, and R. F. Follett. 2002. National-scale estimation of changes in soil carbon stocks on agricultural lands. Environmental Pollution 116:431-438.
Follett, R.F., J.M. Kimble, S. Leavitt, and E. Pruessner. 2004. The potential use of soil C isotope analyses to evaluate paleoclimate. Soil Science. 169:471-488.
U.S. Department of Agriculture. 2004. U.S. Agriculture and Forestry Greenhouse Inventory: 1999-2001. Contributors : J. Brenner, J. Duffield, R. Follett, L. Heath, J. Kimble, D. Kruger, J. Mangino, A. Mosier, S. Ogle, K. Paustian, H. Shapouri, J. Smith, T. Wirth, and P. Woodbury. K. Bickel, *eds.*. Global Change Program Office, Office of the Chief Economist, USDA. Technical Bulletin No. 1907. 164 p.
Follett, R. F., J. Z. Castellanos, and E. D. Buenger. 2005. Carbon sequestration in a Vertisol in Mexico. Soil and Tillage Research (Accepted 6/30/2004).

**The potential for US land resources to sequester carbon to mitigate the greenhouse effect:** A major activity and requirement to participate meaningfully in the national dialogue among scientists is estimation of the potential for US lands to sequester soil carbon. With collaborators, we initiated the concept of potential soil organic carbon (SOC) sequestration in croplands and grazing lands. We determined SOC sequestration under land in the Conservation Reserve Program (CRP), and urban land uses such as lawns, parks, or golf courses. Work within this research unit, with scientists from other USDA agencies, and with US University scientists has been instrumental to providing estimates of the potential for carbon sequestration in US agricultural and other lands. With increased on-farm efforts and programs that encourage improved management practices, our average estimates of the potential rates of sequestration are ~70, 40, 60, and 13 Tg of organic carbon annually on cropland, grazing land, forest, and CRP soils, respectively. This information was distributed to congressional staff and US Department and Agency Administrators. Our estimates benefit other scientists, US policy makers in the USDA and other State and Federal agencies in addressing the role of current and improved practices and possible future policies on carbon sequestration.

**Impact:** This effort served a major role in identifying the importance of SOC and the large potential that exists under different land uses to sequester carbon to mitigate the greenhouse effect. It greatly broadened the scope of lands worthy of consideration as carbon sinks in treaty discussions. ARS has become recognized as a source of authority for SOC sequestration. Our estimates are or have been used by computer modelers, US policy makers in the USDA and other State and Federal agencies in addressing the role of currently used and improved practices and possible future policies on carbon sequestration.

**Documentation:**

Qian, Y.L. and R. Follett. 2002. Assessing carbon sequestration in turfgrass soil using long-term soil testing data. Agronomy Journal. 94:930-935.
Follett, R.F. 2002. The Conservation Reserve Program and Carbon Sequestration. pp. *In :* Carbon as a Potential Commodity. Symposium Proceedings December 3-4, 2002. Denver, Colorado.
Lal**,** R., R.F. Follett, and J.M. Kimble. 2002. Potential of U.S. soils to sequester carbon. p. 72. *In*

: Carbon as a Potential Commodity. Symposium Proceedings. December 3-4, 2002. Denver, Colorado.

Follett, R.F. 2003. The potential for soil carbon sequestration in US grazing lands. Abstracts of the Annual meetings of The American Society of Range Management. February 1-3, 2003. Casper, WY. CD-ROM.

Bandaranayake, W., Y.L. Qian, W.J. Parton, D.S. Ojima, and R.F. Follett. 2003. Estimation of soil organic carbon changes in turfgrass systems using the CENTURY model. Agronomy Journal. 95:558-563.

Follett, R.F. 2003. Pasture Management Systems : Impact on Soil Carbon and Greenhouse Gases. Proceedings of the 2003 Annual meetings of the Canadian Society of Animal Science. June 10-13, 2003. Saskatoon, Saskatchewan. CD ROM.

**Carbon sequestration model (CQESTER) describes soil organic matter** changes: To achieve a net reduction in atmospheric $CO_2$ concentrations, an improved understanding of the capacity to store carbon in soils is needed. A carbon sequestration model (CQESTER) requiring minimum input (RUSLE c-factor files, local weather, management practices, crop biomass, nitrogen content, and soil organic matter) was developed, validated with long-term data, and used to show that increasing biomass production or limiting inversion tillage will promote C storage while practices that bury or remove biomass or promote microbial decomposition will reduce it. Research scientists, NRCS, and other action agency personnel are the primary beneficiaries of this research.

**Impact:** CQESTER is projected as one deliverable product of GRACEnet (**G**reenhouse Gas **R**eduction through **A**gricultural **C**arbon **E**nhancement Network) and is under consideration by the NRCS for nationwide use to estimate carbon sequestration.

**Documentation:**

Rickman, R.W., C.L. Douglas Jr., S.L. Albrecht, L.G. Bundy, J.L.Berc. 2001. CQESTR: A model to estimate carbon sequestration in agricultural soils. Journal of Soil and Water Conservation. 56:237-246.

Rickman, R.W., C.L. Douglas Jr., S.L. Albrecht, and J.L. Berc. 2001. CQESTR-Predicting carbon sequestration in agricultural cropland and grassland soils. p. 177-181. In: J. M. Kimball, R. Lal and R.F. Follett (eds.).Agricultural practices and policies for carbon sequestration in soil. Chapt. 16. CRC Press, Boca Raton, FL.

Rickman R.W. C.L. Douglas, S.L. Albrecht, J.L. Berc, L. Norfleet and Mike Hubbs. 2001. CQESTR, A field level farm carbon sequestration planning tool. World Resource Review. 13(3):356-368.

**Methods and testing of analytical procedures to measure soil carbon pools:** Important to working with and understanding the carbon (C) cycle is the need for methods and ways of understanding the storage, transformations, and transport of C in agricultural and other lands. We found that multiple methods exist for measuring soil C pools, but that both standardization of current methods and new methods are needed. Those benefiting are researchers, laboratory analysts, computer modelers, action agencies, farmers, and the public.

**Impact:** Collaboration was increased across many laboratories and scientists in the use and development of methods to measure soil C pools. Numerous analytical procedures were consolidated for measurement of various soil carbon pools, better interpretations of these pools, increased standardization among laboratories in the measurement methods used, and the use of innovative measurement tools including stable isotopes of C.

**Documentation**:

Kimble, J. M., R. Lal, and R. F. Follett. 2000. Methods for assessing soil carbon pools. pp. 3-12. *In :* Assessment Methods for Soil Carbon. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, *eds.* Lewis Publishers, Boca Raton, Florida. 696 p.

Follett, R. F. and E. G. Pruessner. 2000. Intralaboratory carbon isotope measurements on five soils. pp. 185-192. *In :* Assessment Methods for Soil Carbon. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, *eds.* Lewis Publishers, Boca Raton, Florida. 696 p.

Lal, R., J. M. Kimble, and R. F. Follett. 2000. Methodological challenges towards balancing soil carbon pools. pp. 659-668. *In :* Assessment Methods for Soil Carbon. R. Lal, J. M. Kimble, R. F. Follett, and B. A. Stewart, *eds.* Lewis Publishers, Boca Raton, Florida. 696 p.McCarty, G.W., J. B. Reeves III, V. B. Reeves, R. F. Follett, and J. M. Kimble. 2002. Mid-Infrared and Near-Infrared Diffuse Reflectance Spectroscopy for Measurement of Carbon in Soils. Soil Science Society of America Journal. 66:640-646.

Qian, Y. L., R. F. Follett, S. Wilhelm, A. J. Koski, and M. A. Shahba. 2004. Carbon isotope discrimination of three Kentucky bluegrass cultivars with contrasting salinity tolerance. Agronomy Journal. 96:571-575.

**Remote sensing the spatial distribution of soil carbon:** Terrestrial carbon sequestration has a key role in mitigating the recent increases in atmospheric carbon dioxide ($CO_2$). Long-term use of conservation management practices enhances sequestration of $CO_2$ with added benefits such as reduction of soil erosion and improvement of soil and water quality. The EPIC-CENTURY biogeochemical model was adapted for use in the Corn Belt and changes in soil carbon over a 50-year period under various management scenarios were mapped for a 50 x 100 $km^2$ area in central Iowa. Spatial and temporal distributions of cropping practices and soil tillage intensity are crucial variables affecting soil carbon storage. Advanced multispectral or hyperspectral imaging systems provide local and regional maps of crop residue cover and soil tillage intensity for modeling and monitoring soil carbon. The Natural Resource Conservation Service (NRCS) benefits through the development of appropriate strategies for improved of soil quality and enhanced carbon sequestration in soil.

**Impact:** A robust and objective method to evaluate changes in soil carbon under current and alternative future management practices has been developed.

**Documentation:**

Yost, R., P.C. Doraiswamy, and M. Doubia. 2002. Defining the contract area : using spatial variation in land, cropping systems and soil organic carbon, A Soil Carbon Accounting and Management System for Emissions Trading. pp. 13-40. *In :* Soil Management and Collaborative Research Support Program. Special Publication, SM CRSP 2002-4. University of Hawaii. Honolulu, Hawaii, Daughtry, C.S.T., E.R. Hunt, Jr., and P.C. Doraiswamy. 2002. Assessing carbon dynamics in agriculture using remote sensing. pp.28-35. *In :* International Symposium on Evaluation of Terrestrial Carbon Storage and Dynamics by *In-situ* and Remote Sensing Measurements, CD-ROM. Gifu, Japan. November 2002.

**Infrared spectroscopy method for measuring soil carbon:** Data intensive applications such as precision agriculture require measurement technologies for rapid spatial assessment of fertility parameters within production fields. Rapid methods for soil analysis are also required for assessments of carbon storage in tropical climates. Robust in-field calibrations can be developed using either near- or mid-infrared spectroscopy for various soil properties related to soil fertility. An infrared spectral library was developed for national soil collections from the U.S. and Brazil; this provides the means for developing accurate calibrations for wide spread use in temperate and tropical climates. Additionally, utility of near- and mid-infrared spectroscopy for soil metal determination was shown for soils from Poland. Information derived from this work is useful to industry for development of equipment for site-specific management of agricultural landscapes. Producers benefit through more efficient production with reduced environmental impact. The ability to rapidly measure soil carbon aids establishment of markets for trade in soil carbon credits.

**Impact:** A new method of characterizing soil carbon has been delivered to the public. The accuracy and economy of diffuse reflectance infrared spectroscopy for measuring soil properties in temperate and tropical climates has been established.

**Documentation:**

McCarty, G.W., and J.B. Reeves. 2001. Development of rapid instrumental methods for measuring soil organic carbon. pp. 371-380. *In :* Assessment Methods for Soil Carbon. R.Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart, *eds*. Lewis Publishers, Boca Raton, Florida.

McCarty, G.W., J.B. Reeves III, V.B.Reeves, R.F. Follett, and J.M. Kimble. 2002. Mid-infrared and near-infrared diffuse reflectance spectroscopy for soil carbon measurement. Soil Science Society of America Journal. 66:640-646.

Mimmo, T., J.B. Reeves, G.W. McCarty, and G. Galletti. 2002. Determination of biological measures by mid-infrared diffuse reflectance spectroscopy in soils within a landscape. Soil Science. 167:281-287.

Reeves III, J B., G W. McCarty, and T.V. Mimmo. 2002. The potential of diffuse reflectance spectroscopy for the determination of carbon inventories in soils. Journal of Environmental Pollution. 116:S277-S284.

McCarty, G.W., J.B. Reeves III, V.B. Reeves, R.F. Follett, and J.M. Kimble. 2002. Mid-infrared and near-infrared diffuse reflectance spectroscopy for soil carbon measurement. Soil Science Society of America Journal. 66:640-646.

Mimmo, T.V., J. B. Reeves III, G.W. McCarty, G.C. Galletti. 2002. Determination of biological measures by mid-infrared diffuse reflectance spectroscopy in soils within a landscape. Soil Science. 167:281-287.

Reeves III, J.B., G. W. McCarty, T.V. Mimmo, V.B. Reeves, R.F. Follett, J.M. Kimble, G.C. Galletti. 2002. Spectroscopic calibrations for the determination of C in soils.

Proceedings of World Congress of Soil Science. August. 13-18, 2002. Bangkok, Thailand. CD-ROM
Reeves III, J.B., and G.W. McCarty. 2002. Near- and mid-infrared spectroscopy for the determination of carbon and other analytes in soil. The Soil and Plant Analyst. pp 43-46.

**Carbon dioxide flux measurement during tillage:** Because tillage has a major effect on the amount of carbon stored in soil, methods to understand and quantify its effects are critical to management of soil quality and greenhouse gas emission control. A novel device, which allows continuous monitoring of carbon dioxide loss from soil before, during, and after soil tillage, was designed and tested. Continuous monitoring produces data unobtainable through use of point measurements and this type of data results in a better understanding of the effect of soil disturbance on carbon loss. Researchers benefit through development of a new technique that provides information for improvement of soil quality and reduction of carbon dioxide emissions from soil.

**Impact:** Continuous monitoring enhances our understanding of the effect of tillage on soil gas dynamics.

**Documentation:**
Wuest, S.B., D. Durr, S.L. Albrecht. 2003. Carbon dioxide flux measurement during simulated tillage. Agronomy Journal. 95:715-718.

**Continuous, field-scale measurement of isotopic $CO_2$ fluxes:** Studies estimating the component parts of photosynthesis and respiration in net ecosystem exchange of $CO_2$ are expensive and time-consuming, and they only provide snapshots of the underlying processes. The isotope ratio of respired carbon is a key indicator of the source of that carbon in non-equilibrium systems; for example, systems in transition from C4 grasslands to C3 crops, or systems in rotation between C3 and C4 crops. The carbon isotope ratio also provides a means to separate net ecosystem exchange of $CO_2$ into its component parts of photosynthesis and respiration. Previously, the only way to obtain such information was by sampling air in flasks for subsequent analysis on a mass spectrometer. We used a tunable-diode laser spectroscopy system to continuously sample and analyze air at two heights above a recently harvested soybean field that had previously been cropped in corn. The system worked well in all kinds of weather, and revealed that the source of nearly all respired carbon through the winter was soybean residue, with little contribution from the older corn residue. The system for continuous, field-scale measurement of isotopic $CO_2$ fluxes is valuable for researchers trying to determine sources and sinks of carbon in agricultural and forest ecosystems benefit from this new system.

**Impact:**
Better understanding of these processes improves prediction of the impact of human activities on climate.

**Documentation:**
Griffis, T.J., J.M. Baker, S.D. Sargent, B.D. Tanner, and J.M. Zhang. 2004. Measuring field-

scale isotopic CO2 fluxes with tunable diode laser absorption spectroscopy and micrometeorological techniques. Agricultural and Forest Meteorology 124:15-29.
Zhang, J.M., T.J. Griffis, and J.M. Baker. 2004. Using continuous stable isotope measurements to partition net ecosystem CO2 exchange into photosynthesis and respiration of a corn-soybean ecosystem. P1.11 in Proceedings of the 26th Conference on Agricultural and Forest Meteorology. Vancouver, Canada.

**Radiocarbon isotope method to monitor organic matter oxidation potential in Histosols:** It is important to develop improved methods that evaluate immediate effects of treatment options on oxidation potential of these soils that are subsiding at a rate of 1.3 cm per year, because there are more than 170,000 hectares of these highly productive Histosols. Several methods were compared for their ability to provide rapid and accurate measurements of oxidation potential of Histosols in the Everglades Agricultural Area of Florida. A method that uses radiocarbon isotopes provided the best indicator of organic matter losses due to microbial activity in Everglades' Histosols. Scientists benefit from this new knowledge because it allows better assessment of the success of water table, tillage, and other management options on reducing soil organic matter losses. As scientists better predict the effects of treatments on microbial oxidation, producers benefit by having a greater understanding of the effects of management choices on soil conservation.

**Impact:** These results enable researchers to analyze greater numbers of samples and thereby make better estimates of short-term treatment effects on soil organic matter oxidation.

**Documentation:**

Morris, D. R., and G. H. Snyder. 2001. Substrate induced respiration in soils using $^{14}C$ labeled substrate. *In :* Transactions of the Seventeenth World Congress of Soil Science. Bangkok, Thailand. August, 14-21, 2002. [CD-ROM]. Paper 784. International Union of Soil Sciences. Bangkok, Thailand.
Morris, D. R., B. Glaz, and S. H. Daroub. 2004. Organic matter oxidation potential determination in a periodically flooded Histosol under sugarcane. Soil Science Society of America Journal. 68:994-1001.

**Soil type and tillage impacts vulnerability of soil to losses of sequestered C:** The potential for soil carbon (C) storage to be altered by human activity is important due to both the possible mitigation of rising atmospheric carbon dioxide ($CO_2$) concentration and the affect of soil C on soil quality. We demonstrated that the vulnerability of soil to lose sequestered C when cultivated depends on soil type. Clay loam soils have a much greater potential to sequester C compared to loamy sand soils. However, clay loam soils are more vulnerable to losing a large part of the sequestered C rapidly if they are returned to cultivation. The potential for C storage in agricultural soils is of special interest in policy debates due to the possibility of developing $CO_2$ sequestration credits for land use changes to meet $CO_2$ emission limits. If C credits are developed, understanding the potential losses of C if the land is put back into cultivation is essential. Development of scientific knowledge of the potential of soils to sequester C is essential in settling this international debate.

**Impact:** This research provided increased knowledge in the area of C sequestration in soil. With increasing global interest in elevated atmospheric $CO_2$, the potential for C storage in agricultural and forest soils is at the forefront of the debate as potential options for C sequestration.

**Documentation:**

Torbert, H.A., S.A. Prior, and G.B. Runion. 2003. Impact of land use management decisions on C sequestration. pp.1253-1258. *In:* Soil Management for Sustainability, Proceedings of Sixteenth International Conference of the International Soil Tillage Research Organization. University of Queensland, Brisbane, Australia.

Torbert, H.A., S.A. Prior, and G.B. Runion. 2004. Impact of the return to cultivation on C sequestration. Journal of Soil Water Conservation. 59:1-8.

**Soil organic carbon (SOC) sequestration in a reduced-till, continuous corn production system:** Information is lacking on effects of irrigated cropping systems on soil organic carbon sequestration. The SOC levels in two cropped areas broke out of native sod in 1995 in northern Texas exceed that of the native sod after 6 years of continuous irrigated corn. Root zone soil nitrate levels were increased when nitrogen fertilizer was added to the corn residue after harvest to enhance residue decomposition. Soil organic carbon sequestration rate was unaffected by nitrogen treatment. However, averaged over nitrogen treatments, SOC sequestration appears to be increasing linearly at a rate of 2.0 megagrams per hectare at the sandy loam site and 1.7 megagrams per hectare at the clay loam site annually. This information aids policy makers, carbon commodity traders, USDA-NRCS, and crop consultants in prediction of the effects of irrigated continuous corn production under reduced tillage practices on SOC sequestration.

**Impact:** Potential soil organic carbon sequestration rates have been established for irrigated continuous corn systems under reduced tillage conditions.

**Documentation:**

Halvorson, A.D., L. Murphy, C.A. Reule, R.F. Follett, and J. Poole. 2000. Influence of soil fertility on soil carbon sequestration. *In:* Proceedings of the 2000 Fluid Forum. February 20-22, 2000. Scottsdale, Arizona. Fluid Fertilizer Foundation, Manhattan, KS. 17:204-211.

Halvorson, A., C. Reule, J. Poole, and R. Follett. 2001. Cropping system effects on soil carbon and nitrogen. *In:* Proceedings of the 2001 Fluid Forum. February 18-20, 2001. Scottsdale, Arizona. Fluid Fertilizer Foundation. Fluid Fertilizer Foundation, Manhattan, KS. 18:116-124.

Halvorson, A, C. Reule, J. Poole, and R. Follett. 2002. Influence of soil fertility level on carbon sequestration under irrigated corn. *In:* Proceedings of the 2002 Fluid Forum. February 17-19, 2000. Scottsdale, Arizona. Fluid Fertilizer Foundation. Fluid Fertilizer Foundation, Manhattan, KS. 19:245-252.

Halvorson, A, C. Reule, J. Poole, and R. Follett. 2003. Crop management effects on productivity, soil nitrogen, and soil carbon. *In:* Proceedings of the 2003 Fluid Forum. February 16-18, 2003. Scottsdale, Arizona. Fluid Fertilizer Foundation. Fluid Fertilizer Foundation, Manhattan, KS. 20:102-113.

Halvorson, A.D., C.A. Reule, and Poole, J. 2004. Changes in soil organic carbon and soil

nitrogen under irrigation in northern Texas. *In:* Proceedings of the 2004 Fluid Forum. February 22-24, 2004. Scottsdale, Arizona. Fluid Fertilizer Foundation. Fluid Fertilizer Foundation, Manhattan, KS. 21:112-118.

**Tillage system affects soil organic carbon (SOC) sequestration and corn yields in an irrigated, continuous corn production system:** Information is lacking on the effects of tillage and N fertilization on soil organic carbon sequestration in irrigated cropping systems. Evaluation of a no-till (NT) production system on SOC sequestration compared with a conventional-till (CT) system with several N rates under sprinkler irrigated, continuous corn production on a Fort Collins clay loam showed surface residue cover at planting averaged 88% in the NT system but only 12% in the CT system. Soil erosion potential was reduced by surface residue cover at planting. Continuous corn yields were slightly lesser in NT than CT system, but both increasing with increasing N rate. Residue carbon returned to the soil was similar for both tillage systems and increased with increasing N rate. However, SOC increased only in the NT system and at an annual rate of 1.4 Mg carbon per hectare since conversion to NT in 1999. The increase in SOC in the NT system reduced the total greenhouse gas emissions from this irrigated cropping system, thus reducing global warming potential. Policy makers, carbon commodity traders, USDA-NRCS, and crop consultants benefit from this information in designing irrigated crop management strategies that improve SOC sequestration and reduce greenhouse gas emissions.

**Impact:** Total greenhouse gas emissions from irrigated agricultural systems are reduced on conversion of conventionally tilled irrigated land to a no-till production system and global warming potential was mitigated.

**Documentation:**

Halvorson, A.D., C.A. Reule, and L.S. Murphy. 2000. No-tillage and N fertilization enhance soil carbon sequestration. Fluid Journal. 8:8-11.

Halvorson, A.D., W. Bausch, H. Duke, and C. Reule. 2002. Response of irrigated corn to nitrogen fertility level within two tillage systems. *In :* Proceedings of the Great Plains Soil Fertility Conference. March 5-6, 2002. Kansas State University, Manhattan and Potash and Phosphate Institute, Brookings, South Dakota. 9:132-137.

Halvorson, A.D. 2002. Carbon as a potential commodity: Irrigated Cropland. *In* Proc. Carbon As A Potential Commodity. December 3-4, 2002, Denver, Colorado. Colorado Chapter of Soil and Water Conservation Soc. CD-ROM.

Halvorson, A.D., A.R. Mosier, and C.A. Reule. 2003. Irrigated crop management effects on productivity, soil nitrogen, and soil carbon. Proceedings of the 2003 Fertilizer Industry Round Table. October 28-30, 2003. Winston-Salem, NC. The Fertilizer Industry Round Table, Forest Hill, Maryland. CD-ROM.

Halvorson, A.D., A.R. Mosier, and C.A. Reule. 2004. Nitrogen and crop management influence irrigated crop yields and greenhouse gas emissions. *In :* Proceedings of the 2004 Great Plains Soil Fertility Conference. A. Schlegel, *ed*. March 2-3, Denver, Colorado. Kansas State University, Manhattan and Potash and Phosphate Institute, Brookings, South Dakota. 10:21-27.

Cipra, J., and Halvorson, A.D. 2004. Satellite imagery for small plot research and precision farming - Nitrogen relationships in irrigated corn. Proceedings of the 2004 Great Plains

Soil Fertility Conference. A. Schlegel, *ed*. March 2-3, 2004. Denver, CO. Kansas State University, Manhattan and Potash and Phosphate Institute, Brookings, SD. 10:97-103.
Mosier, A.R., A.D. Halvorson, G.A. Peterson, G.P. Robertson, and L. Sherrod. 2005. Measurement of net global warming potential in three agroecosystems. Nutrient Cycling in Agroecosystems. (Accepted 6/29/04).

**Improvement of soil organic matter content and nutrient transformations by use of conservation tillage:** Retention of soil C and nutrients is paramount in maintaining the productivity of agricultural systems. Carbon retention is especially challenging in climates where organic matter is oxidized rapidly, such as in tropical or subtropical regions. Common agricultural practices, such as frequent deep plowing and fallowing, result in extensive soil organic matter losses by stimulating microbial decomposition of soil organic matter and promote erosion of organic matter-bearing particles. Conservation tillage and residue management regimes that promote humification of crop residues improve soil humus, providing the framework on which to build long-term soil productivity. We found small but measurable increases in soil organic C and N in the top 4-cm of soils under reduced-tillage, as well as measurable increases in bicarbonate-extractable P. Microbiological tests revealed that, in conservation-tilled soils, organic C substrates were distinct from those in plow-tilled soils. Even with modest gains in total organic C in hot climates, changes in the quality of those reserves support changes in microbial activities that are beneficial to crop producers.

**Impact:** Understanding of the potential of reduced-tillage methods for hot climates has been advanced. These changes measurably improve nutrient transformations and retention in agricultural soils. Growers benefit from improved fertility and tilth of the soil, which will result in more productive crops. Other researchers can benefit from these results through increased understanding of the processes involved in improving soil fertility in hot semi-arid climates, and the public at large benefits from the increased C sequestration that results from better soil management protocols.

**Documentation:**
Zibilske, L.M., J.M. Bradford, and J.R. Smart. 2002. Conservation tillage induced changes in organic carbon, total nitrogen and available phosphorus in a semi-arid alkaline subtropical soil. Soil and Tillage Research. 66:153-163.
Zibilske, L.M., and J.M. Bradford. 2003. Tillage effects on phosphorus mineralization and microbial activity. Soil Science. 168:677-685.

**Carbon dioxide efflux controlled by tillage type and intensity:** Loss of soil carbon can be attributed to tillage and crop residue burial. Chisel-type implements buried less crop residue than disc-type implements, especially when the latter were operated at deeper depths and in autumn rather than spring in the southern U.S. The NRCS and persons interested in modeling potential global change impacts and carbon sequestration are the primary beneficiaries of this research.

**Impact:** These studies demonstrated the importance of implement selection and timing of tillage operations, documenting that reduced disturbance of crop residue and the underlying soil during autumn could substantially conserve soil carbon in southern U.S. soils.

**Documentation**:

Raper, R.L. The influence of implement type and tillage depth on residue burial. 2002. Transactions of ASAE 45 (5):1281-1286.

Prior, S.A., R.L. Raper, and G.B. Runion. 2004. Effect of implement type on soil CO2 efflux : fall vs. spring tillage. Transactions of ASAE 47(2):367-373.

**Carbon sequestration potential of arid zone irrigated soils and cropping systems:**
The potential for sequestering atmospheric carbon dioxide in soils through cropping system modifications is well understood for dry-land systems, where the goal is to return soil carbon nearer the native baseline contents. Until recently the potential for using irrigated management systems to sequester carbon in soils at levels exceeding natural baseline carbon contents had been unexplored We found-sequestration of carbon as soil organic matter, exceeding natural baselines, is possible for irrigated pasture and conservation tillage systems, if inorganic carbon was add, all irrigated systems sequestered total carbon above natural baselines, including conventional tillage systems. Several scenarios were developed involving shifts of land usage to maximize the potential for carbon sequestration given the higher yield potential of irrigated agriculture versus rain-fed agriculture and the higher baseline carbon contents of natural rain-fed ecosystems compared to arid ecosystems. Irrigated farmers benefit significantly from these findings if provided cash incentives for carbon sequestration. The general public benefits from the development of a potent new carbon sequestration strategy.

**Impact:** This research demonstrated the potential of irrigated soils to sequester carbon. Carbon sequestration in soil is very positive globally both as one of the few available strategies for slowing global warming and as a path to improved soil productivity.

**Documentation:**

Entry, J.A. 2000. Influence of nitrogen on cellulose and lignin mineralization in blackwater and redwater forested wetland soils. Biology and Fertility of Soils 31:436-440.

Robbins, C.W., L.L. Freeborn, and D.T. Westermann. 2000. Organic phosphorus source effects on calcareous soil phosphorus and organic carbon. Journal of Environmental Quality. 29:973-978.

Entry, J.A., R.E. Sojka, and G.E. Shewmaker. 2002. Management of irrigated agriculture to increase organic carbon storage in soils. Soil Science Society of America Journal. 66:1957-1964.

Entry, J.A., R.E. Sojka, and G.E. Shewmaker. 2003. Irrigation increases carbon in agricultural soils. p. 391-395. *In :* Soil Management for Sustainability. Proceedings of the Sixteenth Triennial Conf. of the International Soil Tillage Research Organization. July 13-18, 2003. Brisbane, Australia.

Sjögersten, S., B.L.Turner, N. Mahieu, L.M. Condron, and P.A. Wookey. 2003. Soil organic matter biochemistry and potential susceptibility to climatic change across the forest-tundra ecotone in the Fennoscandian mountains. Global Change Biology 9:759-772.

Entry, J.A., J.J. Furhmann, R.E. Sojka, and G.E. Shewmaker. 2004. Influence of irrigated agriculture on soil carbon and microbial community structure. Environmental Management. 33:Supplement 1, S363-S373.

Entry, J.A., R.E. Sojka, and G.E. Shewmaker. 2004. Irrigation increases inorganic carbon in agricultural soils. Environmental Management. 33:Supplement 1, S309-S317.

**Residue management significantly impacts soil organic matter levels:** Soil and crop management practices influencing soil organic matter need to be understood so that producers will be willing to adopt more economically and environmentally sustainable practices. Soil carbon and nitrogen concentrations were measured in Pacific Northwest areas historically managed under wheat-fallow where wheat stubble was burned, manure was applied, annual cropping replaced cereal-fallow rotations, or stubble mulching and direct seeding replaced tillage. Any system that included summer-fallow lost soil carbon over time unless large applications of manure were made. Soil organic matter can be maintained or improved if these semi-arid soils are cropped every year and the crop residues are returned.

**Impact:** Management practices that can maintain or increase soil organic matter and improve soil quality were identified for Pacific Northwest areas historically managed under wheat-fallow.

**Documentation:**

Albrecht, S.L., D.F. Bezdicek, M. Fauci, K.W. Skirvin, and R.W. Rickman. 2000. Effects of tillage on soil carbon in semiarid croplands. p. 14-18. In: Columbia Basin Agricultural Research Annual Report. Oregon State Univ. Special Report No. 1012, Corvallis, OR.

Albrecht, S.L., M. Fauci, K.W. Skirvin, and D.F. Bezdicek. 2000. Organic matter fractions from Pacific Northwest soils : Depth and Tillage effects. p. 24-28. In : Columbia Basin Agricultural Research Annual Report. Oregon State Univ. Special Report No. 1012, Corvallis, OR.

Albrecht, S.L., P.E. Rasmussen, and D.E. Wilkins. 2000. Light fraction soil organic matter in long-term semi-arid agroecosystems. In: 15th Conference of the International Soil Tillage Research Organization. July 2-7, 2000. Ft. Worth, TX. [CD-ROM].

Rickman, R.W., C.L. Douglas Jr., S.L. Albrecht, and J.L. Berc. 2002. Tillage, crop rotation, and organic amendment effect on changes in soil organic matter. Journal of Environmental Pollution. 116:405-411.

Bezdicek, D., M. Fauci, S.L. Albrecht, and K. Skirvin. 2002. Soil carbon and C sequestration under different cropping and tillage practices in the Pacific Northwest. p. 101-107. In: Proc. Inland Pacific Northwest Research. Northwest Direct Seed Cropping Systems Conference, Pacific Northwest Direct Seed Association, Moscow, ID. Also available at: http://pnwsteep.wsu.edu/directseed/conf2k4

**Carbon sequestration under grass in Texas soils:** The prairie soils of central Texas have been degraded by long-term agricultural tillage practices, which inverted the soil and buried crop residues resulting in a loss of organic carbon. Changing the management system to continuous grass increases the amount of carbon present in the soils about 1.5 times faster than converting to a no-tillage management system. Also, grass systems appear to store carbon at this rate for extended periods of time (up to 60 years in one study). The effects of grazing varied for different soil types. Sandy soils stored less carbon with grazing, while loamy soils stored more carbon with grazing. Beneficiaries of this work include land managers, environmental regulators and the USDA-Natural Resources Conservation Service.

**Impact:** These data sets have been used to test and calibrate agricultural simulation computer models for potential extension of the knowledge gained to other soils and climates. This work established a rate of carbon sequestration in Texas soils with grass vegetation.

**Documentation:**

Potter, K.N., H.A.Torbert, H.B. Johnson, and C.R. Tischler. 1999. Carbon storage after long-term grass establishment on degraded soils. Soil Science. 164:718-725.

Potter, K.N., J. A. Daniel, W. Altom, and H.A. Torbert. 2001. Stocking rate effect on soil carbon and nitrogen in degraded soils. Journal of Soil and Water Conservation. 56:233-236.

Potter, K.N., S.R. Potter, J.D. Atwood, and J.R. Williams. 2004. Comparing simulated and measured soil organic carbon content on clay soils for time periods up to 60 years. Environmental Management. http://springerlink.metapress.com.

**Moderate grazing pressure improves soil C sequestration potential relative to haying or conservation reserve:** Cattle, grazing on pastures, utilize forage and deposit manure; yet the impacts of cattle on soil carbon sequestration are weakly defined for land in the Southern Piedmont USA. The standing stock of carbon in surface residue and soil under unharvested, hayed, and light and heavy grazing pressures during the first 5 years of bermudagrass management was determined. Soil carbon sequestration was two to three times greater under grazed pastures than under hayed or unharvested management systems. This information aids producers, agricultural consultants, and environmental organizations trying to foster the development of agricultural systems that mitigate greenhouse gas emissions, enhance soil fertility, and improve soil and water quality.

**Impact:** Grazing lands are potentially large sinks for sequestration of carbon in soil and for agricultural activities to mitigate the greenhouse gas emission of carbon dioxide. Producers are guided in grazing land management and consultants are provided an informational database from which to formulate best management practices. The knowledge developed enables environmental trading of greenhouse gas credits and guides environmental polices designed to mitigate greenhouse gas emissions and protect air quality.

**Documentation:**

Franzluebbers, A.J., and J.A. Stuedemann. 2001.Carbon cycling and sequestration in humid grazinglands. Abstracts of the Annual Meetings American Society of Agronomy. October 21-25, 2001. Charlotte, NC. CD-ROM.

Franzluebbers, A.J., and J.A. Stuedemann. 2002. The salem road study : Restoration of degraded land with pasture–Soil quality and carbon sequestration. p. 25-32. *In*: Proceedings of the 57th Southern Pasture and Forage Crop Improvement Conference. April 23-25, 2002. Athens, GA.

Franzluebbers, A.J., and J.A. Stuedemann. 2002. Managing grazinglands for soil organic C sequestration in the southeastern USA. p. 64. *In :* USDA Symposium on Natural Resource Management to Offset Greenhouse Gas Emissions. November 19-21, 2002. Raleigh, NC.

Franzluebbers, A.J., and J.A. Stuedemann. 2002. Soil-profile organic carbon and total nitrogen

under bermudagrass management in the Southern Piedmont USA. p. 166. *In :* USDA Symposium on Natural Resource Management to Offset Greenhouse Gas Emissions. November 19-21, 2002. Raleigh, NC.
Franzluebbers, A.J. Pasture management strategies for sequestering soil carbon. 2003. US-Department of Energy, Carbon Cycle and Carbon Sequestration Program Annual Meeting. 16-17 October, 16-17, 2003. Boulder, CO.
Franzluebbers, A.J., and J.A. Stuedemann. 2003. Impact of cattle and forage management on soil surface properties in the Southern Piedmont USA. 10 p. *In :* Proceedings of Sod-Based Cropping Systems Conference. http://nfrec.ifas.ufl.edu/ sodrotation/ Conf%20PDF%20files/ PDF%20FILES /franzluebbers.pdf. February 20-21, 2003. Quincy, Florida.

**Interseeding yellow-flowering alfalfa into native rangelands increases soil C and N (soil quality):** Native rangeland soils in the Great Plains are generally deficient in N, which contributes to their lower productivity and forage quality. Legumes are a minor component of these native rangeland ecosystems so introduction of a legume into the ecosystem should contribute significantly to overall productivity, forage quality and enhanced soil C storage. Evaluation of northern mixed-grass rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata)* for 4 to 36 years showed an average increase in soil N content of 27% and an 84% increase in forage production. The increase in total forage production and soil N of these interseeded rangeland sites resulted in a 4, 8, and 17% increase in soil organic C after 4, 14, and 36 years, respectively. Static chamber measurements of nitrous oxide fluxes were also conducted to assess whether the additional N fixed by the legumes would enhance the potential for increased emissions of this trace gas. Nitrous oxide emissions seem unaffected by management when interseeded rangelands are compared with native rangeland pastures. Use of this management strategy measurably increases overall forage productivity and quality. This management strategy increases sequestration of atmospheric carbon dioxide as soil organic carbon. Findings from this research benefit livestock producers using grazing lands because interseeding yellow-flowering alfalfa into grazing lands significantly increases forage resource quality. This practice has also resulted in a 50% average increase in forage production. The general public benefits from this research because this management practice increases sequestration of carbon and mitigates effects of greenhouse gases on climate change.

**Impact:** New management strategies were identified that mitigate increases in atmospheric carbon dioxide. Incorporation of N from fixation by interseeded legumes enhances resource use efficiency and carbon sequestration without contributing greenhouse gas emissions.

**Documentation:**

Mortenson, M. C. 2003. Effects of interseeded alfalfa (*Medicago sativa* ssp. *falcata*) on forage production, forage quality and carbon sequestration on a mixed-grass rangeland. M.S. Thesis. Department of Renewable Resources, University of Wyoming. Laramie.
Mortenson, M. C., G. E. Schuman and L. J. Ingram. 2004. Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). Environmental Management 33 Supplement : S475-S481.
Schuman, G. E., L. J. Ingram and T. B. Parkin. 2004. Nitrous oxide emissions from a northern

mixed-grass rangeland interseeded with yellow-flowering alfalfa (*Medicago sativa* ssp. *falcata*). pp. 180. *In :* Rangelands in Transition, 57th Abstracts of the Annual Meeting of the Society for Range Management, January 24-30, 2004, Salt Lake City, Utah. Society for Range Management. Denver, Colorado.

**Forage crops in rotation with corn enhance C sequestration in Midwest cropping systems:** Cropping systems that include forage crops in rotation with corn enhance accumulation of soil organic C relative to continuous corn, especially corn-soybean cropping systems, for two sets of long-term plots (23 and 48 years) under chisel and moldboard tillage, respectively. Nitrogen fertilization rates ranging from 0 to 270 kg $ha^{-1}$ (0 to 240 lb/acre) had little if any effect on organic C sequestration in soils of the same long-term plots, which are located in north central and northeastern Iowa. Data from two other long-term experimental sites show little or no effect of N fertilizer additions on soil organic C dynamics in Midwestern corn-soybean cropping systems under conventional tillage. Increasing N fertilization caused only a small increase in total organic C inputs to the soil relative to the increase in grain yield. Variability in root production had a large influence on the size of the organic C inputs. Stimulation of organic C decay rate by N fertilization is the only plausible explanation for lack of a net effect of N fertilizer additions on soil C sequestration. The information developed aids regulators and action agencies in development and implementation of national programs that enhance sequestration of C in soils.

**Impact:** Soil quality is enhanced and global warming is mitigated by sequestering C that would otherwise be present in the atmosphere as greenhouse gasses.

**Documentation:**

Russell, A.E., D.A. Laird, and T.B. Parkin. 2005. Impact of nitrogen fertilization and cropping system on carbon sequestration in mid-Western corn belt Mollisols. Soil Science Society America Journal. **(**Accepted 09/31/04**).**

**Management practices to reduce soil organic losses matter in Histosols:** More than 170,000 hectares of highly productive Histosols are subsiding, due to microbial activity, at the rate of 1.3 cm per year. Effects of water-table management and tillage on the oxidation potential of Histosols in the Everglades Agricultural Area of Florida were quantified. Raising water tables to 15 cm below the soil surface for 2 weeks following a 1-week flood resulted in oxidation potentials that were similar to those measured during flood periods. Tillage to 38 cm soil depth resulted in an average of 1.7 times more potential for soil loss compared to no-till over a 42-day period. This new knowledge that continuous flood is not the only means of controlling soil oxidation benefits scientists in devising strategies to conserve organic soils. Producers benefit through adoption of practical recommendations to conserve organic soils.

**Impact:** These results enhance the ability of researchers to develop water-table and tillage management practices to reduce soil organic matter losses in the Everglades' Histosols.

**Documentation:**

Morris, D.R., B. Glaz, and S.H. Daroub. 2004. Organic soil oxidation potential due to periodic

flood and drainage depth under sugarcane. Soil Science. 169:(Accepted 6/20/04).
Morris, D.R., R.A. Gilbert, D.C. Reicosky, and R.W. Gesch. 2004. Oxidation potentials of soil organic matter in Histosols under different tillage methods. Soil Science Society of America Journal. 68:817-826.

**Root biomass and soil organic matter:** Increased soil organic matter that is frequently observed when tillage is reduced (e.g. no-till) or cultivated land is returned to natural vegetation (e.g. grass buffers or CRP) is usually attributed to larger inputs of surface residue. The contributions of root residue and soil aggregation processes are often ignored or underestimated. Results from a series of growth chamber experiments demonstrated that 75% of new soil carbon (C) under no-till conditions came from roots. Most of the new C was occluded within macro-aggregates in the form of root-derived particulate organic matter (POM) C and 66% of the surface residue C was lost as $CO_2$. Further study showed no difference in soil organic carbon (SOC) after 30 years of moldboard plowing in a corn silage cropping system when compared to conventional cash grain continuous corn. The effect of removing surface residue on SOC was negated by the impact of long-term plowing.

**Impact:** This research was the first to directly document the partitioning of C from plant roots and surface residue to POM. The effect of C partitioning on soil aggregate formation and stabilization has been hypothesized by researchers, but this is the first verification of the concepts. For the first time it was demonstrated that roots contribute more new C to soil organic matter than surface residue when the soil is not disturbed by tillage. This definitively established the relationship among root C, POM C and the formation and stabilization of soil aggregates. An immediate impact of this research is the support it provides for the emergence of a new paradigm describing plant residue/soil organic matter/soil aggregation interrelationships.

**Documentation:**
Gale, W.J. and C.A. Cambardella. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. Soil Science Society of America Journal. 64:190-195.
Gale, W.J., C.A. Cambardella, and T. Bailey. 2000. Surface residue- and root-derived carbon in stable and unstable aggregates. Soil Science Society of America Journal. 64:196-201.
Gale, W.J., C.A. Cambardella, and T. Bailey. 2000. Root-derived carbon and the formation and stabilization of aggregates. Soil Science Society of America Journal. 64:201-207.
Cambardella, C.A. 2002. Aggregation and soil organic matter. pp 41-44. *In :* Encyclopedia of Soil Science. Rattan Lal, *ed*. Marcel Dekker, Inc. NYC.
Reicosky, D.C., S.D. Evans, C.A. Cambardella, R.R. Allmaras, A.R. Wilts, and D.R. Huggins. 2002. Continuous corn with moldboard tillage : Silage and fertility effects on soil carbon. Journal of Soil and Water Conservation. 57:277-284.
Marquez, C. O., V.J. Garcia, C.A. Cambardella, R.C. Schultz, and T.M. Isenhart. 2004. Aggregate size-stability distribution and soil stability. Soil Science Society America Journal. 68:725-735.

**Microbial processes influence C storage in soil aggregates:** With concern over rising atmospheric $CO_2$ levels, methods are needed to decrease the net amount of C released into the atmosphere. One option is adoption of practices that result in increases in soil carbon. Several promising research lines for increasing our knowledge of C storage and potential soil C management were identified. We found a close correlation between fungal activity and total soil C; it was stored more efficiently in soils with greater fungal to bacterial ratios. Massive C and N losses occurred when soil cores were transplanted from a cooler wetter climate to a warmer dryer climate. Most C and N loss occurred from the particulate organic matter fraction (greater than 53 micrometers in diameter). Greater enzymatic activity occurs in micro-aggregates, but this fraction accounts for only a small fraction of the total soil C. Larger macro-aggregate-derived enzyme activities have the greatest impact on the total microbial activity of the whole soil. Microbial community composition and its functioning are important factors in the use and storage of C in a wide range of soils. Scientists benefit from identification of factors affecting decomposition of soil organic matter.

**Impact:** Knowledge has been developed concerning basic underlying mechanisms that promote soil C storage.

**Documentation:**

Bailey, V.L., J.L. Smith, and H. Bolton, Jr. 2002. Fungal-to-bacterial ratios in soils investigated for enhanced C sequestration. Soil Biology & Biochemistry. 34:997-1007.

Bell, J.M., J.L. Smith, V.L. Bailey and H. Bolton, Jr. 2003. Priming effect and C storage in semi-arid no-till spring crop rotations. Biology and Fertility of Soils 37:237-244.

Link, S.O., J.L. Smith, H. Bolton, Jr., and J.J. Halvorson. 2003. A reciprocal transplant experiment within a climatic gradient in a semi-arid shrub-steppe ecosystem : effects on bunchgrass growth and reproduction, soil carbon, and soil nitrogen. Global Change Biology. 9:1097-1105.

**Soil clays influence the formation and stabilization of humic materials in soils:** This research addresses fundamental processes that impact nutrient cycling, soil quality, and carbon sequestration. Upper Midwestern soils contain two distinct forms of clay-humic complexes. Diffuse films of humic material were found on surfaces of fine clay particles and discrete high-density humic materials were found in the course clay fraction. New soil humic materials selectively accumulate in fine clay fractions. Humic material associated with the fine clay fraction was more readily mineralized during aerobic incubations and had a younger radiocarbon age than humic materials associate with the coarse clay fraction. Clay catalyzed dehydration of plant sugars and polymerization of the byproducts has potential of making new soil organic matter. The information helps scientists design new agricultural management systems that enhance the accumulation of stable forms of organic matter in soils.

**Impact:** Knowledge regarding the chemical and physical mechanisms responsible for both the formation of new, and stabilization of existing, humic materials in soils has been developed.

**Documentation:**

Laird, D.A., D.A. Martens, and W.L. Kingery. 2001. Nature of clay-humic complexes in an agricultural soil : I. Chemical, biochemical, and spectroscopic analyses. Soil Science Society of America Journal. 65:1413-1418.

Laird, D.A. 2001. Nature of clay-humic complexes in an agricultural soil: (II) Scanning electron microscopy analyses. Soil Science Society of America Journal. 65:1419-1425.
Gonzales, J.M. 2002. Role of clay minerals on soil organic matter stabilization and humification. Ph.D. Dissertation, Soil Chemistry, Agronomy Department, Iowa State University.
Gonzalez, J.M., and D.A. Laird. 2003. Carbon sequestration in clay mineral fractions from 14C-labeled plant residues. Soil Science Society of America Journal. 67:1715-1720.
Gonzalez, J.M., and D.A. Laird. 2004. Role of smectites and Al-substituted goethites on the catalytic condensation of arginine and glucose. Clays and Clay Minerals. 52:443-450.

**Carbon dynamics in reclaimed ecosystems:** Reclamation of disturbed landscapes through reconstruction of diverse, species-rich native ecosystems can increase soil organic C (SOC) and enhance C sequestration to mitigate increases in atmospheric CO2. No consistently positive changes in SOC could be identified for a chronosequence of reconstructed native prairies in place on the landscape for times varying from 1 to10 years. We identified two short-term indicators of the longer-term potential to sequester stabilized SOC : (1) accumulation of C in the heavy sub-fraction of particulate organic matter (POM), a biologically-active form of SOC, was greatest in native prairie remnant soils, intermediate in the oldest reconstructed prairie soils, and least in cultivated agricultural soil; (2) normalized surface soil C content was increased with reconstructed prairie age, suggesting C preferentially accumulates in surface soil horizons in these systems. In a comparison of several perennial systems in central Iowa, the SOC content increased an average of 11 Mg $ha^{-1}$ in the upper 35 cm of soil during 6 years in switchgrass and mixed poplar/cool season grass plots. These results document the potential for SOC content to increase in relatively short time periods in perennial systems with limited species diversity. In California grassland systems, elevated $CO_2$ increased the retention of older SOC but retarded the movement of newly fixed C from roots to stabilized SOC pools. For agroforestry systems in Costa Rica, we found that 1) increased biodiversity resulted in greater soil nutrient-supply capacity and C storage, 2) roots drove soil C accrual in these systems, and 3) root organic matter quality, and not the amount of root inputs, best explained effects of species diversity on soil C sequestration. Scientist benefit because knowledge gaps related to the relationships of C sequestration and terrestrial ecosystem processes have been filled. Land managers benefit because the results guide development of management decision-aids for selection of appropriate species mixtures in reclaimed ecosystems for enhancement of soil C storage and nutrient-use efficiency.

**Impact:** These results led to the development of a new research area at Ames, Iowa in collaboration with Iowa State Univ., Iowa-DNR, state NRCS, and federal F&WS personnel to investigate the relationship among landscape-scale soil, plant, and hydrologic parameters and the subsequent impacts on C sequestration and water quality.

**Documentation:**

Marquez, C.O., C.A. Cambardella, T.M. Isenhart, and R.C. Schultz. 1999. Assessing soil quality in a riparian buffer strip system by testing organic matter fractions. Agroforestry Systems. 44:133-140.
Cardon, Z.G., B.A. Hungate, C.A. Cambardella, F.S. Chapin III, C.B. Field, E.A. Holland, and H.A. Mooney. 2000. Contrasting effects of elevated CO2 on old and new carbon pools.

Soil Biology and Biochemistry. 33:365-373.
Russell, A.E., C.A. Cambardella, J.J. Ewel, and T.B. Parkin. 2003. Species, rotation, and life-form-diversity effects on soil carbon in experimental tropical ecosystems. Ecological Applications. 14:47-60.
Cambardella, C.A., K. Schilling, P. Drobney, T. Isenhart and R. Schultz. 2004. Soil carbon assessment across a native prairie restoration chronosequence. pp. 49-53. *In:* S. Fore, *ed*. Proceedings of the 18th Annual North American Prairie Conference. June 23-27, 2002. Truman State University Press. Kirksville, Missouri.

**The ability of wetland soil to sequester atmospheric carbon** Sequestration of atmospheric carbon is an international social goal and soil represents a potential significant sink for retention of carbon dioxide as organic matter. Studies conducted in collaboration with the USDI-USGS Northern Prairie Biological Research Center suggest that restoration of semi-permanent wetlands in the prairie pothole region of the Northern Great Plains will serve as a significant sink for atmospheric carbon. Carbon concentrations in the surface sediments of semi-permanent wetlands show a significant increase in organic carbon following restoration. The results aid policy makers and natural resource managers in the identification of the potential resource available for mitigation of greenhouse gas emissions.

**Impact:** Partly as a result of this research, wetlands have been presented to the UN Intergovernmental Panel on Climate Change for consideration as mitigants of greenhouse gas emissions. Significant resources have been given to the USDI-USGS Northern Prairie Biological Research Center to pursue further research regarding carbon sequestration in prairie wetlands.

**Documentation:**

Euliss, N.H., R. Gleason, A.E. Olness, R.L. Mcdougal, H. Murkin, R. Robarts, R. Bourbonniere, B. Warner. 2002. Prairie wetlands of the United States important for carbon storage: Implications for Future Research and Management. Abstracts of Proceedings of Global Climate Change Conference. p. 67.
Gleason, R.A., N.H. Euliss, A.E. Olness, B. Browne. 2002. Prairie wetlands of North America important for carbon storage. National Conference on Carbon Sequestration. Abstract. p. 67.
Olness, A.E., Euliss, N.H., Gleason, R.A. 2002. carbon and nitrogen sequestration in northern native and restored prairie wetlands. Proceedings of Prairie Wetland Carbon Research Meeting. Jamestown, North Dakota. Abstract. 1 p.
Euliss, N.H., R.A.Gleason, A.E. Olness, R.L. Mcdougal, H.R. Murkin, R. Robarts, R. Bourbonniere, B.G. Warner. 2002. Prairie wetlands of North America important for carbon storage. Proceedings of Prairie Wetland Carbon Research Meeting. Jamestown, North Dakota. 1 p.
Euliss, N.H., R.A. Gleason, A.E. Olness, R.L. McDougal, H.R. Murkin, R. Robarts, R. Bourbonniere, B.G. Warner. 2002. Prairie Wetlands of North America Important for Carbon Storage. Abstracts of Proceedings of USDA Symposium on Natural Resource Management to Offset Greenhouse Gas Emissions. p. 67.
Euliss, N.H., R. Gleason, A.E. Olness, R.L. Mcdougal, H. Murkin, R. Robarts, R. Bourbonniere, B. Warner. 2003. Prairie wetlands of North America important for carbon storage

[abstract]. Geological Society of America. Paper no. 110-10.

**Water quality and C sequestration in wetland systems:** Restoration of riparian buffers along streams and rivers is important for improved water quality as well as enhanced plant and animal biodiversity within agricultural ecosystems. Assessment of these benefits is needed for better cost/benefit analysis of conservation practices. Studies found higher content of nitrogen and phosphorus in herbaceous and woody plants in a riparian wetland impacted by agriculture when compared to a nearby wetland not under influence of agriculture indicating significant uptake of agricultural nutrients. Species diversity, species richness, and species evenness were all lower within the agriculturally influenced wetland than within the non-agricultural site. Increased import of soil to the wetland ecosystem associated with agricultural activity increased sequestration and storage of carbon in the wetland. The organic carbon content of the wetland soil was closely correlated with 210Pb activity, which suggests close linkage of upland sediment import and carbon storage within the wetland. These studies provide information on the impact of riparian buffers on carbon storage within agricultural ecosystems for action agencies and producers. This leads to better assessment of the impact of agriculture on climate change and aids accounting for impacts of agriculture on climate change by government agencies and for issuance of carbon credits within an carbon emissions trading market. As a chronological marker, of sedimentation and carbon deposition, 210Pb provides a new tool for environmental scientists to assess ecosystem carbon dynamics.

**Impact** : Water quality, wildlife habitat, and carbon sequestration in wetlands are improved within agricultural ecosystems through better management of riparian wetlands and buffer ecosystems. The role of riparian vegetation in retention of nutrients in agriculturally influenced wetlands and its value in protecting waterways has been documented. As a chronological marker of sedimentation and carbon deposition, 210Pb provides a new tool for environmental assessment of ecosystem carbon dynamics.

**Documentation:**

McCarty, G.W., J.M. Kimble, J.B. Reeves, and R. Yost. 2002. Evaluation of methods for measuring soil carbon in developing countries. Abstracts of the Annual Meetings of the American Society of Agronomy. Oct. 21-25, 2002. Indianapolis, Indiana. CD ROM.

McCarty, G.W., and J.C. Ritchie. 2002. Impact of soil movement on carbon sequestration in agricultural ecosystems. Environmental Pollution. 116:423-430.

Stuczynski, T.I., G.W. McCarty, and G. Siebielec. 2003. Response of soil microbiological activities to cadmium, lead, and zinc salt amendments. Journal of Environmental Quality. 32:1346-1355.

Calderon, F.J., G.W. McCarty, J.S. Van Kessel, and J.B. Reeves III. 2004. Carbon and nitrogen dynamics during incubation of manured soil. Soil Science Society of America Journal. 68:1592-1598.

**Long-term regional climatic conditions affect carbon sequestration with adoption of no tillage:** Characterizing geographical regions for their potential to store soil organic carbon with adoption of no-tillage management is needed to understand environmental effects on soil carbon sequestration. Available literature was assembled and data analyzed to develop relationships between macroclimatic indices and the change in soil organic carbon with adoption of no tillage. Long-term temperature and precipitation records for 39 locations in North America were effective in developing a regression approach to describe changes in soil organic carbon with adoption of no tillage, in which highest rates of soil organic carbon accumulation with adoption of no tillage occurred in the relatively mild climatic region of the east-central USA. Producers, agricultural consultants, and environmental policy makers benefit from this information to maximize the benefits derived from adoption of no-tillage management.

**Impact:** This knowledge serves as a guide for government conservation incentive programs, intergovernmental agreements defining the potential of various eco-regions to sequester soil carbon with conservation tillage, and environmental policy aimed at mitigating the greenhouse effect and developing incentives to sequester carbon in agricultural land.

**Documentation:**

Franzluebbers, A.J., and J.L Steiner. 2002. Climatic influences on C storage with no tillage. p. 71-86. *In :* Agricultural Practices and Policies for Carbon Sequestration in Soil. J.M. Kimble, R. Lal, and R.F. Follett, *eds*. Lewis Publishers. Boca Raton, Florida.

Franzluebbers, A.J., and D.A. Abrahamson. 2002. Macroclimatic indices to define potential soil organic carbon storage with no tillage. Abstracts of the American Society of Agronomy. November 10-14, 2002. Indianapolis, Indiana. CD-ROM.

**Managing pastures improves soil quality and increases carbon sequestration:** Strategies to measure improvements in long-term soil fertility and to mitigate rising $CO_2$ concentrations in the atmosphere are needed. Particulate and non-particulate organic carbon fractions in southern Piedmont pastures were measured and used to show that accumulations of soil organic carbon in pastures were intermediately susceptible to decomposition if the soils were disturbed.

**Impact:** Producers implementing improved pasture management strategies will benefit from increased forage production and improved soil quality, while scientists and others developing soil organic carbon models and natural resource monitoring approaches will benefit from the improved understanding of soil carbon fractions and decomposition processes.

**Documentation**:

Franzluebbers, A.J. 2000. Total and particulate organic C under pasture management in the Southern Piedmont USA. p. 41. In : Advances in terrestrial ecosystem carbon inventory, measurements, and monitoring. October 3-5, 2000. Raleigh, NC. (available at http://www.sgcp.ncsu.edu/carbon2002/conf/2000packet.pdf)

Franzluebbers, A.J., and J.A. Stuedemann. 2002. Particulate and non-particulate organic C depth distribution under pasture management in the Southern Piedmont USA. Environmental Pollution. 116:S53-S62.

**Improvements in water infiltration and soil structure are related to stratification of soil organic matter:** Quantitative relationships between soil organic matter and soil ecosystem functioning are needed. The relationships between soil organic carbon stratification and water infiltration, soil aggregation, and soil porosity were determined. Although the total quantity of soil organic carbon had positive effects on water infiltration and storage, it was the stratification of soil organic carbon with depth that had a much greater positive effect on these important soil physical properties. This information benefits agricultural consultants and producers by providing a tool to identify land management strategies that restore critical soil functions, such as water infiltration and storage. This information provides other scientists with a theoretical basis for conducting detailed field studies.

**Impact:** A diagnostic tool was developed to describe the restoration of the critical soil functions of water infiltration and storage.

**Documentation:**

Franzluebbers, A.J. 2002. Water infiltration and soil structure related to organic matter and its stratification with depth. Soil and Tillage Research. 66:195-203.

**The impact on carbon sequestration of using corn stalks as a biofuel source in a northern climate:** Soil organic carbon (SOC) is sensitive to corn (Zea mays L.) management schemes of tillage, residue (stover) harvest, and N fertilization, but little is known about contributions to root biomass including rhizo-deposition. Natural C isotope abundance (13C) and total C content, measured in paired (stover harvested and stover returned) corn plots were used in a model to estimate corn-derived SOC (cdSOC) changes of C produced over 13 years of continuous corn, as well as the in situ contribution of non-harvestable biomass (crown, roots, and rhizodeposits) to the SOC pool. Stover harvest compared to stover return reduced total source C by 20%, cdSOC by 35%, and total SOC irrespective of other management treatments. Total SOC was maintained only by both N fertilization and stover return during the 13-yr period. Tillage controlled the fraction of C retained as cdSOC, even though N fertilization, stover harvest, and tillage all impacted source C. Decomposition of labile rhizo-deposits was undoubtedly a major component of the non-humified fraction. Overall, rhizodeposition was as much as three times greater than suggested by laboratory and other controlled studies. To fully understand and manage the entire C cycle in agroecosystems, roots, and especially rhizodeposition must be included in the analysis at the field level. At least 50% of the above-ground residues must be returned to the field in order to prevent significant losses of C and N, resulting in severe effects to soil quality. This research provides critical guidance for policy makers regarding the expanded use of corn residues in fuel production.

**Impact:** Critical guidance for policy makers regarding the expanded use of corn residues in fuel production has been developed.

**Documentation :**

Clapp, C.E., R.R. Allmaras, M.F. Layese, D.R. Linden, and R.H. Dowdy. 2000. Soil organic carbon and $^{13}C$ abundance as related to tillage, crop residue, and nitrogen fertilization under continuous corn management in Minnesota. Soil and Tillage Research. 55:127-142.

Linden, D.R., C.E. Clapp, and R.H. Dowdy. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil and Tillage Research. 56:167-174.

Allmaras, R.R., D.R. Linden, and C.E. Clapp. 2004. Corn-residue transformations intoroot and soil carbon as related to nitrogen, tillage, and stover management. Soil Science Society of America Journal. 68:1366-1375.

## Soil Water Component

Water is the most limiting soil factor for crop growth and yield in most agricultural soils, accounting for approximately 80% of crop yield variability. Soil water, directly or indirectly, affects most soil physical, chemical, and biological properties and processes. It also functions as a transport medium for chemicals and microorganisms into, through, and below the soil profile. Most crop production problems associated with soil water relate to its supply and availability; infiltration adequacy and timing; and prevention, elimination, or mitigation of soil water excesses. High infiltration rates of water into soil reduce negative impacts of runoff and erosion; however, the soil must be able to retain enough water to sustain crop growth. Excessive soil water retention can slow soil warming and decrease soil oxygen diffusion to roots. Soil water availability depends not only on how much water the soil can retain, but also rainfall distribution over the season, lateral redistribution of water in the field, and stresses (such as compaction or aeration) that reduce crop use of the water. Appropriate techniques for measuring and modeling soil water and solute transport will be required to understand soil water processes. Characterization of soil properties affecting soil water remains difficult, slowing progress on other fronts, especially development and validation of new soil water concepts, theories and models. The overall target of the research in the Soil Water Component is to increase understanding of soil-water related processes and phenomena to provide improved and environmentally safe management of soil water.

Research within the Soil Water Component of the Soil Resource Management National Program was conducted in four Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a workshop held at the start of the current five-year National Program cycle. The four Problem Areas are: (Problem Area 8) Soil management strategies and technological advances are needed to optimize infiltration, retention, and water availability for crop production. (Problem Area 9) Management practices and strategies are needed to improve soil water availability to crops. (Problem Area 10) New strategies are needed to prevent onset of excess soil water in systems where such management is possible and to mitigate problems from soil water excess. (Problem Area 11) Tools are needed to assess and predict soil water processes and storage, and movement of chemicals and other constituents through the soil.

Soil water research is currently conducted by the following ARS locations: Akron, Colorado; Ames, Iowa; Auburn, Alabama; Beltsville, MD; Bushland, Texas; Canal Point, Florida; Florence, South Carolina; Fort Collins, Colorado; Kimberly, Idaho; Mandan, North Dakota; Pendleton, Oregon; and Riverside, California.

# Soil Water Component

**Problem Area 8:** Soil management strategies and technological advances are needed to optimize water infiltration, retention, and availability for crop production.

**Background:** Infiltration and water retention are affected by both intrinsic and manageable soil properties linked to soil physical, chemical, and biological processes. Whether a soil benefits from increased or decreased infiltration or water retention depends on the management system requirements and specific production and environmental impacts that result from these processes in each system. Soils with high infiltration rates often have low water retention, and soils with high water retention capacity often have restricted infiltration. High infiltration rates can benefit soil profile water storage by minimizing runoff, but if the rates are excessive, rapid movement of surface-applied chemicals below the root zone and/or into groundwater can occur. Water retention generally benefits plant growth by slowing the onset of drought stress. However, high water retention can also slow warming in spring, contribute to compaction by reducing soil strength facilitating physical deformation, and decrease soil oxygen diffusion for root respiration. A favorable balance of infiltration and water retention is needed to optimize soil water relations for plant productivity and environmental protection.

The goals of this research were:

Develop an improved understanding of soil properties that control water infiltration and retention.

Develop management practices to enhance water interception, infiltration, retention and utilization.

**Accomplishments:**

**Capacitance probes for measuring soil water response to rain:** Reliable and real time monitoring of soil water status can help producers to better manage their fertilizer and water resources under their specific climate, crop, soil, and water conditions. Continuous and real time measurement of water movement by use of capacitance sensor probes within the soil profile can provide important information on dynamics for agricultural and environmental scientists to more accurately test and improve their water balance models for characterizing and predicting solute transport through unsaturated field soils. Capacitance probes, along with other dielectric methods for measuring soil water content, commonly show a diurnal response that may be partially due to sensor response to changes in temperature. Research involving real time measurement of soil water by use of capacitance probes showed that rainfall characteristics, antecedent and current soil-water content, presence of plants, and soil hydraulic properties all interact to create a unique time series of water content values that are different for every storm. Detailed monitoring studies have been carried out to describe complex temporal processes of infiltration, redistribution, drainage and evaporation as affected by tillage and row positions. Results obtained are specifically helpful for the management of no-tillage and plow-tillage systems on silty loam soils, an abundant soil texture found in the humid Mid-Atlantic region of the U.S., in differentiating their potentials for chemicals and pesticide transport. This research also has resulted in a reimbursable agreement between ARS and Simplot Soil Builders to characterize temperature effects on soil-water measurements with multi-sensor capacitance probes for soil textures ranging from sand to clay.

**Impact:** Detailed information on rainfall infiltration under different conditions can guide managers and policy makers to devise improved management practices for row crop production systems.

**Documentation:**

Bower, M.A., Starr, J.L. 2002. Multi-sensor capacitance probe scaled frequency temperature response by soil type and volumetric water content. Transaction of First International Symposium on Soil Water Measurement Using Capacitance and Impedance. Chapter 1.5. p. 1-12.

Starr, J.L., Paltineanu, I.C. 2002. Chapter 3.1.3.6.Methods for measurement of soil water content: capacitance devices. p. 463-474. In: J.C. Dane, and C.G. Topp (Eds.) Methods of Soil Analysis. Soil Sci. Soc.Am., Inc., Madison.

Starr, J.L., and Timlin D.J. 2004. Using High-resolution soil moisture data to assess soil water dynamics in the vadose zone. Vadose Zone J. 3(3):926-935.

Precision and accuracy of capacitance probes under varying temperature gradients and soil condition. Reimbursable Agreement with Simplot Soil Builders.

Monitoring and evaluation of irrigation practices in the Mid-Atlantic region. Extramural Agreement with T-Systems International (11/1/01 - 12/31/04).

Assessing TriSCAN for simultaneously measuring soil water and salinity under humid and intermittent rainfall conditions. Cooperative Agreement (4/12/04 – 12/31/05) with Sentek Pty Ltd.

**Improved infiltration and soil water retention strategies:** Maintaining infiltration rate above water application rate is the key to reducing runoff and erosion, as well as optimizing water storage from both irrigated and rainfed systems. Infiltration of water into soil was increased by applying polyacrylamide (PAM) in irrigation water and controlling sprinkler droplet size, which increased the water available to the crop. Annual legume/grain-forage crops (e.g. oat-pea hay) had improved water use efficiency compared to traditional spring grains and retained high quality as biomass production increased.

**Impact:** Farmers benefit from this research through water conservation and increased production and the general public benefits from the reduction of environmental impairment caused by runoff and erosion contamination of surface water.

**Documentation:**

Sojka, R.E., R.D. Lentz, C.W. Ross, T.J. Trout, D.L. Bjorneberg, and J.K. Aase. 1998.Polyacrylamide effects on infiltration in irrigated agriculture. J. Soil Water Cons. 53(4): 325-331.

Bjorneberg, D.L. 1998. Temperature, concentration, and pumping effects on PAM viscosity. Trans. ASAE 41(6): 1651-1655.

Aase, J.K. and J.L. Pikul, Jr. 2000. Water use in a modified summer fallow system on semiarid northern Great Plains. Agric. Water Manage. 43:345-357.
Lehrsch, G.A. and D.C. Kincaid. 2000. Sprinkler droplet energy effects on infiltration and near-surface, unsaturated hydraulic conductivity. p. 283-286. In: D. Bosch, et al. (ed.) Preferential flow: Water movement and chemical transport in the environment. Proc. 2nd Int. Symp., Honolulu, HI. 3-5 Jan. 2001. ASAE, St. Joseph, MI.

**Effect of biopore accumulation under no till on infiltration:** In arid and semi-arid environments, yield and profit are directly correlated with water supply. Runoff prevention is also the key to erosion prevention and surface water quality protection. In order to design effective erosion control techniques using no-till cropping systems, it is important to understand how no-till changes runoff and erosion characteristics. Collecting intact soil cores from long-term no-till and tilled plots, we examined the number, sizes, and distribution of pores formed by roots and soil organisms. Although increases in large pores related to increased earthworm populations were measured, we found that biopores did not accumulate with time in no-till cropping systems. Factors other than undisturbed biopores are more important to the infiltration characteristics of no-till, suggesting that certain types of soil disturbance may not decrease the infiltration effectiveness of no-till and could increase the management system options for producers.

**Impact:** Knowledge of the relative role of biopores in improving water infiltration, compared to soil aggregation and other soil properties, will help farmers and their advisors develop successful conservation systems by guiding selection of tillage and residue management strategies.

**Documentation:**
Wuest, S.B. 2001. Soil biopore estimation: effects of tillage, nitrogen, and photographic resolution. Soil Tillage Res. 62:111-116.

**Tillage and residue management practices to increase rain infiltration and storage as soil water:** Sustainable dryland cropping systems must optimize the storage and use of limited precipitation. Crop rotation sequences, therefore, include fallow periods to increase the opportunity for storing precipitation as soil water for subsequent crop use. Tillage and residue management practices may improve water conservation by fracturing soil layers that limit infiltration and rooting depth, or by using residue to intercept irradiant energy that drives evaporation losses of soil water. Crop rooting characteristics also vary with species and may be managed to optimize water use. Study objectives are to quantify tillage and residue management effects on soil properties, rain infiltration, precipitation storage as soil water, and the growth and yield of various crops. Deep tillage did not significantly increase rain infiltration, which was regulated at the soil surface by rapid crusting. Deep tillage generally reduced cone-penetrometer resistance and bulk density, but precipitation storage as soil-water during fallow was unaffected. In contrast, no-tillage residue management increased soil water content after fallow primarily by reducing evaporation. Introducing a pulse crop such as cowpea into the summer fallow phase of a rotation may achieve more efficient soil water use by extracting water stored deeper in the profile.

**Impact:** Our research results showed that costly deep paratillage was ineffective for increasing rain infiltration; however, no-tillage residue management practices that decreased evaporation were effective methods for maximizing storage of precipitation as soil water in semiarid drylands for subsequent crop use. Substituting a pulse crop such as cowpea into the summer fallow phase of a rotation may increase both cropping system water use efficiency and overall productivity. This information is relevant to agricultural producers and their advisors for implementing tillage and residue management practices that increase water conservation and subsequent crop growth and yield.

**Documentation:**

Baumhardt, R.L. and O.R. Jones. 2002. Residue management and paratillage effects on some soil properties and rain infiltration. Soil Tillage Res. 65:19-27.

Baumhardt, R.L. and O.R. Jones. 2002. Residue management and tillage effects on soil-waterstorage and grain yield of dryland wheat and sorghum for a clay loam in Texas. Soil Tillage Res. 68:71-82.

Baumhardt, R.L., R.C. Schwartz, and R.W. Todd. 2002. Effects of taller wheat residue afterstripper header harvest on wind run, irradiant energy interception, and evaporation IN E. van Santen (ed.) Proc. 25th Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Alabama Agric. Exp. Sta., Spec. Rpt. No. 1, June 24-26, 2002, Auburn, AL. pp. 386-391.

Jones, O.R. and R.L.Baumhardt. 2003. Furrow dikes. IN B.A. Stewart and T.A. Howell (eds.) Encyclopedia of Water Science, Marcel-Dekker, NY. pp. 317-320.

Moroke, T.S., R.C. Schwartz, K.W. Brown, and A.S.R. Juo. 2005. Soil water depletion and root distribution of three dryland crops. Soil Sci. Soc. Am. J. (in press).

**Rock fragments influence on infiltration, summaries of infiltration and retention:** Rock fragments have significant effects on the spatial pattern of infiltration and runoff. At saturation, infiltration increased with rock fragment content; but under tension, the infiltration decreased with rock fragment content. This was related to continuity of water films between the fine earth fraction and the rock fragments. High rock fragment content downslope allowed runoff from upslope to infiltrate rather than running into the waterway. Short reviews were completed on infiltration processes, amount of soil water initially, and soil water potential status, which controls soil water retention.

**Impact:** This study addressed important infiltration processes in a landscape containing rock fragments, which is helpful for hydrologists and soil scientists who need information on chemical transport by water, and plant water availability within a landscape. The short reviews may be useful for scientists and students who want a snapshot background on infiltration and retention processes.

**Documentation:**

Sauer, T.J., and S.D. Logsdon. 2002. Hydraulic and physical properties of stony soils in a small watershed. Soil Sci. Soc. Am. J. 66:1947-1956.

Logsdon, S.D. 2003. Infiltration of water into soils. p. 930-933. In: B.A. Stewart and T. Howell

(Eds.) Encyclopedia of Water Science. Marcel Dekker, New York.
Logsdon, S.D. 2003. Antecedent soil water. p. 858-860. In: B.A. Stewart and T. Howell (Eds.) Encyclopedia of Water Science. Marcel Dekker, New York.
Logsdon, S.D. 2003. Soil water energy concepts. p. 868-870. In: B.A. Stewart and T. Howell (Eds.) Encyclopedia of Water Science. Marcel Dekker, New York.

**Effect of soil carbon on soil water holding capacity:** Understanding the effect of carbon on soil water retention and hydraulic conductivity properties is needed to describe how climate change and agricultural management affect the water available for use by plants and the movement of water and solutes through soils. In a study using the NRCS soil characterization database, it was determined that the sensitivity of the water retention to changes in organic carbon content was highest in sandy soils with low organic carbon contents. Increase in organic carbon content led to increase of water retention in sandy soils, and to a decrease in fine-textured soils. At high organic carbon content, all soils showed an increase in water retention. The largest increase was in sandy and silty soils. Soil water retention at -33 kPa is affected by the organic carbon more strongly than water retention at -1500 kPa. The organic carbon effect on saturated hydraulic conductivity was shown to be directly related to the organic carbon effect on water retention. ARS scientists developed functions utilizing soil survey information to predict the effect of carbon on the soil water retention and conductivity properties.

**Impact:** Existing models lack the feedback effect of organic carbon content accumulation on water retention and saturated hydraulic conductivity. The procedures developed can be used by NRCS to evaluate the effect of carbon sequestration on soil water retention and conductivity properties and can improve the predictive ability of natural resource models.

**Documentation:**
Rawls, W.J., J.C. Ritchie, Y.A. Pachepsky, T.M. Sobecki, and H. Bloodworth. 2003. Effect of soil organic carbon on soil water retention. Geoderma, 116:61-76.
Rawls, W.J., A. Nemes, and Y. Pachepsky. 2005. Effect of soil organic carbon on soil hydraulic properties. Chapter in Development of Pedotransfer Functions In Soil Hydrology, Elsevier (in press).

# Soil Water Component

**Problem Area 9:** Management practices and strategies are needed to improve soil water availability to crops.

**Background:** Soil water availability is directly or indirectly responsible for most of the crop yield and quality variability across a typical farm or for browse production and quality variation in rangeland. It also influences vegetation density and species variation across rangeland to much the same extent. Soil water availability to plants is affected by growing season, soil, crop, and climatic factors as well as management of water gains and losses during the off-season. The sufficiency of soil water available to plants depends on requirements for plant water use, especially for evapotranspiration. Soil water availability to plants in a field is controlled by water capture and storage in soil; root growth, extent, and function; and profile and landscape water redistribution. Significant management skill and inputs are often needed for even subtle improvements in soil water availability because of the overriding influence of intrinsic soil properties or climatic variability. However, since even small improvements in water availability can result in large improvements in crop production in most situations, this avenue of soil management research holds great promise for increased productivity and profit for farmers and ranchers.

Goals of this research were:

Identify crops, cultivars, systems, management criteria, decision aids, and technologies to avoid, resist, or tolerate stresses of inadequate soil water.

Develop new soil and crop management strategies to conserve and improve availability of soil water resources and protect against losses from excess evaporation, transpiration, and drainage.

Determine the contribution of redistributed water to the available soil water pool and develop management strategies that maximize efficient water use in all areas of the field.

**Accomplishments:**

**Water-use in continuous cropping systems:** Since water use of crops is one of the prime factors to be considered when planning dynamic production systems, farmers using a diversity of new crops in the semiarid Northern Great Plains need to know the impact of one crop's water use on the following crop. ARS scientists showed that deeply rooted oilseed crops consistently use the most soil water, and shorter-season pulse crops, such as dry pea, used the least water, with small grain crops having a moderately low water use. Sunflower and safflower used the most soil water among the crops commonly cultivated in the northern Great Plains. Dry pea was shown to use the least soil water. Flax, soybean, and canola used relatively larger quantities of soil water in some years, and wheat and barley were moderate to light water-users. Dry pea left greater than 4 inches more water in the soil in the spring compared to sunflower. Results indicate the water-use of crops is one of the factors to be considered when planning dynamic soil-crop production systems. Also, continuous crop rotations combined with no-till management help preserve the soil resource and improve water usage, thereby making continuous cropping a viable option for the northern Great Plains.

**Impact:** Producers within the northern Great Plains use this information to determine the appropriate sequence of crops to grow. Through proper management, producers will observe more soil organic matter, greater aggregate stability, and faster water infiltration rates in continuous crop, no-till management systems. Farmers in the northern Great Plains can improve soil quality and agricultural sustainability by adopting production systems that employ continuous cropping practices with reduced tillage management for water conservation.

**Documentation:**


Merrill, S.D., D.L. Tanaka, and J.D. Hanson. 2002. Root length growth of eight crop species in Haplustoll soils. Soil Sci. Soc. Am. J. 66(3):913-923.

Merrill, S.D., D.L. Tanaka, J.M. Krupinsky, M.A. Liebig, J.R. Hendrickson, J.D. Hanson, J.S. Fehmi, and R.E. Ries. 2002. Soil water use and soil residue coverage by sunflower compared to other crops. p. 88-96. Proceedings of the 24th Sunflower Research Workshop, National Sunflower Association, Bismarck, North Dakota.

Merrill, S.D., D.L. Tanaka, J.M. Krupinsky, M.A. Liebig, J.R. Hendrickson, J.D. Hanson, and R.E. Ries. 2002. Soil water use, soil residue coverage and root growth in crop sequences under conservation tillage. p. 27-33.Proceedings of the 24th annual Manitoba-North Dakota Zero Tillage Farmers Association Workshop. Manitoba-North Dakota Zero Tillage Farmers Association. Minot, North Dakota.

Ma, L., D.C. Nielsen, L.R. Ahuja, R.W. Malone, S.S. Anapalli, K.W. Rojas, J.D. Hanson, and J.G. Benjamin. 2003. Evaluation of RZWQM under varying irrigation levels in eastern Colorado. Transactions ASAE 46:39-49.

Merrill, S.D., D.L. Tanaka, and J.M. Krupinsky. 2003. Soil water use and coverage by residue under sunflower compared to other crops. Proceedings of the 25th Sunflower Research Workshop, January 16-17, Fargo, ND, National Sunflower Assoc. (Research Forum Papers located under Research & Statistics at http://www.sunflowernsa.com/research_statistics/research_workshop/), Bismarck, ND.

Anderson, R.L., D.L. Tanaka, and S.D. Merrill. 2003. Yield and water use of broadleaf crops in a semiarid climate. Agric. Water Manage. 58:255-266.

Tanaka, D.L., and R.L. Anderson. 2003. Summer fallow. p. 942-945. *In:* Stewart, B.P., and T.A. Howell (ed.), Encyclopedia of Water Science. Marcel Dekker, Inc. New York, NY.

Merrill, S.D., D.L. Tanaka, J.M. Krupinsky, and R.E. Ries. 2004. Water use and depletion by diverse crop species on Haplustoll soil in the Northern Great Plains. J. Soil Water Conserv. 59:176-183.


**Soil water holding capacity expressed as a function of foliage density and weather data:** Maps of the spatial distribution of soil water holding capacity are needed to increase crop production efficiency and optimize fertilizer inputs using precision agriculture technologies. Relationships between soil water holding capacity and foliage density expressed as leaf area index, and weather data were tested using a crop growth model, neural networks and regression trees in cooperation with CRADA partner Geosys International, Minneapolis, MN. Significant relationships between soil water holding capacity, and leaf area index and weather data were obtained using data collected from research plots in Maryland, while weaker relationships were found with these techniques using data from mainly publicly-available data from southern Minnesota. Maps of soil water holding capacity could be generated inexpensively for large areas of farmland given leaf area index maps generated from remotely sensed data archives and weather records, thus reducing the need for costly, labor-intensive ground-based sampling of soil water holding capacity.

**Impact:** The CRADA partner is incorporating the soil water holding capacity mapping, and LAI retrieval findings into its web-based precision farming products. The Maryland Department of Agriculture is considering use of the neural network approach as a new tool for predicting corn and soybean yields as a function of selected soil characteristics and weather data. The limitations of using data available from sources other than the research community suggest that alternative algorithms are needed when using models of environmental systems as aids to management decision-making.

**Documentation:**

Walthall, C., M. Kaul, D.Timlin, and C. Daughtry. 2001. Linking within-field crop response with soil characteristics to define crop response zones for management zone delineation. Proc. Third International Conference on Geospatial Information in Agriculture and Forestry, Denver, Colorado, 5-7 November 2001. (CD-ROM).

"Mapping Consistent Within-Field Patterns of Variability Using Multitemporal Satellite Images." CRADA with Geosys International.

Kaul, M., R. Hill, and C. Walthall. 2005. Artificial neural networks for corn and soybean yield prediction. Agricultural Systems (In press).

**Evaluating soil suitability for plant growth using the Least Limiting Water Range (LLWR):** A term defined as the Least Limiting Water Range (LLWR) incorporates limitations of the soil environment for crop production based on water holding capacity, soil strength, and soil aeration. ARS scientists devised a method, coined Water Stress Day (WSD), to account for dynamic changes in water stress on crop yield. The LLWR concept was a good predictor for determining soil effects on crops such as wheat that rely primarily on stored soil water for survival in the central Great Plains. For crops such as corn that rely much on in-season precipitation, the LLWR was inadequate to predict soil effects on crop yield. The WSD indicator was much better that LLWR or bulk density criteria in that it accounts for the in-season water stress on crop plants.

**Impact:** The huge improvement of the predictive capability using LLWR makes model experimentation more effective for predicting soil management effects on the soil physical condition and subsequent effects on crop yield.

**Documentation:**

Benjamin, J.G., D.C. Nielsen and M.F. Vigil. 2003. Quantifying effects of soil conditions on plant growth and crop production. Geoderma 116:137-148.

**Spatial variability and scaling of soil water:** Topographic attributes (*e.g.*, slope, aspect, and higher-order derivatives) can now be economically and accurately measured with GPS technology, and have been used to predict variability of soil, water, and plant processes. Spatial correlations with key topographic attributes have been evaluated for crop yield and near-surface (0-30 cm) soil moisture in eastern Colorado. Spatial patterns of these variables also have been quantified using geostatistics and fractal geometry. Simple fractal behavior is shown to be ubiquitous in terms of quantifying spatial patterns of crop yield, soil water and topographic attributes. Surface soil water content displayed spatial structure despite low correlations with topographic attributes during the commonly dry surface conditions. A new index of fractal anisotropy was derived and estimated from field data.

**Impact:** These basic scientific advances have provided new information and guidance for field researchers and extension agents to collect soil water (moisture) at representative locations within a farm field and to account for spatial correlations in experimental designs. These advances will ultimately guide site-specific management through the use of spatially explicit agricultural system models, such as the one being developed by these investigators. Farm advisors and progressive farmers, as well as scientists will use the information.

**Documentation:**

Ahuja, L.R., T.R. Green, R.H. Erskine, L. Ma, J.C. Ascough II, G.H. Dunn, M.J. Shaffer, and A. Martinez. 2002. Topographic analysis, scaling and models to evaluate spatial/temporal variability of landscape processes and management. In: L.R. Ahuja, L. Ma, and T.A. Howell (Eds), Agricultural System Models in Field Research and Technology Transfer. CRC Publishers, Boca Raton, FL. p. 265-272. (Refereed Book Chapter)

Ascough, J.A., T.R. Green, J.E. Cipra, B.C. Vandenberg, R.L. Flynn and J.B. Norman. 2003. AgSimGIS: Integrated GIS and Agricultural System Modeling, Proc. ESRI Users Conf., San Diego, CA, 7-11 July 2003. CD-ROM.

Green, T.R., L.R. Ahuja, and J.G. Benjamin. 2003. Advances and challenges in predicting agricultural management effects on soil hydraulic properties in space and time. Geoderma 116(1-2):3-27.

Green, T.R. and R.H. Erskine. 2004. Measurement, scaling, and topographic analyses of spatial crop yield and soil water content. Hydrol. Process. 18:1447-1465.

**Regional crop yield assessments:** Accurate and timely assessment of crop yields at county and state levels are very important to USDA's operational agencies, such as NASS and FAS, and to agribusiness. Temporal and spatial biophysical parameters were retrieved from satellite imagery and integrated into crop yield models. Crop yields were simulated at 1.6 $km^2$ spatial resolution and integrated to provide county and state level production estimates for corn, soybeans, and spring wheat in the U.S. and in Kazakhstan. The standard vegetation products from the new MODIS satellite sensor were found to be unsuitable for regional crop production assessment. New algorithms based on extensive field evaluations were proposed and successfully evaluated in the U.S. and Kazakhstan. Iowa county-level crop yields were accurately assessed several months prior to the official NASS report. NASS and FAS will greatly benefit in adapting these algorithms because their current assessment techniques are based on statistical sampling and do not use spatially integrated techniques.

**Impact:** This research provided a rigorous evaluation of several data products from the new MODIS sensor and proposed and evaluated improved algorithms for global crop production estimates. The Production Estimates Crop Assessment Division of FAS has adapted the crop model for their operational use. NASS is currently evaluating the potential use of the algorithms for assessing county level yields in an operational model.

**Documentation:**

Doraiswamy, P.C., P. Zara, and A.J. Stern. 2001. Satellite remotely sensed data application in estimating crop condition and yields. *In*: Remote Sensing Applications. M.S. Srinivas (ed.). Narosa Publishing House, New Delhi. Chapter 24: pp 229-240.

Stern, A.J., P.C. Doraiswamy, and P.W. Cook. 2001. Spring wheat classification in an AVHRR image by signature extension from a Landsat TM classification image. Photogrammetric Engineering and Remote Sensing, 67: 207-211.

Doraiswamy, P.C., N. Muratova, A.J. Stern, and B. Akhmedov. 2002. Evaluation of MODIS data from assessment of regional spring wheat yields in Kazakhstan. Proceedings of IGARSS 2002 Symposium pp.487-490.

Doraiswamy, P.C., S. Moulin, P. W. Cook, and A. Stern. 2003. Crop Yield Assessment from remote sensing. Photogrammetric Engineering and Remote Sensing, 69: 665-674.

Doraiswamy, P. C., J. L. Hatfield, T.J. Jackson, J.H. Prueger, B. Akhmedov, A.J. Stern. 2005. Crop condition and yield simulations using Landsat and MODIS imagery. Remote Sensing of Environment. (In Press).

**Soil water dominates factors controlling Coastal Plain spatial variability:** Water holding characteristics appear to be the primary factor controlling spatial variation in Coastal Plain soils because of their profound impact on crop yield. Soil water balances (computed from rainfall, runoff, infiltration, and drainage) differed dramatically among soil types explaining within-season responses to water availability and stress and explaining that final grain yields were achieved by widely disparate means of water usage. The primary beneficiaries of this research are modelers who are using this information to explain water usage across soil types and evaluate the impact of severe drought.

**Impact:** Soil water availability is better understood and models can more accurately predict the effects of soil water management on crop yield. This will help producers improve water and nutrient use efficiencies throughout the southeastern Coastal Plain.

**Documentation:**

Bauer, P.J., Sadler, E.J. and Busscher, W.J. 1998. Spatial analysis of biomass and N accumulation of a winter wheat cover crop grown after a drought-stressed corn crop in the SE coastal plain. J. Soil and Water Cons. 53 (3):259-262.

Sadler, E.J., Bauer, P.J. and Busscher, W.J. 2000. Site-specific analysis of a droughted corn crop. I. Growth and grain yield. Agron. J. 92 (3):395-402.

Sadler, E.J., Bauer, P.J., Busscher, W.J. and Millen, J.A. 2000. Site-specific analysis of a droughted corn crop. II. Water use and stress. Agron. J. 92 (3):403-410.

## Soil Water Component

**Problem Area 10:** New strategies are needed to prevent onset of excess soil water in systems where such management is possible and to mitigate problems from soil water excess.

**Background:** High soil water content is an ecological requirement of wetland environments and crops grown predominately under flooded or wet conditions. Water excess and aeration status, however, affect soil resource management of most other productive cropping systems. Excess soil water can promote leaching or transport of nutrients, chemicals, salts, and microorganisms; restrict oxygen availability; change the chemical reaction environment; induce production of toxic chemicals and biological products; accelerate invasion by pathogens; damage roots; and initiate release of nitrogen or greenhouse gases into the atmosphere. Soil water excess can result from flawed management due to inadequate or incorrect information about soil water status or from poor decision aids, in over application of water or failure to initiate drainage. Soil water excess also can result from inadequate surface or internal drainage during unpreventable occurrences of high rainfall, run-on from other fields or areas, water table rise, or subsurface compaction. Excess water is the most common, but not the sole, cause of poor soil aeration.

Goals of this research were:

Identify crops, cultivars, systems, management criteria, decision aids, and technologies to resist, tolerate, or mitigate stresses of excess soil water or poor aeration.

Improve understanding of the role of excess soil water in the production of greenhouse gases.

**Accomplishments:**

**Soil aeration measurement and effects of tillage:** Worldwide crop, forest, and landscaping annual losses to flooding and aeration impairment rival drought losses in most years, largely because the losses are catastrophic in most instances and not incremental, as is usually the case with drought. Recent literature on the principles and measurement of soil aeration and on how tillage affects soil aeration were compiled and reviewed for a widely circulated encyclopedia of soil science.

**Impact:** This information will serve as the basis of general instruction in the topic area for many undergraduate and graduate students in the soil and earth sciences.

**Documentation**:
Horne, D.J., and R.E. Sojka. 2002. Aeration, tillage effects on. p. 30-33. In: R. Lal (ed). Encyclopedia of Soil Science, 1st Edition. Marcel Dekker, Inc., New York.
Sojka, R.E., and H.D. Scott. 2002. Aeration measurement. p. 27-29. In: R. Lal (ed). Encyclopedia of Soil Science, 1st Edition. Marcel Dekker, Inc., New York.

**Use of oxygen diffusion rate to characterize macropore function in soil:** The oxygen diffusion rate technique measures the rate of oxygen movement to an electrode, similar to oxygen movement to a root. The spatial pattern of oxygen diffusion rate within a sample was used to characterize two-dimensional aerobic and anoxic zones. The autocorrelation length was greater for samples that were disturbed, but size and number of aerobic zones were greater for the undisturbed no-till samples. This suggests connected macropores in the no-till samples allowed greater air exchange than the more homogeneous disturbed samples.

**Impact:** This two-dimensional approach could be further developed to compare management effects on continuity of aeration pathways in soils. At this stage of development, the information is primarily of interest to scientists who would like to use the variable oxygen diffusion rate technique to further study soil properties.

**Documentation:**

Logsdon, S.D. 2003. Within sample variation of oxygen diffusion rate. Soil Sci. 168:531-539.

**Physiological and morphological response of sugarcane growing under high water tables:** Raising water tables helps conserve the organic soils on which sugarcane is grown in Florida by reducing microbial activity, but high water tables also reduce crop yields. It is important to learn how to sustain or improve sugarcane yields while reducing microbial activity because Florida is the largest sugar producing state in the U.S. Small holes (aerenchyma) in sugarcane stalks, if formed before sugarcane is exposed to flood, help sustain yields when flooded. Rates of sugarcane photosynthesis were maintained, and sometimes moderately enhanced, by periodic floods and high water tables. Soluble carbohydrates in the root zone varied between cultivars. Greater soluble carbohydrates around the roots of some cultivars at higher water-table depths suggest that adaptation to high water tables involves efficiency of carbohydrate storage by the plant. Strategies for sugarcane tolerance to high water tables also include increased root mass and root length and reduced root diameter near the soil surface. This research benefits both researchers and producers by improving our understanding of physiological and morphological responses to sugarcane grown in flooded conditions.

**Impact**: This new knowledge better enables growers to identify high-water-table tolerance in their commercial cultivars, and enhances the ability of researchers to develop new, higher yielding cultivars with high water-table tolerance.

**Documentation:**

Glaz, B., D.R. Morris, and S.H. Daroub. 2004. Periodic flooding and water table effects on two sugarcane genotypes. Agronomy Journal. 96:832-838.

Morris, D.R. and P.Y. P.Tai. 2004. Water table effects on sugarcane root and shoot development. J. Am. Soc. Sugarcane Tech. 24:41-59.

Morris, D.R., P. Y.P.Tai, and D. Struve. 2004. Sugarcane yield and rhizosphere characteristics in flooded organic soil determined from a pot study. J. Am. Soc. Sugarcane Tech. 24:18-30.

Glaz, B.D. R. Morris, and S.H. Daroub. 2004. Sugarcane photosynthesis, and stomatal conductance due to flooding and water table. Crop Science. (Accepted 3/4/04).

## Soil Water Component

**Problem Area 11:** Tools are needed to assess and predict soil water processes and storage, and movement of chemicals and other constituents through the soil.

**Background:** Soil water must be managed more effectively to produce crops while safeguarding the environment. This will require development of theory, mathematical descriptions and functions, models, and computerized decision aids to understand and manage complex transport processes and other production and environmentally important processes. All soil water phenomena and transport of materials in soil water are affected by soil properties, water contents, and the energy that binds water to soil. Characterization of these soil properties, and adequate measurement of soil water content and potentials are major obstacles to understanding all soil water processes and phenomena. These needs are especially critical to better determine, interpret, and predict the movement and destination of salts, chemicals and other constituents in soil. This requirement will become more important with time, as agriculture is forced to use grey waters and other waters of impaired quality for crop production.

Goals of the research were:

Develop new and improved instruments and concepts, especially non-contact and remotely sensed capabilities, to assess soil water processes and storage.

Develop new and improve existing theories and concepts, including more accurate and precise transport predictive capability, to relate soil and plant properties to water withdrawal and loss, crop water availability and use, movement of water borne chemicals, salts, and other pollutants in soil.

Improve understanding of soil properties and develop new soil management strategies that account for effects of dissolved or suspended water contaminants.

**Accomplishments:**

**Inverse optimization strategies with the tension disc permeameter:** *In-situ* measurements of soil hydraulic properties are crucial towards modeling the dynamic processes of water flow in the field and predicting the outcomes of alternative management scenarios. Field and laboratory investigations were carried out to develop and evaluate inverse parameter optimization methods to estimate soil hydraulic properties using infiltration measurements from a tension disc permeameter. Inverse optimizations also included transient soil water contents measured by time-domain reflectometry (TDR) probes, soil water contents from extracted soil cores, and/or water characteristics data. Optimization strategies that used multiple sources of measured data permitted close, simultaneous fits to cumulative infiltration, the soil water characteristics curve, and transient soil water contents and led to improved parameter estimability. The optimization strategies were incorporated into user-friendly software entitled *IDSfit* that inversely estimates soil hydraulic parameters for two-dimensional axisymmetric water flow beneath a disc source. **Impact:** The new methods offer a practical way to incorporate multiple sources of information in the optimization process thereby permitting a more robust estimation of field hydraulic properties. The optimization framework implemented by *IDSfit* greatly enhances the capability of Federal, State, and private researchers to inversely estimate soil hydraulic parameters for use in simulation models.

**Documentation:**

Baumhardt, R.L., Lascano, R.J., and Evett, S.R. 2000. Soil material, temperature, and salinity effects on calibration of multisensor capacitance probes. Soil Sci. Soc. Am. J. 64:1940-1946.

Schwartz, R.C. 2002. The *IDSfit* Code for Inverse Estimation of Field Hydraulic Properties Using a Disc Infiltrometer. Conservation and Production Research Laboratory, Agricultural Research Service, USDA, Bushland, TX. (Windows Software). Available at http://www.cprl.ars.usda.gov/wmru/rschwartz/tools.html

Schwartz, R.C. and S.R. Evett. 2002. Estimating hydraulic properties of a fine-textured soil using disc infiltrometer. Soil Sci. Soc. Am. J. 66:1409-1423.

Schwartz, R.C. and S.R. Evett. 2003. Conjunctive use of tension infiltrometry and Time-Domain Reflectometry for inverse estimation of hydraulic properties. Vadose Zone J. 2:530-538.

Schwartz, R.C., S.R. Evett, and P.W. Unger. 2003. Soil hydraulic properties of cropland compared with reestablished and native grassland. Geoderma 116:47-60.

**Frequency-dependent dielectric properties of soil clays:** Time domain reflectometry (TDR) has been used to determine soil water content, based on dielectric properties. Inconsistent results were shown for soils high in smectite clays when long cables reduced the effective frequency into the range where dielectric properties change with frequency. By examining the dielectric spectra across a range of frequencies, more soil properties can be examined than just soil water. The first studies on pure mono-saturated smectite clays showed that water contained within the smectites contributed to electrical conductivity within the system. Factors derived from the electrical spectra of the clay - water system were affected by the associated cation, amount of water, properties of the clay, and temperature. Recent analysis of soil electrical spectra has shown differences related to soil mineralogy and water content. This research has led to a specific cooperative agreement with Wright State University (Ohio) to address pathways of charge movement in smectite clays.

**Impact:** This represents one of the first systematic characterization of electrical spectra of clays across a range of frequencies, water contents, and temperatures. These results are important to scientists who use TDR and other equipment assumed to measure soil water and salt content, but are measuring smectite-water interactions as well. These results are needed for manufacturers of soil electrical equipment to broaden their scope of consideration beyond merely determining water and salt content. These results are also of interest to scientists examining smectite-water interactions for the impact on clay sorption of organics in soils, the effect on soil aggregation, and temperature influence on water storage and release from smectite interlayers and the impact on plant water availability.

**Documentation:**

Logsdon, S.D. 2000. Effect of cable length on TDR calibration for high surface area soils. Soil

Sci. Soc. Am. J. 64:54-61.
Logsdon, S.D., and D.A. Laird. 2002. Dielectric spectra of bound water in hydrated smectite. J. Non-Crystalline Solids. 305:243-246.
Logsdon, S.D. 2002. Dielectrics – beyond water content. 1.3:1-17. In I.C. Paltineanu (Ed.) Transactions First International Symposium on Soil Water Measurement using Capacitance and Impedance. Beltsville, MD, Nov. 6-8, 2002. Paltin International Inc.
Logsdon, S.A., and D.A. Laird. 2003. Ranges of bound water properties associated with a smectite clay. p. 101-108. In: Proceedings Fifth International Conference on Electromagnetic Wave Interaction with Water and Moist Substances. Rotorua, New Zealand, Mar. 23-26, 2003.
Logsdon, S.D., and D.A. Laird. 2004. Cation and water content effects on dipole rotation activation energy of smectites. Soil Sci. Soc. Am. J. 68:1586-1591.
Logsdon, S.D., and D.A. Laird. 2004. Electrical conductivity spectra of smectites as influenced by saturating cation and humidity. Clays Clay Minerals 52:411-420.
Logsdon, S.D. 2004. Bound water in soils. p. 1-5. In: B.A. Stewart and T. Howell (Eds.) Encyclopedia of Water Science. Marcel Dekker, New York.
Charge carriers in frequency-dependent electrical conductivity of smectites. Specific Cooperative Agreement with Wright State University.

**Improved monitoring of soil water status:** Improved monitoring of soil water content is essential to improving management for crop production and environmental protection. Direct automated measurement of soil water status has been difficult because of lost sensitivity of the instruments in high salinity environments. ARS scientists have improved procedures for calibrating and using electromagnetic sensors (Time Domain Reflectometry and Capacitance Probes) to rapidly and nondestructively monitor soil water content, especially in saline environments.

**Impact:** The new and improved methods and tools for characterizing soil water status will aid in the development of soil management practices that enhance crop production while protecting soil and environmental resources. Beneficiaries include farmer and extension groups and consultants, environmental consulting firms, irrigation and water districts, government research laboratories, federal agencies, universities dealing with soil, agronomic and/or environmental research, and the general public.

**Documentation:**

Castiglione, P. and P.J. Shouse. 2003. The effect of ohmic cable losses on time domain reflectometry measurements of electrical conductivity. Soil Sci. Soc. Am. J. 67:414-424.
Kelleners, T.J., R.W.O. Soppe, J.E. Ayars, T.H. Skaggs. 2004. Calibration of capacitance probe sensors in a saline silty clay soil, Soil Sci. Soc. Am. J. 68:770-778.
Kelleners, T.J., R.W.O. Soppe, J.E. Ayars, T.H. Skaggs. 2004. Calibration of capacitance probe sensors in a saline silty clay soil, Soil Sci. Soc. Am. J. 68:430-439.

**Improved characterization of soil water status and soil hydraulic properties:** Improved understanding the soil hydraulic properties that control the movement of water in soil, is essential to improving management for crop production and environmental protection. Direct measurement of soil water status and hydraulic properties is laborious and time consuming. Rapid, indirect methods for estimating soil hydraulic properties and soil water conditions are needed to improve management. ARS scientists have (i) developed new procedures and software for characterizing soil hydraulic properties (water retention and transmission), including new theoretical descriptions of macroporous soils and associated preferential (rapid) flow phenomena, (ii) put together new and improved electronic databases of measured soil hydraulic and related physical properties (including the international UNSODA soil hydraulic property database as well as a database of measured properties for the Southern Great Plains region); and (iii) improved models and software (ROSETTA v. 1.2) for estimating soil hydraulic properties from more easily measured soils data (e.g., soil texture, bulk density and/or organic matter content).

**Impact:** The new and improved tools for characterizing soil water status and soil hydraulic properties will aid in the development of soil management practices that enhance crop production while protecting soil and environmental resources. Beneficiaries include farmer and extension groups and consultants, environmental consulting firms, irrigation and water districts, government research laboratories, federal agencies, universities dealing with soil, agronomic and/or environmental research, and the general public.

**Documentation**:
Schaap, M.G. and F.J. Leij. 2000. Improved prediction of unsaturated hydraulic conductivity with the Mualem-van Genuchten model. Soil Sci. Soc.Am. J. 64:843-851.

Hollenbeck, K.J., J. Simunek and M.Th. van Genuchten. 2000. RETCML: Incorporating maximum-likelihood estimation principles in the RETC soil hydraulic parameter stimation code. Computers & Geosciences . 38:1-8.

Skaggs, T.H., L.M. Arya, P.J. Shouse, and B.P. Mohanty. 2001. Estimating particle-size distribution from limited soil texture data. Soil Sci. Soc.Am. J. 65:1038-1044.

Schaap, M.G., F.J. Leij, and M.Th. van Genuchten. (2001). ROSETTA: A computer program for estimating soil hydraulic properties with hierarchical pedotransfer functions. J. Hydrol. 251:163–176.

Nemes, A., M.G. Schaap, and F.J. Leij. 2001. Description of the unsaturated soil hydraulic database UNSODA version 2.0. J. of Hydrol. 251:151-162.

Mohanty, B.P., P.J. Shouse, D.A. Miller and M. Th. van Genuchten. 2002. Soil property database: Southern Great Plains 1997 hydrology experiment. Water Resour. Res. 38(5), 10.1029/2000WR000076.

Schaap, M.G., F.J. Leij and M.Th. van Genuchten. 2002. Estimating the unsaturated soil hydraulic properties using a hierarchical set of pedotransfer functions. In: Proceedings nd Federal Interagency Hydrologic Modeling Conference, "Hydrologic Modeling for the 21st Century" Las Vegas, NV, July 28-August 1, 2002. (CD-ROM). Proceedings. 1B:1-11.

Nemes, A., Schaap, M.G., Wosten, J.H.M. 2003. Functional evaluation of pedotransfer functions derived from different scales of data collection. Soil Sci. Soc. Am. J. 67:1093-1102.

van Genuchten, M.T. and M.G. Schaap. 2004. Improved description of the hydraulic properties of unsaturated structured media near saturation. In: B. Faybishenko and P.A. Witherspoon (eds.) Proc. 2nd International Symposium on Dynamics of Fluids in

Fractured Rock. Feb. 10-12, 2004. LBNL-54275. Lawrence Berkeley National Laboratory, University of California, Berkeley, CA. Proceedings -LBNL 54275. 255-259.

**Contribution of preferential flow to solute leaches:** The literature reports monitoring and studies in which small amounts of herbicide have been shown to rapidly leach to tiles or shallow water tables. Macropore number and hydraulic properties were determined from tension infiltration measurements and used in solute modeling efforts. In one study tritium and bromide leaching were not affected by tillage (no-till vs. chisel till). Another study showed that number of macropores did not differ between no-till and moldboard plow, yet herbicides were transported more rapidly through no-till soil.

**Impact:** Modeling results suggested that lower matrix hydraulic conductivity and less sub-surface porosity may have resulted in more transport through macropores in no-till. This research is of interest to scientists and regulators who want to understand tillage management effects on rapid solute leaching. The information is also useful for those desiring to parameterize preferential flow models.

**Documentation:**

Logsdon, S.D., K.E. Keller, and T.B. Moorman. 2002. Measured and predicted leaching from multiple undisturbed soil columns. Soil Sci. Soc. Am. J. 66:686-695.

Logsdon, S.D. 2002. Determination of preferential flow model parameters. Soil Sci. Soc. Am. J. 66:1095-1103.

Malone, R.W., S. Logsdon, M.J. Shipitalo, J. Weatherington-Rice, L. Ahuja, and L. Ma. 2003. Tillage effect on macroporosity and herbicide transport in percolate. Geoderma 116:191-215.

**Confirmation of subsurface flow pathways with remote sensing:** Subsurface flow pathways in agricultural fields were confirmed with remotely sensed vegetative indices. Identifying locations for monitoring subsurface flow of water and chemicals is especially difficult because conventional sampling methods are inadequate for measuring this highly variable, yet critical process. Analysis of remotely sensed imagery over several years confirmed the existence and extent of the subsurface water flow network in agricultural fields and quantified the impact of hydrologically-active zones on corn yields. Remotely sensed imagery is useful in locating these subsurface flow pathways when ground-penetrating radar data are either unavailable or ineffective.

**Impact:** Knowing the location of subsurface flow pathways in crop fields will allow NRCS and crop producers to design and establish effective biological buffer zones around crop fields. These strategically located buffer zones will reduce nitrate flows from croplands and thus reduce the detrimental impact of agriculture on neighboring ecosystems.

**Documentation:**

Dulaney, W.P., C.S.T Daughtry, C.L.Walthall, and T.J. Gish. 2001. The use of remote sensing techniques to determine the impact of preferential flow on corn grain yields. Proceedings

2nd International Preferential Flow Symposium, Am Soc. Agric. Eng. (and on CD-ROM), Hawaii, Jan 3-5, 2001, pp. 2095-212.
Walthall, C.L., T.J. Gish, C.S.T. Daughtry, W.P. Dulaney, K.-J.S. Kung, G.D. McCarty, D. Timlin, J.T. Angier, P. Buss, and P.R. Houser. 2001. An Innovative approach for locating and evaluating subsurface pathways for nitrogen loss. *In:* Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World 1:223-229.
Walthall, C.L., T.J. Gish, A. Chinkuyu, W.P. Dulaney, M.N. Kaul, and C.S.T. Daughtry. 2004. Analysis of surrogate indicators for evidence of subsurface preferential flow pathways: Impact of subsurface preferential flow on variability of NDVI. Proc. Int. Geoscience Remote Sensing Symp. CD-ROM.

**Subsurface hydrology impacts surface nitrate runoff:** Nitrate surface runoff fluxes were 18 times larger on one 4 ha watershed relative to three adjacent watershed even though they had similar textures, slopes, climatic conditions, and organic mater content distributions. In the past, determining the interaction and impact of surface runoff and subsurface flow processes on the environment has been hindered by our inability to characterize subsurface soil structures on a watershed scale. The locations of discrete subsurface flow pathways in four small watersheds were identified and confirmed by combining ground penetrating radar, surface topography, and remotely sensed images in a geographic information system. Significant differences in nitrate runoff fluxes among the four watersheds could only be explained with knowledge of the subsurface hydrology, especially the area drained by the subsurface flow channels and their depth below the soil surface.

**Impact:** Detailed knowledge of the surface-subsurface hydrologic response will enable scientists to better understand how agricultural activities are influenced by landscape features and climate. These studies will also provide data to improve water quality models by including surface and subsurface flow patterns influencing water and chemical fluxes exiting agricultural lands. In addition, this data can be used to develop sound environmental policy.

**Documentation:**
Chinkuyu, A.J., T. Meixner, T.J. Gish, and C.S.T. Daughtry. 2004. The importance of seepage zones in predicting soil moisture content and surface runoff from watersheds using GLEAMS and RZWQM. Trans. Am. Soc. Agric. Eng. 47:427-438.
Daughtry, C.S.T., T.J. Gish, W.P. Dulaney, C.L. Walthall, K.-J.S. Kung. G. McCarty, J.T. Angier, and P. Buss. 2001. Surface and subsurface nitrate flow pathways on a watershed scale. *In:* Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific World 1:155-162.
Gish,T.J., W.P. Dulaney, C.S.T. Daughtry, and K.-J.S.Kung. 2001. Influence of preferential flow on subsurface runoff fluxes. Proceedings 2nd International Preferential Flow Symposium, Am Soc. Agric. Eng. (and on CD-ROM), Hawaii, Jan. 3-5, 2001, pp 205-209.

**Measuring and modeling soil physical changes in dryland agriculture:** To understand agricultural systems we require a generalization of the changes in soil conditions caused by soil management. Soil hydraulic properties vary in both space and time. These properties are influenced by soil management practices such as tillage, wheel traffic and crop rotation as well as inherent soil characteristics based on soil texture and landscape position. ARS scientists provided data that was used to synthesize the current understanding of how soil management will influence hydraulic properties and to summarize these changes for use in process-based models. This was part of a regional project in the Great Plains to investigate the influence of crop rotation, tillage, and time on soil physical characteristics. Sites in this study were selected to incorporate climate variables as well as soil type variables. The sites were located in Saskatchewan, North Dakota, Montana, South Dakota, Nebraska, Colorado, and Texas.

**Impact**: These studies showed the inconsistency of generalizing changes in soil properties based on soil management operations. The effects of soil type and climate had a large influence on the soil response to wheel traffic and tillage and need to be addressed more fully in future experiments. These studies point out the need for systematic studies to address the mechanics of soil change due to forces placed on the soil.

**Documentation:**

Ahuja, L.R., Benjamin, J.G., Dunn, G.H., Ma, L., Green, T.R. and Peterson, G.A., 2000. Quantifying wheel-track effects on soil hydraulic properties for agricultural systems modeling. p. 407-414. 4th Intl. Conf. on Soil Dynamics, Adelaide, Australia.

Green, T.R., L.R. Ahuja and J.G. Benjamin. 2003. Advances and challenges in predicting agricultural management effects on soil hydraulic properties. Geoderma 116:3-27.

Pikil, J.L. Jr. R. Schwartz, J. Benjamin, L. Baumhardt, and S. Merrill. 2003. Soil physical characteristics of contrasting cropping systems in the Great Plains: preliminary findings. p. 205-209. *In:* Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismark, ND, August 4-7.

**New remote sensing techniques to quantify crop variability:** Direct sampling of agricultural fields over large areas is impractical or nearly impossible. Leaf area index (LAI) was estimated from satellite and airborne remotely sensed images using traditional approaches that required site-specific calibration and two new approaches that do not require calibration. One of the tested procedures uses image spectral and spatial information and may thus be more suitable to high spatial resolution imagery needed for within-field applications. The two new approaches performed reasonably well relative to calibrated methods. These new procedures show promise as candidates for operational implementation by producers, and USDA action agencies for monitoring the progress of within-season domestic and foreign agricultural production.

**Impact:** Procedures suitable for high spatial resolution precision farming applications were developed that may be more successful at LAI retrieval than previously developed LAI retrieval methods. The analysis comparing different remote sensing methods for LAI retrieval serves as a benchmark study and will provide guidance to users on the selection of remote sensing-based LAI retrieval.

**Documentation:**

Liang, S., H. Fang, M. Chen, C. Shuey, C. Walthall, C. Daughtry, J. Morisette, C. Schaff, and A. Strahler. 2002. Validating MODIS land surface reflectance and albedo products: Methods and preliminary results. Remote Sens. of Environ. 83(1-2):149-162.

Walthall, C., W. Dulaney, M. Anderson, J. Norman, H. Fang, and S. Liang. 2004. A Comparison of empirical and neural network approaches for estimating corn and soybean leaf area index from Landsat ETM+ imagery. Remote Sens. of Environ. (In press).

# Soil Biology Component

Soil is a dynamic, living matrix that is an essential part of the terrestrial ecosystem. It is a critical resource not only to agricultural production but also to the maintenance of most life processes. The living portion of the soil is composed of plant roots as well as communities of biota (living soil organisms) critical to the function of soils. Soils have enormous numbers of diverse organisms assembled in complex and varied communities. Soil that contains a balance of active biological components is essential to all agricultural systems. Our understanding of these soil communities is limited, fragmentary and too often treated as a black box whose mechanisms are hidden or mysterious. Soil biota may be beneficial, neutral, or detrimental to plant growth; thus they must be effectively managed for maximum productivity. Improved soil biological management requires that we understand soil organisms and their ecological interactions. Land managers need unbiased information that will enable them to develop biologically-based management strategies to control or manipulate soil stabilization, nutrient cycling, crop diseases, pest infestations, and detoxification of natural and manmade contaminants. These strategies will require improved understanding of the effects on soil biota of habitats, food sources, host interactions, and the soil physical and chemical environment. Understanding the ecology regulating both beneficial and detrimental organisms is essential to harnessing and controlling their activity in agroecosystems. This knowledge will greatly benefit production of abundant, high quality agricultural products with less dependence upon external inputs. Our goal has been to understand soil biota for increasing crop productivity and quality, reducing input costs, and reducing negative environmental impacts.

Research within the Soil Biology Component of the Soil Resource Management National Program was conducted in five Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a planning workshop held at the start of the current five-year National Program cycle. The five Problem Areas are: (Problem Area 12) A better understanding of the ecology of beneficial and harmful organisms is needed to utilize and control their expression in agricultural systems. (Problem Area 13) The functions and interactions of organisms in the zone of soil immediately surrounding plant roots (rhizosphere) and seeds (spermosphere) are poorly understood. (Problem Area 14) Soil biota could make agricultural production systems more sustainable by reducing nonrenewable inputs and negative environmental impacts, but this soil management approach has been largely ignored. (Problem Area 15) Research is needed to develop management practices to use soil biota to control plant diseases, pests, and weeds. (Problem Area 16) A greater understanding is needed of the role of soil biota in the degradation/detoxification of pesticides and other xenobiotics to enhance the process.

Soil biology research is currently conducted by the following ARS locations: Akron, Colorado; Ames, Iowa; Beaver, West Virginia; Beltsville, Maryland; Columbia, Missouri; Coshocton, Ohio; Lincoln, Nebraska; Mandan, North Dakota; Morris, Minnesota; Orono, Maine; Oxford, Mississippi; Pendleton, Oregon; Prosser, Washington; Pullman, Washington; St. Paul, Minnesota; Salinas, California; Sidney, Montana; Stoneville, Mississippi; Temple, Texas; Tifton, Georgia; Urbana, Illinois; Watkinsville, Georgia; and Wyndmoor, Pennsylvania.

## Soil Biology Component

**Problem Area 12:** A better understanding of the ecology of beneficial and harmful organisms is needed to utilize and control their expression in agricultural systems.

**Background:** Soil ecology involves the interrelationships among soil organisms and between those organisms and their environment. All organisms have certain requirements for growth and survival and are dependent upon the environment for needed nutrients, growth factors, and suitable habitat. The complex interactions among the soil chemical, physical and biological properties regulate the behavior of soil biota, the biologically mediated processes in soil, and the functioning of the soil ecosystem. Soil management controls and manipulates the organisms responsible for nutrient cycling, crop diseases, and pest damage through the manipulation of soil physical, chemical, and biological habitat, food sources, and host interactions. Biotic processes impact long-term productivity, soil fertility, soil aggregation, erosion, and other indicators of soil quality. In turn, the soil biota and their interactions play a part in the success of any management decision. A better understanding of the ecology of beneficial and harmful organisms is needed to utilize and control their expression in agricultural systems. The gaps in basic soil ecology largely arise from poor understanding of the interaction of specific organisms or functional groups with their environment. These gaps increase as natural and introduced genetic adaptations proliferate. An understanding of soil biota and their ecology should be developed, so that the ecological and biological effects of resident soil populations can be used to reduce inputs of nonrenewable resources while still increasing productivity needed to meet food, feed, and fiber demand.

The goals of this research were:

Develop fundamental understanding of soil ecology to (a) identify interactions with fertility, cultural, spatial and temporal factors, (b) predict root, seed, soil, and biotic interactions, and (c) develop effective strategies to manage soil biota.

Enhance knowledge of soil biological components and processes that influence plant growth and soil ecosystem functions.

Develop improved methods to identify and characterize soil biological populations and activities.

**Accomplishments**

**Glomalin characterized as important component of soil organic matter:** Glomalin is an insoluble glycoprotein produced by arbuscular mycorrhizal fungi that is resistant to decomposition and found in relatively large quantity in soil. The classical chemical extraction procedure for soil organic matter does not isolate protein, and therefore, a procedure to isolate glomalin was developed. Soils from across the US were sequentially extracted for light-fraction organic matter (LFOM), glomalin, humic acid (HA), and fulvic acid (FA). Glomalin was unique in protein, C, H, and N concentration compared with LFOM, HA, and FA. Soil organic C was composed of ca. 20% glomalin. A recalcitrant glomalin pool was discovered that might have a functional role in water-stability of aggregates. Using nuclear magnetic resonance, glomalin was distinct from HA. Extracted glomalin contained tightly bound iron, organic matter, amino acids, and carbohydrates. Glomalin was greater in soils with conservation tillage and higher crop diversity than in soils from conventional management. Glomalin production under controlled conditions was negatively affected by irradiation, which killed the fungi that produce this compound.

**Impact:** This research has advanced scientific understanding of a previously ill described component of soil organic matter. Glomalin's place in soil organic matter fractionation has been established. Soil scientists, ecosystem modelers, and agricultural practitioners will be able to use this information to develop more sustainable agricultural management systems.

**Documentation:**

Nichols, K., S. Wright, W. Schmidt, M. Cavigelli, L. Dzantor. 2002. Carbon contribution and characteristics of humid acid, fulvic acid, particulate organic matter, and glomalin in diverse ecosystems. p. 365-367. *In* Proc. Humic Substances: Nature's Most Versatile Materials. Int. Humic Subst. Soc., Boston, MA.

Nichols, K. 2003. Characterization of Glomalin - A Glycoprotein Produced by Arbuscular Mycorrhizal Fungi. Ph.D. diss. Univ. of Maryland, College Park.

**Relationship between glomalin and soil properties and its response to management:** Glomalin is a glycoprotein component of soil organic matter, produced by arbuscular mycorrhizae. It is linked with the ability of soil to retain stable soil structure. Collaborative research has quantitatively described the relationship of glomalin with soil properties and its response to management in various ecosystems across North America. In an annual grassland in California, glomalin and aggregate stability decreased with artificial warming. Concentration of glomalin in soil was dependent upon plant species. A structural equation model indicated that the direct effect of glomalin was stronger than the direct effect of fungal hyphae on aggregate stability. In a rangeland in New Mexico, higher levels of organic C and N and glomalin were found under mesquite shrubs than open grassy areas. In cultivated soil in Colorado, quantitative relationships were found among glomalin, electrical conductivity, and yield potential. In a tropical soil in Hawaii, concentration of glomalin was related to soil age and consisted of 4-5 % of total soil C and N. Carbon dating indicated a turnover time of several years to decades. In a lowland rainforest in Costa Rica, glomalin had a shorter turnover time in high than in low fertility sites. Glomalin accounted for 3.2 % of total C and 5% of total N in the 0-10-cm soil depth. Arbuscular-mycorrhizal hyphae growth was estimated at 10% of above-ground primary production of the forest. In polluted soils from mine locations, glomalin sequestered significant quantities of potentially toxic elements, such as Cu, Cd, and Pb. Glomalin could be considered a biostabilization mechanism to remediate polluted soils.

**Impact:** This research has advanced scientific understanding of a key component of soil organic matter important in soil aggregation. Beginning with no knowledge that a soil protein such as glomalin existed before its discovery in 1996, research from 2000 to present has revealed the ubiquity, quantity, and role of glomalin in soil. Soil scientists, ecosystem modelers, natural resource practitioners, and enviromental pollution control managers will be able to use this information to design effective strategies to combat soil erosion and predict environmental change.

**Documentation:**


Rillig, M.C., S.F. Wright, B.A. Kimball, P.J. Piner, G.W. Wall, M.J. Ottman, and S.W. Leavitt. 2001. Elevated carbon dioxide and irrigation effects on water stable aggregates in a sorghum field: A possible role for arbuscular mycorrhizal fungi. Global Change Biol. 7:333-337.

Rillig, M.C., S.F. Wright, K.A. Nichols, W.F. Schmidt, and M.S. Torn. 2001. Large contribution of arbuscular mycorrhizal fungi to soil carbon pools in tropical forest soils. Plant Soil 233:167-177.

Bird, S.B., J.E. Herrick, M.M. Wander, and S.F. Wright. 2002. Spatial heterogeneity of aggregate stability and soil carbon in semi-arid rangeland. Environ. Poll. 116:445-455.

Rillig, M.C., S.F. Wright, and V.T. Eviner. 2002. The role of arbuscular mycorrhizal fungi and glomalin in soil aggregation: Comparing effects of five plant species. Plant Soil 238:325-333.

Rillig, M.C., S.F., Wright, M.R. Shaw, and C.B. Field. 2002. Artificial climate warming positively affects arbuscular mycorrhizae but decreases soil aggregate water stability in an annual grassland. Okios 97:52-58

González-Chávez, M.C., R. Carrillo-González, S.F. Wright, and K.A. Nichols. 2004. The role of glomalin, a protein produced by arbuscular mycorrhizal fungi, in sequestering potentially toxic elements. Environ. Poll. 130:317-323.

Johnson, C.J., R.A. Drijber, B.J. Wienhold, S.F. Wright, and J.W. Doran. 2004. Linking microbial-scale findings to farm-scale outcomes. Prec. Agric. 5:311-328.

Lovelock, C.E., S.F. Wright, D.A. Clark, and R.W. Ruess. 2004. Soil stocks of glomalin produced by arbuscular mycorrhizal fungi across a tropical rain forest landscape. J. Ecol. 92:278-287.

Lovelock, C.E., S.F. Wright, and K.A. Nichols. 2004. Using glomalin as an indicator for arbuscular mycorrhizal hyphal growth: An example from a tropical rain forest soil. Soil Biol. Biochem. 36:1009-1012.


**Soil microbial activity responds to environmental changes:** Soil microbial biomass and its activity in soil are important regulators of nutrient transformations, soil organic matter dynamics, and greenhouse gas emission. ARS scientists and cooperators from the US and Canada determined soil microbial activity in response to different environmental conditions. In four distinct ecoregions of North America that represented a factorial arrangement of two levels each of temperature and precipitation (Alberta - cold/dry, Maine - cold/wet, Texas, hot/dry, and Georgia, hot/wet), soil microbial biomass and potential activity were higher per mass of soil and 2-3 times greater per unit of soil organic C in hot than in cold regions. This occurred despite soils in hot regions having lower organic C than in cold regions. In a tallgrass-prairie ecosystem in Kansas, water-filled pore space and soil temperature interacted significantly to control the majority of soil microbial activity and whole-ecosystem respiration. The contribution of soil microbial activity could be effectively separated from whole-ecosystem respiration through predictions with regression equations developed and measurement of environmental (i.e., soil organic C, soil temperature, and water-filled pore space) and physiological (i.e., plant growth rate) controls on soil C dynamics. In a volcanic disturbance gradient at Mount St. Helens in

Washington, soil microbial activity was highly related to the extent of lupine plants that developed following volcanic eruption. Lupine influence on microbial activity was greatest at the soil surface and soil microbial communities were more diverse under lupines than in bare areas. In response to elevated atmospheric $CO_2$ concentration, clover growth was enhanced, which resulted in higher soil bacterial population and greater soil microbial activity. Elevated $CO_2$ concentration also shifted the types of soil microbial communities present.

**Impact:** Soil scientists, ecosystem modelers, and natural resource practitioners will be able to use this information to (a) improve models of decomposition and nutrient cycling, (b) better account for the effect of environmental factors on soil microbial activity, and (c) plan management strategies to respond to elevated $CO_2$ concentration and environmental disturbances. This research has impacted scientific knowledge by quantitatively determining soil responses to environmental changes and disturbances. Soil and ecosystem responses to elevated $CO_2$ concentration and environmental change may affect policy development.

**Documentation:**

Franzluebbers, A.J., R.L. Haney, C.W. Honeycutt, M.A. Arshad, H.H. Schomberg, and F.M. Hons. 2001. Climatic influences on active fractions of soil organic matter. Soil Biol. Biochem. 33:1103-1111.

Franzluebbers, K., A.J. Franzluebbers, and M.D. Jawson. 2002. Environmental controls on soil and whole-ecosystem respiration from a tallgrass prairie. Soil Sci. Soc. Am. J. 66:254-262.

Montealegre, C.M., C. van Kessel, M.P. Russelle, and M.J. Sadowsky. 2003. Changes in microbial population activity and composition in a pasture ecosystem exposed to elevated atmospheric carbon dioxide. Plant Soil 243:197-207.

Halvorson, J.J., J.L. Smith, and A.C. Kennedy. 2004. Lupine effects on soil development and function during early primary succession at Mount St. Helens (in press). *In* V.H. Dale et al. (ed.) Ecology responses to the 1980 eruptions of Mount St. Helens. Springer-Verlag, New York.

**Soil ecological relationships with soil organic matter summarized:** Concise descriptions of soil ecological processes for the lay audience are needed. Scientific literature on fungi, on soil microbial communities, on tillage and residue management, on endophyte relationships, on C and N cycling, and on activities of soil animals was summarized by ARS scientists in Beltsville MD, Mandan ND, Pullman WA, and Watkinsville GA for several reference books. Environmental and biotic interactions of soil microorganisms with various management systems suggest strong human control of soil ecological processes that can be used to benefit or deteriorate the environment. Soil biology is recognized as a key component along with other soil disciplines for the understanding and development of land management systems to help sustain and improve ecosystem functioning on local, regional, and global scales.

**Impact:** These reference works provide scientists, agricultural practitioners, and land managers with concise and synthesized information on how management affects soil organic matter and the organisms that process organic matter. These contributions will impact soil and environmental scientists and the general public as a source of readily available, simply formulated documentation of the activities of soil microorganisms in agriculture and the environment.

**Documentation:**

Franzluebbers, A.J. 2002. Animals and ecosystem functioning. p. 68-71. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, New York.

Franzluebbers, A.J. 2002. Ecology and the cycling of carbon and nitrogen. p. 374-377. *In* R. Lal (ed.) Encyclopedia of soil science. Marcel Dekker, New York.

Franzluebbers, A.J. 2002. Endophyte grasses. p. 94-96. *In* 2002 yearbook of science and technology. McGraw-Hill, New York.

Franzluebbers, A.J. 2002. Soil biology. *In* R. Lal (Honorary Theme Editor) Encyclopedia of life support systems. United Nations Educational, Scientific, and Cultural Organization, EOLSS Publishers, Oxford, UK. http://www.eolss.net.

Franzluebbers, A.J. 2004. Tillage and residue management effects on soil organic matter. p. 227-268. *In* F. Magdoff and R.R. Weil (ed.) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

Franzluebbers, A.J. 2004. Decomposition of organic residues. (in press). *In* D. Hillel et al. (ed.) Encyclopedia of soils in the environment. Academic Press, New York.

Kennedy, A.C., T.L. Stubbs, and W.L. Schillinger. 2004. p. 295-326. *In* F. Magdoff and R.R. Weil (ed.) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

Nichols, K.A., and S.F. Wright. 2004. Contributions of fungi to soil organic matter in agroecosystems. p. 179-198. *In* F. Magdoff and R.R. Weil (ed.) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton, FL.

**A key fungal mediator of soil aggregation quantified:** Soil biological activity by strongly influencing soil aggregation substantially affects a key soil ecosystem function - the partitioning of water flow in the environment. Soil aggregation is an important component of how soil partitions rainfall into infiltration and water runoff. Collaborative research identified and isolated a basidiomycete fungus (BB1) from corn residue that has the ability to aggregate and stabilize soil particles. When soil was amended with the basidiomycete, aggregates were more resistant to biodegradation and maintained their stability longer than when the soil was supplemented with plant residues without the basidiomycete. Using periodate treatment and lectin cytochemistry, involvement of fucose sugar residue was identified as a mechanism for soil binding. An enzyme-linked immunosorbent assay (ELISA) for the detection and quantification of soil-aggregating basidiomycete fungi was developed. Undisturbed grass borders of agricultural fields contained more soil-aggregating fungi than adjacent cultivated soils. Soil under no tillage also contained more soil-aggregating fungi than soil under conventional tillage. Soil scientists and natural resource practitioners could use this information to improve understanding of soil biology in ecosystem functioning and design management systems to increase infiltration, decrease water runoff, and improve the sustainability of agriculture.

**Impact:**

This research has advanced scientific understanding of soil biological involvement in soil aggregate formation and ecosystem functioning. The method developed has added a new biological approach to monitor soil quality. Information from this research is being transferred to farmers and ranchers in the Great Plains and beyond.

**Documentation:**

"Friend not foe: Fungus improves soil quality", http://www.cnn.com/2000/NATURE/06/02/fungus.enn, posted 2 June 2000 by Cable News Network.

Caesar-TonThat, T. C., and V.L. Cochran. 2000. Soil aggregate stabilization by a saprophytic lignin decomposing basidiomycete fungus. I. Microbiological aspects. Biol. Fertil. Soils 32:374-380.

Caesar-TonThat, T. C., W. Shelver, R.G. Thorn, and V.L. Cochran. 2001. Generation of antibodies for soil-aggregating basidiomycete detection to determine soil quality. Appl. Soil Ecol. 18:99-116.

Caesar-TonThat, T. C. 2002. Soil binding properties of mucilage produced by a basidiomycete fungus in a model system. Mycological Res. 106:930-937.

Holtz, B. A., M.V. McKenry, and T.C. Caesar-TonThat. 2004. Wood chipping almond brush and its effect on the almond rhizosphere, soil aggregation and soil nutrients. Acta Hort. 638:127-134.

**An improved microbial community-profile procedure developed:** Identification of bacteria is a time-consuming, but critical task performed in clinical, veterinary, environmental, and agricultural research laboratories. An ARS scientist devised modifications to a commercially available system for microbial identification using gas chromatography of fatty acid profiles (Microbial Identification System, MIDI Inc., Newark, Delaware, USA) to increase sensitivity and speed of analysis. Sensitivity was increased almost 1000-fold, making it possible to identify much smaller quantities of bacteria than previously possible. A sample preparation method was devised that more than doubled the number of samples that could be prepared per day, while a gas chromatographic technique was developed that was approximately six-fold faster than the conventional system. Biological scientists in soil, environmental, and health fields will benefit from the development of this improved procedure to identify communities of microorganisms.

**Impact:**

The development of this high-sensitivity technique will allow scientists to identify slow-growing bacteria and bacteria that might never reach high culture density. The improved technique will be useful for rapid identification of bacterial cultures in clinical and environmental laboratories.

**Documentation:**

Buyer, J.S. 2002. Identification of bacteria from single colonies by fatty acid analysis. J. Microbiol. Methods 48:259-265.

Buyer, J.S. 2002. Rapid sample processing and fast gas chromatography for identification of bacteria by fatty acid analysis. J. Microbiol. Methods 51:209-215.

Buyer, J.S. 2003. Improved fast gas chromatography for FAME analysis of bacteria. J. Microbiol. Methods 54:117-120.

**Rapid analysis of soil microbial biomass and potential activity developed:** Estimates of nutrient mineralization are needed by agricultural consultants to optimize fertilizer applications to meet economic and environmental goals of producers. Soil microbial biomass and biological activity are key determinants of nutrient mineralization. ARS scientists and university cooperators developed methods for rapidly characterizing soil microbial activity and nutrient cycling processes. Drying/rewetting, oxidation of organic matter, and chloroform fumigation-extraction of microbial biomass were evaluated on different soils. New methodologies requiring only one to three days of incubation were as effective in assessing nutrient mineralization and soil microbial activity as more traditional methods requiring potentially dangerous chemicals and taking up to a week or longer. Agricultural consultants and soil testing facilities will be able to use this information to improve predictions of soil nutrient availability for agricultural producers.

**Impact:** This research impacts the way soil biology is viewed from a practical sense, such that decisions on whether fertilization might be necessary could be made on short notice throughout the growing season of a crop, thereby affecting the economics of crop production. This research also impacts how nutrient recommendations will be developed by soil testing facilities.

**Documentation:**


Haney, R.L., A.J. Franzluebbers, F.M. Hons, L.R. Hossner, and D.A. Zuberer. 2001. Molar concentration of K2SO4 and soil pH affects estimation of extractable C with chloroform fumigation-extraction. Soil Biol. Biochem. 33:1501-1507.

Haney, R.L., F.M. Hons, M.A. Sanderson, and A.J. Franzluebbers. 2001. A rapid procedure for estimating nitrogen mineralization in manured soil. Biol. Fertil. Soils 33:100-104.

Picone, L.I., M.L. Cabrera, and A.J. Franzluebbers. 2002. A rapid method to estimate potentially mineralizable nitrogen in soil. Soil Sci. Soc. Am. J. 66:1843-1847.

Haney, R.L., A.J. Franzluebbers, E.B. Porter, F.M. Hons, and D.A. Zuberer. 2004. Soil carbon and nitrogen mineralization: Influence of drying temperature. Soil Sci. Soc. Am. J. 68:489-492.

# Soil Biology Component

**Problem Area 13:** The functions and interactions of organisms in the zone of soil immediately surrounding plant roots (rhizosphere) and seeds (spermosphere) are poorly understood.

**Background:** The rhizosphere and spermosphere are zones in soil immediately surrounding plant roots and seeds. The functioning of organisms in these zones can have a profound effect on both plant growth and nutrient cycling. The spermosphere is a critical area of study because seed colonization is the first step in root colonization. Microorganisms established on the germinating seed can multiply and colonize the length of the root as it emerges and grows through the soil. Thus, colonization of the imbibing seed may predispose future colonization of the root and greatly impact crop growth. The significance of the rhizosphere arises from the release of organic material from the root and the subsequent effect of increased biological activity on nutrient cycling and plant growth. The growth of a root through an area of soil increases the population of some microorganisms and influences the microbial interactions that benefit plant growth, such as plant growth-promotion, decomposition, nutrient cycling, and others. Because of the greater activity of soil biota in the microenvironment of the rhizosphere, it is a very different environment from that of the bulk soil and needs to be managed as such. Knowledge of the rhizosphere and the myriad of interactions within this zone have increased greatly since the term was first introduced in 1904, yet the rhizosphere and spermosphere are still poorly understood. The challenge is to understand these portions of the soil to manage the communities of living soil organisms and thus increase plant productivity and overall sustainability of the agricultural production systems. With further study and an increased knowledge of the biology and ecology of these zones, many more benefits are likely.

The goals of this research were:

Evaluate roles and mechanisms of plant genotype, plant-plant interactions, and rooting patterns in controlling space-time distribution of biotic communities, including ecological characteristics and diversity in the rhizosphere and spermosphere.

Evaluate management effects (e.g., crop species, crop rotations, tillage, amendments, and grazing management) on rhizosphere and spermosphere ecology in agricultural systems (annual and perennial cropping systems and natural plant communities).

**Accomplishments:**

**An improved method for determining root surface area developed:** Root growth and how roots explore the volume of soil are important components of ecosystem analysis, yet because roots are difficult and tedious to quantify, these measurements have been neglected. ARS scientists developed (a) equipment for extracting roots from soil that will process multiple samples and (b) methodology for measuring root surface area that does not require sample cleaning. Sample cleaning for root weight and surface area measurements can require 20 hours per sample. The procedure developed without root cleaning resulted in equal root surface area as with cleaned samples, but required only 2 hour. Soil scientists will be able to use this information to obtain a greater number of high quality estimates of root growth and distribution in soil**.**

**Impact:** This methodology can produce estimates of root surface area in $\leq$5% of the time required by traditional root washing methodology. These estimates will be important for understanding nutrient uptake, soil quality improvement, and threats to environmental quality.

**Documentation:**

Benjamin, J.G., and D.C. Nielsen. 2004. A method to separate plant roots from soil and analyze root surface area. Plant Soil (in press).

**Water vapor controls seed germination:** Seed germination in soil is a fundamental ecological process that has been difficult to predict and model under relatively dry soil conditions. An ARS scientist conducted research on the historical topic of seed germination using new techniques that allowed more robust and incontrovertible results to be obtained. Research demonstrated that, in contrast to previous assumptions, vapor was the major source of water for seed germination.

**Impact:** This research has changed scientific knowledge and approaches to understanding the influence of vapor on seed germination. Soil and crop scientists, agricultural engineers, and ecosystem modelers will be able to use this information to design better seed planting equipment and strategies for successful crop establishment under difficult environmental conditions.

**Documentation:**

Wuest, S. B. 1999. Vapor transport vs. seed-soil contact in wheat germination. Agron. J. 91:783-787.

Wuest, S. B. 2002. Water transfer from soil to seed: The role of vapor transport. Soil Sci. Soc. Am. J. 66:1760-1763.

**Endophyte infection of tall fescue alters soil microbial activity:** A fungus naturally infects tall fescue (endophyte infection), resulting in production of toxins that can reduce cattle weight gain. Pastures with high occurrence of endophyte-infected tall fescue have also been found with greater soil organic C and N concentration. ARS scientists from Watkinsville, Georgia, in collaboration with researchers from the University of Georgia and Texas A&M University demonstrated that mineralization of C was reduced in the presence of endophyte infection, which could explain why soil organic matter accumulates more with endophyte infection. Although mineralization of C was reduced, mineralization of N was enhanced with exposure of soil to endophyte-infected tall fescue leaves, suggesting that complex biochemical transformations occurred. Accumulation of soil organic C with long-term exposure of soil to endophyte-infected tall fescue occurred preferentially in macroaggregates, suggesting that soil physical processes are affected by the endophyte association as well. The chemical compounds in endophyte-infected tall fescue (ergot alkaloids) that are responsible for animal health disorders were found in soil, suggesting that these chemicals might be persistent in the environment.

**Impact:** This research has increased scientific understanding of fungal-plant interactions on soil microbial dynamics and soil organic C storage. Soil scientists, forage agronomists, animal scientists, environmental toxicologists, and agricultural practitioners will be able to use this information to (a) better manage grasses affected by endophytes for both production and environmental quality aspects and (b) better understand the ecological impacts of animals grazing tall fescue, and possibly to identify and cultivate other similar associations for improving soil organic matter storage.

**Documentation:**


Franzluebbers, A.J., M.B. Jenkins, D.A. Zuberer, and N.S. Hill. 2002. Belowground responses to tall fescue endophyte infection. p. 167. *In* USDA Symp. Nat. Resour. Mgt. Offset Greenhouse Gas Emissions, 19-21 November 2002, Raleigh NC.

Franzluebbers, A.J., N.S. Hill, M.B. Jenkins, D.A. Zuberer, S.B. Humayoun, and J.A. Stuedemann. 2004. How does soil respond to wild-type endophyte infection? Paper #310. *In* Proc. 5th Int. Symp. Neotyphodium/Grass Interactions, 23-26 May 2004, Fayetteville AR.

Franzluebbers, A.J., and J.A. Stuedemann. 2005. Soil carbon and nitrogen pools in response to tall fescue endophyte infection, fertiliization, and cultivar. Soil Sci. Soc. Am. J. (in press).

Franzluebbers, A.J., and N.S. Hill. 2005. Soil carbon, nitrogen, and ergot alkaloids with short- and long-term exposure to endophyte-infected and -free tall fescue. Soil Sci. Soc. Am. J. (in press).


**Liming improves colonization of plant growth-promoting rhizobacteria:** Heterotrophic microbial survival and growth in agricultural soil is dependent on metabolizable C, much of which results from rhizodeposition. Soil chemistry interacts with crop roots, altering rhizodeposition, and hence microbial community structure and function. Determining the nature and extent of soil chemical-biological interactions is important for predicting the successful colonization of roots by plant growth-promoting rhizobacteria. Management of the rhizosphere can improve inoculation or selection of indigenous microflora in the establishment of legume-based pastures on the acidic and low-nutrient soils of the Appalachian Region. Research demonstrated that liming (0.5 pH increase) of nonsterile and acidic (pH ~4.6) soil microcosms promoted rhizobial functioning (flavonoid recognition and infection) and growth and development of white clover root hairs, leading to successful symbiosis establishment and nodulation. Using model symbionts (gusA-marked rhizobia) and saprophytes (lacZY-marked pseudomonads), survival of plant growth-promoting rhizobacteria was enhanced by liming, whether assessed in nonsterile soils or derivative soil solutions. A field experiment, conducted by interseeding forage legumes into a well-established tall fescue sward, demonstrated that soil rhizobia were abundant in a soil with pH of 7.2. Symbiosis establishment and nodule development of white clover, red clover and alfalfa were related to root growth and development, which were enhanced by sward renovation.

**Impact:** Soil scientists, ecosystem modelers, and agricultural practitioners will be able to use this information to improve the utilization of introduced and naturally occurring rhizobacteria for improving nutrient use efficiency, controlling nutrient loss to the environment, and improving the sustainability of agriculture. This research has expanded scientific knowledge on chemical-biological interactions in the rhizosphere, indicating that acidic, low-nutrient soils of the

Appalachian Region require only minimal soil pH adjustment to enhance the survival and functioning of beneficial root-colonizing bacteria. This research has also re-oriented research from seeking a biological (symbiosis establishment inhibition) solution to the constraints on forage legume renovation of tall fescue swards to soil chemical/physical solutions.

**Documentation:**

Staley, T.E., and P.W. Voigt. 2000. Methodological considerations for elucidating low-level liming effects on white clover symbiosis establishment in an acidic soil model system. Soil Sci. 165:567-577.

Staley, T. E. 2002. Low-level liming affects early white clover nodulation but not root development in a small-volume acidic soil model system. Soil Sci. 167:211-221.

Staley, T.E. 2003. Initial white clover nodulation under saturation levels of rhizobia relative to low-level liming of an acidic soil. Soil Sci. 168:540-551.

Staley, T.E., and D. P. Belesky. 2004. Nodulation and root development of forage legumes sown into tall fescue swards. Grass Forage Sci. (in press).

Voigt, P.W., and T.E. Staley. 2004. Selection for aluminum and acid-soil resistance in white clover. Crop Sci. 44:38-48.

Brauer, D., and T.E. Staley. 2005. Early developmental responses of white clover root hairs to calcium, hydronium and aluminum in solution and soil culture. Crop Sci. (in press).

## Soil Biology Component

**Problem Area 14:** Soil biota could make agricultural production systems more sustainable by reducing nonrenewable inputs and negative environmental impacts, but this soil management approach has been largely ignored.

**Background:** Soil biota can have both positive and negative effects on production agriculture and the environment. Soil biota both provide and compete for plant nutrients. Soil organisms are both regulated by and regulate plant and organism activity around them. Plant growth can be enhanced or inhibited by compounds produced by the soil biota. When symbiotic and free-living bacteria fix nitrogen, mineralize nutrients stored in organic materials, and compete with organisms causing and thus inhibit crop diseases, the effects of the soil biological community is positive. Soil microorganisms are responsible for the degradation of pesticides and other chemicals that may have deleterious effects on the environment. The breakdown of roots and residue by organisms in the soil food web greatly influences soil organic matter, soil structure, and infiltration. Negative effects of soil biotic activity include plant disease, loss of soil organic matter, nutrient immobilization, pesticide and metal release, and competition with plants for soil oxygen. Much of the evidence of soil degradation has been manifested through changes in biotic communities and activities. Whether the effects of the soil biota are positive or negative depend upon environmental circumstances and management. Producers and other land managers cannot balance potential positive and negative impacts of their decisions on soil biota until the effects of individual components and their interactions within entire agricultural systems are understood.

The goals of this research were:

Determine short- and long-term effects of agricultural management practices on soil biological community populations, biodiversity, functioning, and resilience.

Improve understanding of soil biotic interactions with soil chemical and physical processes to (a) maximize efficient use of soil biota for crop growth, (b) minimize impact of management systems on the environment, and (c) produce abundant, economical, profitable, and high quality agricultural products.

Develop knowledge and techniques for sustainable soil and crop management that emphasize preservation, enhancement, and management of the soil biota for the benefit of soil structure, inherent soil fertility, environmental protection, and farm profitability.

**Accomplishments:**

**Conservation cropping systems increase soil biological potential:** The ability of soil to function effectively as a medium to decompose organic inputs, recycle nutrients, and create a stable soil structure is dependent upon biological attributes of soil. Understanding the dynamic nature of soil biological quality is essential to enhancing resource use efficiency. ARS scientists and collaborators demonstrated that soils under conservation cropping systems had greater soil microbial biomass, particulate organic matter, and mineralizable N than conventional systems (e.g., continuous cropping compared with crop-fallow systems, diverse crop rotations compared with monoculture, cover cropping compared with winter fallow, and no tillage or reduced tillage compared with inversion tillage). Microbial community structure was also expanded under conservation compared with conventional cropping systems in both Minnesota and Maine.

**Impact:** Soil scientists, plant pathologists, and agricultural practitioners will be able to use this information to design and implement management strategies that encourage more functional and robust soil microbial communities. This research has expanded scientific understanding of the dynamic nature of the soil biological community, both in the long-term and in during the growing season, and will aid further investigations into this complex soil community.

**Documentation:**

Carpenter-Boggs, L., P.D., Stahl, M.J. Lindstrom, and T.E. Schumacher. 2003. Soil microbial properties under permanent grass, conventional tillage, and no-till management in South Dakota. Soil Tillage Res. 71:15-23.

Larkin, R.P. 2003. Characterization of soil microbial communities under different potato cropping systems by microbial population dynamics, substrate utilization, and fatty acid profiles. Soil Biol. Biochem. 35:1451-1466.

Liebig, M.A., L. Carpenter-Boggs, J.M. Johnson, S.E. Wright, and N.W. Barbour. 2003. Soil biological characteristics of contrasting cropping systems in the Great Plains: Summary of preliminary findings. p. 210-214. *In* J.D. Hanson and J.M. Krupinsky (ed.) Proc. Dynamic Cropping Systems: Principles, Processes, and Challenges. 5-7 August 2003, Bismarck, ND.

Griffin, T.S., and G.A. Porter. 2004. Altering soil carbon and nitrogen stocks in intensively tilled two year rotations. Biol. Fertil. Soils 39:366-374.

**Carbon and nitrogen biochemistry of arbuscular mycorrhizal symbiosis:** High input farming practices, which includes excessive fertilizer and pesticide applications have depleted our soil of beneficial organisms such as arbuscular mycorrhizal [AM] fungi. Triacylglycerol was found to be the carbon currency of the fungus and is transported from the intraradical hyphae to the external mycelium and spores. Carbon, although transported from plant to plant, does not transfer from plant host to plant host. The AM fungus delivers nitrogen to its host plant roots in the form of the amino acid arginine. This movement is coupled to the up-regulation of the urea cycle genes. Labeling experiments showed that arginine is converted in the urea cycle by urease to ammonium that is transferred to the host. Replenishment of beneficial soil fungi, which aid roots in the uptake of nutrients and which impart disease resistance to plants, allows reduced use of chemicals and fertilizers, reduces soil erosion and limits global warming. In addition the scientific community has benefited from the new methods we have introduced for studying the symbiosis of AM fungi.

**Impact:** These findings add basic knowledge of the life cycle of mycorrhiza and the fate of carbon. The methodology has been adopted and aided several scientific studies. Numerous presentations now refer to and demonstrate the value of this methodology for the study of the AM symbiosis and the eventual realization of axenic culture.

**Documentation:**

Bago, B, Y. Shachar-Hill, P.E. Pfeffer. 2001. Could the urea cycle be translocating nitrogen in the arbuscular mycorrhizal symbiosis? New Phytologist 149:4-8.

Pfeffer P.E., B.Bago, and Y. Shachar-Hill. 2001. Exploring Mycorrhizal Function with NMR Spectroscopy New Phytologist. 150: 543-553.

Lammers, P. J., J. Jun, J. Abubaker, R. Arreola, A. Gopalan, B. Bago, C-H. Sebastia, J. W. Allen, D.D. Douds, P.E. Pfeffer, Y. Shachar-Hill. 2001. The glyoxylate cycle in an arbuscular mycorrhizal fungus. Carbon flux and gene expression. Plant Physiology. 127:1287-1298.

Comis, D. 2001. Soil fungi critical to organic success. Agricultural Research. pp 20-21. USDA. USGPO.

Jun, J., J. Abubaker, C. Rehrer, P.E. Pfeffer, Y. Shachar-Hill, P.J. Lammers. 2002. Expression in an arbuscular mycorrhizal fungus of genes involved in metabolism, transport, the cytoskeleton and the cell cycle. Plant and Soil. 244:141-148

Bago B., P.E. Pfeffer, J. Abubaker, J. Jun, J. W. Allen, J. Brouillette, D.D. Douds, P.J. Lammers, Y. Shachar-Hill. 2003. Carbon export from arbuscular mycorrhizal roots involves the translocation of glycogen as well as lipid. Plant Physiology. 131:1496-1507.

Pfeffer, P.E., D.D. Douds, Jr., D.P. Schwartz, M. Govindarajulu, H. Bücking, Y. Shachar-Hill. 2003. Exploring the Bidirectional Transfer of Carbon and Nitrogen Between Fungus and Host in the Arbuscular Mycorrhizal Symbiosis International Conference on Mycorrhizae August 10-13, 2003. Montreal, Canada. #778. p704.

Abubaker, J., M. Govindarajulu, P.E. Pfeffer, H. Bücking, P.J. Lammers, Y. Shachar-Hill. 2003. The Effects of Glucose on Carbon Metabolism in *Glomus Intraradices* during Arbuscular Mycorrhizal Symbiosis, International Conference on Mycorrhizae August 10-13, 2003 Montreal, Canada. #269. p304.

Abubaker J, J.W.B. Allen, B.Bago, H. Bücking, D.D. Douds, Jr., M. Govindarajulu, H. Jin, J. Jun, P.J. Lammers, P.E. Pfeffer, Y. Shachar-Hill. 2003. Nitrogen and Carbon metabolism and transfer in the AM symbiosis. International Conference on Mycorrhizae August 10-13, 2003. Montreal, Canada. #275. p310.

Pfeffer, P.E., D.D. Douds, Jr., H. Bücking, D.P. Schwartz, Y. Shachar-Hill. 2004. The fungus does not transfer carbon to or between roots in an arbuscular mycorrhizal symbiosis. New Phytologist. 163:617-627.

**Monoxenic and axenic cultural methods for mycorrhizal fungi:** Monoxenic and axenic (without a host plant) culture methods for arbuscular mycorrhizal fungi are needed to develop commercial cultures of beneficial fungi that contribute to soil resource use efficiency. For the axenic approach, the first three steps of the fungal life cycle have been completed by making use of a rapid and sensitive bioassay. Soluble chemical compounds (from host root exudates) that cause a rapid increase in hyphal branching of *Gigaspora gigantea* have been partially purified. Fungal hyphal branching and percent colonization of host roots was increased directly with blue light (430 nm) and near ultraviolet light (390 nm). Carbon dioxide, in the presence of semi-purified chemical signals, caused a particular type of branching pattern previously observed only in the presence of roots. A synergistic stimulation with blue light and chemical signals led to the conclusion that a second messenger is involved in the branching process. For the monoxenic approach, we have been able to complete the life cycle of *G. gigantea* with carrot roots in culture; but the process is slow and the yield of spores is poor. Our results have greatly increased the knowledge about the growth of AM fungi and have provided microbiologists with the tools to use a molecular biological approach to reveal the biochemical signals and pathways in this important symbiosis.

**Impact:** An *in vitro* culture technology has been developed and is now being used by mycorrhizal researchers in several countries to study root exudate components and steps in the life cycle of various AM fungi.

**Documentation:**


Douds Jr., D.D., and G. Nagahashi. 2000. Signaling and recognition events prior to the colonization of roots by arbuscular mycorrhizal fungi. p 11-18. In: Current Advances in Mycorrhizae Research. G. Podila and D.D. Douds, Jr., *eds. pub.* American Phytopathological Society, St. Paul, MN.

Nagahashi, G., and D.D. Douds, Jr. 2000. Partial separation of root exudate components and their effects upon the growth of germinated spores of AM fungi. Mycological Research. 104:1453-1464.

Nagahashi, G., D.D. Douds, Jr., and M. Buee. 2000. M. Light-induced hyphal branching of germinated AM fungal spores. Plant and Soil. 219:71-79.

Gadker, V., R. David-Schwartz, G. Nagahashi, D.D. Douds, Jr., S. Wininger, andY. Kapulnik. 2003. Root exudates of pmi tomato mutant M161 reduces AM fungal proliferation in vitro. FEMS Microbiology Letters. 223:193-198.

Nagahashi, G., and D.D. Douds, Jr. 2003. Action spectrum for the induction of hyphal branches of an arbuscular mycorrhizal fungus: exposure sites versus branching sites.Mycological Research. 107:1075-1082.

Nagahashi, G., and D. D. Douds, Jr. 2004. Synergism between blue light and root exudates compounds and evidence for a second messenger in the hyphal branching response of Gigaspora gigantea. Mycologia. 96:947-953.

Douds, Jr., D.D., G. Nagahashi, P. Pfeffer, W.M. Kayser, and C. Reider. 2004. On-farm production and utilization of arbuscular mycorrhizal fungus inoculum. Canadian Journal of Plant Science (Accepted 02/10/04).

Nagahashi, G., and D.D. Douds, Jr. 2004. Chapter 13. Environmental factors that affect hyphal branching and growth of AM fungi. In the series: Soil biology: Root-organ Culture of Mycorrhizal Fungi. A.K.Varma, *ed.* Springer Verlag, (Accepted 02/02/04).

Nagahashi, G., and D. D. Douds, Jr. 2004. Isolated root caps, border cells, and Mucilage from host roots stimulate hyphal branching of the arbuscular mycorrhizal fungus, Gigaspora gigantea. Mycological Research. 108:1-10.


**Improved management and utilization of arbuscular mycorrhizal fungi:** Arbuscular mycorrhizal fungi (AMF) are obligate symbionts that impart a variety of benefits to their host plants, including enhanced nutrient uptake, better water relations, and improved disease resistance. Soil aggregation is also improved in the presence of AMF. Large-scale inoculum production has not occurred due to the obligate symbiotic nature of these fungi. Therefore, it is important to identify agricultural practices that encourage long-term propagation of these fungi in soils. Collaborative research has identified several management techniques that promote AMF inoculum in soil, including no tillage, cover cropping, and reduction of fertilizer inputs. Winter cover cropping was found to be particularly beneficial, because of more immediate inoculum carryover, as well as fixing N (legume cover crops) or retaining soil N (grass cover crops), retarding erosion, and controlling weed pressures at a time when soils would otherwise lie bare. In addition, progress was made on inoculum production techniques: (a) modification of a split-plate culture method increased AMF spore production 3-fold compared with a conventional method and (b) on-farm production of AMF inoculum was enhanced using precolonized bahiagrass (*Paspalum notatum*) seedlings transplanted into raised-bed cultures, in which tens of million propagules of AMF could be cost-effectively produced per cubic foot of media. This inoculum increased potato tuber yield 45% over that of uninoculated controls. Agronomists, soil scientists, agricultural practitioners, and agricultural engineers will be able to use this information to design and develop more resource-efficient cropping systems to further reduce soil erosion, reduce fertilizer inputs, and increase soil quality.

**Impact:** This technology has been transferred to farmers in the region to better utilize available nutrients, to manage soil biota, and to develop more sustainable farming systems.

**Documentation:**


Douds, D.D., Jr., V. Gadkar, and A. Adholeya. 2000. Mass production of VAM fungus biofertilizer. p. 197-215. *In* K.G. Mukerji et al. (ed.) Mycorrhizal biology. Kluwer Academic/Plenum Publishers, New York.

Franke-Snyder, M., D.D. Douds, Jr., L. Galvez, J.G. Phillips, P. Wagoner, L.E. Drinkwater, and J.B. Morton. 2001. Diversity of communities of arbuscular mycorrhizal (AM) fungi present in conventional versus low-input agricultural sites in eastern Pennsylvania, USA. Appl. Soil Ecol. 16:35-48.

Galvez, L., D.D. Douds, L.E. Drinkwater, and P. Wagoner. 2001. Effect of tillage and farming system upon VAM fungus populations and mycorrhizas and nutrient uptake of maize. Plant Soil 228:299-308.

Galvez, L., D.D. Douds, Jr., and P. Wagoner. 2001. Tillage and farming system affect AM fungus populations, mycorrhiza formation, and nutrient utilization of winter wheat in a high P soil. Am. J. Altern. Agric. 16:152-160.

Douds, D.D. 2002. Increased spore production by Glomus intraradices in the split-plate monoxenic culture system by repeated harvest, gel replacement, and resupply of glucose to the mycorrhiza. Mycorrhiza 12:163-167.

Douds, D.D., and C. Reider. 2003. Inoculation with mycorrhizal fungi increases the yield of green peppers in a high P soil. Biol. Agric. Hortic. 21:91-102.

Douds, D.D., and N.C. Johnson. 2003. Contributions of arbuscular mycorrhizas to soil biological fertility. p. 129-162. *In* L.K. Abbott and D. Murphy (ed.) Soil biological fertility, Kluwer Academic Press.

"Cultivating diversity underground for better yields above", http://www.newfarm.org/depts/NFfield_trials/0903/daviddouds, posted by NewFarm.org.

Douds, D.D., G. Nagahashi, P.E. Pfeffer, W.M. Kayser, and C. Reider. 2004. On-farm production and utilization of arbuscular mycorrhizal fungus inoculum. Can. J. Plant Sci. (in press).

"Cultivating beneficial fungi to increase yields",

http://www.newfarm.org/depts/NFfield_trials/0404/mf_update, posted by NewFarm.org.
"Improve your soil, increase your yields, and reduce your expenses with AM fungi", http://www.newfarm.org/depts/NFfield_trials/0604/factsheet, posted by NewFarm.org.

**Protease inhibitor has potential to manage soil nitrogen mineralization:** Farmers have been able to manage the timing of fertilizer and manure application, the largest inputs of N to their crops, but have not been able to manage N supply from soil organic matter. Collaborative research demonstrated that a protease inhibitor can delay soil N mineralization. More complete synchronization of N availability with N demand by crops could be developed with this approach. Protease inhibitors have been used in HIV-AIDS treatment and to protect plants from insect attack, but this finding could now provide farmers and crop consultants with a new tool to help prevent N loss from soil.

**Impact:** More research is needed to develop this tool, but high potential exists to regulate organic N mineralization in the field. Although cost of the protease inhibitor is high, research indicates that plants with high protease inhibitor activity could be used to deploy similar inhibition under field conditions. With more efficient utilization of organic N, input cost of agricultural production could be reduced and environmental consequences of N lost from soil could be greatly minimized.

**Documentation:**
Kumar, K., C.J. Rosen, and M.P. Russelle. 2003. A novel approach to regulate soil nitrogen mineralization. Paper No. S03-kumar285158. *In* Agron. Abstr. CD-ROM, ASA-CSSA-SSSA, Madison, WI.
Kumar, K., C.J. Rosen, and M.P. Russelle. 2003. A novel approach to regulate nitrogen mineralisation in soil. *In* 12th N Workshop: Controlling the Flows and Losses. 21-24 September 2003, Exeter, UK.

**Cattle grazing systems enhance the biological activity of surface soil:** The effect of forage management strategies on soil microbial biomass and activity is of importance to the understanding of greenhouse gas emissions, agronomic productivity, and changes in soil quality. ARS scientists and cooperators demonstrated that soil microbial biomass and potential activity increased with time following conversion of degraded cropland to pastures managed with different approaches. Whether fertilization was from organic or inorganic sources had no effect on soil microbial biomass and activity. Cattle grazing systems resulted in twice the accumulation of soil microbial biomass than did unharvested grass or grass that was harvested for hay. Soil scientists, forage agronomists, and agricultural practitioners could use this information to design sustainable agricultural systems with high productivity and efficient nutrient cycling.

**Impact:** This research has advanced scientific understanding of the role of soil biological activity in grass management systems. Cattle grazing systems have the potential to enhance the biological activity of soil, resulting in better plant productivity, soil quality, and environmental management.

**Documentation:**

Kisselle, K.W., A.J. Franzluebbers, M. Molina, R.A. Burke, and J.A. Stuedemann. 2001. Effects of nutrient inputs and forage utilization (cattle grazing) on soil microbial community. p. 44. *In* Proc. Soil Ecol. Soc., 20-23 May 2001, Pine Mountain, GA.
Franzluebbers, A.J., and J.A. Stuedemann, 2003. Bermudagrass management in the Southern Piedmont USA. III. Particulate and biologically active soil carbon. Soil Sci. Soc. Am. J. 67:132-138.

**Managing earthworms to improve water quality:** Earthworms are abundant soil organisms in many agricultural fields. By burrowing in soil and ingesting crop residues, they can have profound effects on soil aggregation, soil porosity, availability of plant nutrients, and fate and transport of agrochemicals and other potential contaminants. Soil disturbance with tillage, however, often reduces earthworm populations, especially deep burrowing species that rely on surface crop residue for food. Collaborative research has demonstrated that deep burrows can act as preferential flow paths, which under some soil, tillage, and rainfall conditions, reduce surface runoff, thereby decreasing loss of soil and agricultural chemicals in overland flow. Although enhanced infiltration is normally desirable, in rare instances it can result in increased chemical movement through the soil or inappropriate distribution of irrigation water and liquid wastes. Earthworm burrows in the vicinity of subsurface drains in particular, can promote rapid offsite movement of injected liquid animal waste. In affected fields, farmers might be able to use precision farming technology to till only the soil above the tile or to avoid waste application in the immediate vicinity of tile. Alternatively, blocking tiles when animal waste is to be injected, might allow nutrients to be adsorbed into the surrounding soil. Soil scientists, ecosystem modelers, environmental regulators, and agricultural practitioners will be able to use this information to improve the beneficial effect of earthworms on soil structure and reduce the undesirable consequences of nutrients and contaminants that preferentially flow through soil and into tile drains or ground water.

**Impact:** Results of the research have been used by a multi-agency working group to predict environmental consequences of land application of liquid manure. The research resulted in revisions to the NRCS Field Office Technical Guide. Reducing preferential flow of nutrients and contaminants will improve yield and reduce input costs for farmers and preserve environmental quality for society.

**Documentation:**

Shipitalo, M.J., and F. Gibbs. 2000. Potential of earthworm burrows to transmit injected animal wastes to tile drains. Soil Sci. Soc. Am. J. 64:2103-2109.
Shipitalo, M.J. 2002. Structure and earthworms. p. 1255-1258. *In* R. Lal (ed.) Encyclopedia of soil science, Marcel Dekker, New York.
Shuster, W.D., M.J. Shipitalo, P.J. Bohlen, S. Subler, and C.A. Edwards. 2003. Population dynamics of ambient and altered earthworm communities in row-crop agroecosystems in the Midwestern U.S. Pedobiologia 47:825-829.
Shuster, W.D., M.J. Shipitalo, S. Subler, S. Aref, and E.L. McCoy. 2003. Earthworm additions affect leachate production and nitrogen losses in typical Midwestern agroecosystems. J. Environ. Qual. 32:2132-2139.
Shipitalo, M.J., and R.-C. Le Bayon. 2004. Quantifying the effects of earthworms on soil

aggregation and porosity. p. 183-200. *In* C.A. Edwards (ed.) Earthworm ecology, 2nd ed. CRC Press, Boca Raton, FL.

Shipitalo, M.J., V. Nuutinen, and K.R. Butt. 2004. Interaction of earthworm burrows and cracks in a clayey, subsurface-drained, soil. Appl. Soil Ecol. 26:209-217.

# Soil Biology Component

**Problem Area 15:** Research is needed to develop management practices to use soil biota to control plant diseases, pests and weeds.

**Background:** Ecologically-oriented pest management within viable, integrated systems is gaining popularity as pesticide use and tillage for pest control are less favored. Biological means of pest management need to be explored to develop additional successful pest management options. The soil biota can influence the growth of not only other soil organisms but also larger life forms such as insects, and plants (both crop and weed). These effects may be either positive or negative, and thus should be considered in pest management strategies. The rate and extent of buildup or maintenance of pathogens or pests depend on many environmental and cultural factors, including residue, organic matter and cover crop issues, plant stress, improper irrigation management, poor fertilization practices, crop genetics, and insufficient pesticide use. In some cases, deterioration of agricultural soils stems from changes in soil biotic communities, reducing their capacity to suppress root pathogens and pests by biological means. The nature of the pest, whether bacterial, fungal, viral, nematodal, insect, or weed, indicates the kind of management strategies needed to restrict or eliminate its activities. The strategies available to farmers are cultural, chemical, and biological; however, not all strategies are feasible for every cropping system. Further study will be required to determine the ecological and biological effects of the resident soil organism population or introduced antagonist on pest growth before effective pest management strategies can be developed.

The goals of this research were:

Develop management strategies to reduce negative impacts of diseases, pests, and weeds by introducing antagonists or by managing resident biota to increase their activity.

**Accomplishments:**

**Weed-suppressive soils characterized:** Weeds are a nuisance and, oftentimes, an economic drain on the productivity of agriculture. However, herbicide application to control weeds can be costly and can possibly lead to unintended impacts on the environment. Cropping systems with low pesticide use are needed to increase the sustainability of agriculture. ARS scientists and their collaborators demonstrated that biological indicators of soil quality can be used to identify weed-suppressive soils. Weed-suppressive bacteria increased in soils with high organic matter concentration, high potential biological activity, and little or no pesticide use. Weed-suppressive bacteria decreased growth and vigor of weed seedlings. Weed scientists, agronomists, soil scientists, and agricultural practitioners will be able to use this information to identify weed-suppressive soils, design and implement management strategies to encourage weed suppression, and integrate this approach into a systems analysis for resource-efficient farming.

**Impact:** This research has increased scientific understanding of weed suppression and biological soil quality. When incorporated with other compatible components of conservation farming, agricultural producers will be able to effectively reduce use of herbicides without loss of profit.

**Documentation:**

Kremer, R.J. 2000. Growth suppression of annual weeds by deleterious rhizobacteria integrated with cover crops. p. 931-940. *In* N.R. Spencer (ed.) Proc. Xth Int. Symp. Biol. Control Weeds, 4-14 July 1999, Montana St. Univ., Bozeman, MT.

Li, J., and R.J. Kremer. 2000. Rhizobacteria associated with weed seedlings in different cropping systems. Weed Sci. 48:734-741.

Kremer, R.J., and T. Souissi. 2001. Cyanide production by rhizobacteria and potential for suppression of weed seedling growth. Curr. Microbiol. 43:182-186.

Kremer, R.J. 2002. Bioherbicides - Potential successful strategies for weed control. p. 307-323. *In* O. Koul and G. Dhaliwal (ed.) Microbial biopesticides. Taylor and Francis, London.

Li, J., R.J. Kremer, and L.M. Ross, Jr. 2002. Electron microscopy of root colonization of Setaria viridis by deleterious rhizobacteria as affected by soil properties. Symbiosis 32:1-14.

**Crop sequence influences disease incidence in wheat and barley:** Plant diseases are costly to crop production systems, whether left unchecked resulting in yield loss or chemically treated resulting in higher production cost. Therefore, minimizing the occurrence of plant diseases is of utmost importance for optimizing the economics and environmental consequences of crop production. ARS scientists and their cooperators demonstrated that crop sequence had a major impact on the incidence of disease in spring wheat and barley. With spring wheat and barley the risk for leaf spot diseases was lower following specific crops in the Northern Great Plains. The occurrence of Sclerotinia stem rot (white mold) on canola, crambe, safflower, and sunflower was influenced by crop sequence treatments. Crop diversification improved management of plant diseases by manipulating host factors such as crop and cultivar selection, interrupting the concurrent host-disease life cycles, and eliminating volunteer crop plants. In post-CRP fields, the severity of leaf spot diseases on winter wheat was decreased with N fertilizer application. Agronomists, plant pathologists, soil scientists, and agricultural practitioners will be able to use this information to design and implement cropping systems that minimize the impact of diseases on crop production in the Great Plains and beyond.

**Impact:** This research information is being transferred to agricultural producers to reduce the negative economic consequences of plant disease in cropping systems of the Great Plains. Rotation of crops will change the social and economic aspects of crop production strategies. Adoption of this information could improve the sustainability of agriculture in the region by greatly reducing disease inoculum.

**Documentation:**

Krupinsky, J.M., and D.L. Tanaka. 2001. Leaf spot diseases on winter wheat influenced by nitrogen, tillage and haying after a grass/alfalfa mixture in the conservation reserve program. Plant Dis. 85:785-789.

Gulya, T.J., J.M. Krupinsky, M. Draper, and L.D. Charlet. 2002. First report of charcoal rot (Macrophomina phaseolina) on sunflower in North and South Dakota. Plant Dis. 86:923.

Krupinsky, J.M., K.L. Bailey, M.P. McMullen, B.D. Gossen, and T.K. Turkington. 2002. Managing plant disease risk in diversified cropping systems. Agron. J. 94:198-209.

Krupinsky, J.M., D.L. Tanaka, S.D. Merrill, M.A. Liebig, J.R. Hendrickson, R.L. Anderson, R.E.

Ries, and J.D. Hanson. 2002. Crop sequences influence crop seed production and plant diseases. p. 13-19. *In* Proc. 24th Ann. Manitoba-North Dakota Zero Tillage Farmers Assoc. Workshop, Minot, ND.
Turkington, T.K., M. Hartman, J.M. Krupinsky, H.R. Kutcher, M.P. McMullen, J.P. Tewari, and K. Xi. 2003. Plant disease management and diversity. p. 37-59. *In* J.D. Hanson and J.M. Krupinsky (ed.) Proc. Dynamic Cropping Systems: Principles, Processes, and Challenges, Bismarck, ND.
Krupinsky, J.M., D.L. Tanaka, M.T. Lares, and S.D. Merrill. 2004. Leaf spot diseases of barley and spring wheat as influenced by preceding crops. Agron. J. 96: 259-266.

**Soil-borne fungi that infect and decay wild oat seeds were identified:** Wild oat is a widespread and highly competitive weed in the Pacific Northwest. Non-chemical management options are needed to help control this invasive weed in wheat cropping systems. The diverse microbial community structure of surface soils under no tillage could potentially offer greater opportunities for biological attack of weed seeds. Led by an ARS scientist in Pullman WA, collaborative research demonstrated that although wild oat seed reduction directly due to decay was relatively low, it can be significant. The proportion of weed seed loss was generally similar under no tillage and minimum tillage. Soil fumigation drastically altered overall soil microbial community structure, as well as in the spermosphere, probably due to changes in seed exudates. Soil-borne fungi were identified that infect and decay wild oat seeds. These fungi could contribute to depletion of the weed seed bank through seed infection leading to loss of germination and vigor. Soil biologists, weed scientists, agricultural engineers, and agricultural practitioners will be able to use this information to design and implement cropping systems that rely less on chemical control strategies and more on biological control mechanisms to increase the sustainability of agriculture in the Pacific Northwest and beyond.

**Impact:** This research has increased scientific understanding of how crop and residue management strategies alter soil microbial communities, weed infestation, and weed seed bank. This research will enable scientists to create conditions necessary for weed-suppressive soils.

**Documentation:**
Kennedy, A.C., B.N. Johnson, and T.L. Stubbs. 2001. Host range of a deleterious rhizobacterium for biological control of down brome. Weed Sci. 49:792-797.
Gallandt, E.R., E.P. Fuerst, and A.C. Kennedy. 2004. Effect of tillage, fungicide seed treatment, and soil fumigation on seed bank dynamics of wild oat (*Avena fatua*). Weed Sci. 52:597-604.
de Luna, L., T.L. Stubbs, A.C. Kennedy, and R. Kremer. 2004. Deleterious rhizobacteria. (in press). *In* The Rhizosphere, ASA Monogr., ASA-CSSA-SSSA, Madison, WI.

**Cover crops effective at controlling weeds:** Controlling weed seed bank and weeding costs are important considerations for agricultural producers, especially those of high-value vegetable crops. Although organic production systems do not consider herbicide control measures, even conventional production systems have economic and environmental reasons to limit herbicide application. Cover crops may be a viable management option to suppress weed proliferation. ARS scientists demonstrated the effectiveness of particular cover crops in suppressing weeds in potato and organic vegetable production systems. In Washington, isothiocyanate from Brassica cover crops inhibited weed seed germination and growth. Herbicide inputs could be reduced in a subsequent potato crop following mustard, sorghum-sudangrass, winter wheat, and oat/vetch cover crops while maintaining weed control and potato yield. In California, above-ground biomass production of cover crops was similar, but weed suppression was best with mustard and rye, intermediate with oat, and poor with legume/cereal mixtures. Weed suppression was related to early season canopy development, light interception, seeding rate, and crop variety. Agronomists, soil and weed scientists, and agricultural practitioners will be able to use this information to design and implement more sustainable production systems that reduce input costs of production, reduce negative impacts of production on the environment, and improve soil quality.

**Impact:** This research has increased the scientific understanding of weed suppression by cover crops in different ecosystems. Results are being transferred to farmers through field days and extension briefs. In California, results challenge the weed suppressive capabilities of the typical approach by organic producers who use legume/cereal mixes to trap nitrate and add biologically fixed nitrogen to the soil. In the Pacific Northwest, fall-planted mustard cover crops have increased to >23,000 acres in 2003.

**Documentation:**

Boydston, R.A., and S.F. Vaughn. 2002. Alternative weed management systems control weeds in potato (Solanum tuberosum). Weed Technol. 16:23-28.

Brennan, E.B., and R. Smith. 2003. Cover crop cultivar and planting density impacts on cover crop productivity, and weed biomass and seed production in an organic system in the Central Coast of California. p. 80-88. *In* Proc. California Chap. Am. Soc. Agron., California Plant and Soil Conf., Modesto, CA.

Boyd, N.S., and E.B. Brennan. 2004. Rotary hoe effects on growth and weed control in a winter cover crop mixture of legumes and rye. p. 116-119. *In* Proc. California Conf. Biol. Control IV, Berkeley, CA.

Boydston, R.A. 2004. Take cover from the elements. Brassica cover crops can control weeds and reduce the use of crop protectants in vegetable rotations. p. 18-19. *In* Am. Veg. Grower, March 2004.

Boydston, R.A., K. Al-Khatib, S.F. Vaughn, H.P. Collins, and A.K. Alva. 2004. Weed suppression using cover crops and seed meals. p. 16. *In* First Int. Symp. Biofumigation: A Possible Alternative to Methyl Bromide. Bologna, Italy.

Boydston, R., H. Collins, A. Alva, P. Hamm, and E. Riga. 2004. Fall planted cover crop trial in four year crop rotation. p. 19. *In* Ecol. Organic Farm Manage. Workshop Proc., Wilsonville, OR.

Brennan, E.B., and N.S. Boyd. 2004. Cover crop variety and seeding rate effects on winter weed dynamics in a central coast organic vegetable system. p. 27-33. *In* Proc. California Conf. Biol. Control IV, Berkeley, CA.

## Soil Biology Component

**Problem Area 16:** A greater understanding is needed of the role of soil biota in the degradation/detoxification of pesticides and other xenobiotics to enhance this process.

**Background:** Abatement of contaminated air, water, and soil depends upon soil biota and their biological, chemical, and physical processes that interact to transform, detoxify and store pesticides, xenobiotics (compounds foreign to biological systems), and natural toxins. Modern agriculture relies on synthetic agrichemicals to maintain productivity. Difficulties in their management often have caused them to become sources of nonpoint pollution of ground and surface water. Likewise, industrial activities have continued to introduce numerous xenobiotics into the biosphere. Natural products, e.g., biotic and plant-produced chemicals, and approaches that utilize natural antagonistic interactions are being developed to replace synthetic herbicides, insecticides, and other pesticides. As these technologies are developed, there is also a need for critical assessment of the fate and effectiveness of these agents and compounds in the environment and the effects on soil processes. The metabolism and processes controlling pesticide, natural product and xenobiotic fate and persistence need to be addressed to minimize effects on nontarget environments and organisms and to determine their effects on agricultural sustainability.

A natural synergy exists between soil microorganisms and plants for contaminant detoxification. Plant roots indirectly stimulate microbial degradation of contaminants in the rhizosphere, and this can be exploited. The intrinsic ability of certain plants for uptake, translocation, transformation, and detoxification of xenobiotics also offers a newly recognized resource in the management of xenobiotics. Thus, the concept of phytoremediation, the use of plants for abatement and containment of pollution, is developing as an acceptable management technique. This concept is also being applied in other environments, such as riparian zones and filter strips. Although understanding of biotic and plant transformations of xenobiotics in soil has advanced in recent years, knowledge of the specific pathways for degradation/detoxification and of the role of specific organisms and communities is limited. This knowledge is essential for understanding the ability of soil to maintain a biological buffering barrier for pollution and in the design of systems to decontaminate soil and water.

The goals of this research were:

Develop knowledge and techniques to minimize impacts of agrochemicals and other xenobiotics in the environment.

Develop approaches to promote degradation of xenobiotics in soils.

Develop improved methods and decision-making tools for soils requiring remediation to improve soil productivity, protect human health, and prevent environmental degradation.

**Accomplishments:**

**Herbicides lost from adjacent cropland can be abated with vegetative buffer strips, riparian zones, and wetlands:** Herbicide may be lost from agricultural fields to adjacent non-target areas. Vegetative buffer strips, riparian zones, and adjacent wetlands are typical receptors of water runoff from agricultural fields and deposition zones for soil erosion and various agricultural pollutants. Little is known of the fate of herbicides once they reach these filtering zones. ARS scientists and their collaborators demonstrated that soils under vegetative buffer strips and riparian zones contained higher bacterial and fungal populations, greater enzymatic activity, more diverse soil microbial communities, and higher soil organic matter concentration than adjacent cropland. These enriched soil biological characteristics were important regulators for more rapid dissipation of the herbicides, metolachlor and fluometuron. In a constructed wetland, fluometuron degraded rapidly (<1-month half-life) when the soil was saturated, but degraded slowly when the soil was flooded. Atrazine degraded rapidly under both saturated and flooded conditions. Soil microbial community structure 2 years after wetland construction was similar to a natural wetland. Soil and weed scientists, agronomists, ecologists, agricultural engineers, environmental regulatory specialists, and agricultural practitioners will be able to use this information to design and implement edge-of-field soil erosion and runoff retention systems to reduce the offsite impacts from runoff of agricultural pollutants.

**Impact:** This research has advanced scientific understanding of herbicide fate from agricultural fields. State and federal environmental regulatory agencies will be able to improve abatement and mitigation strategies for environmentally sensitive agricultural ecosystems.

**Documentation:**

Zablotowicz, R.M., M.A. Locke, W.J. Staddon, M. Shankle, D.W. Shaw, and W.R. Kingery. 2001.Microbiological characteristics of a Mississippi Delta forested riparian zone. p. 219-222. *In* R.A. Rebich and S.S. Knight (ed.) Mississippi Delta management systems evaluation project, 1995-2000, Mississippi Agric. For. Exp. Stat. Inf. Bull. 377.

Staddon, W.J., M.A. Locke, and R.M. Zablotowicz. 2001. Microbiological characteristics of a vegetative filter strip soil and degradation and sorption of metolachlor. Soil Sci. Soc. Am. J. 65:1136-1142.

Locke, M.A., R.M. Zablotowicz, and L.A. Gaston. 2002. Environmental fate of fluometuron in a Mississippi Delta watershed. p. 206-225. *In* C. Barefoot et al. (ed.) Terrestrial field dissipation studies: Purpose, design and interpretation. Amer. Chem. Soc. Symp. Ser. 842.

Shankle, M.W., D.R. Shaw, W.L. Kingery, and M.A. Locke. 2004. Fluometuron adsorption to soil influenced by best management practices: Established filter strip and riparian zones. p. 164-178. *In* M.T. Nett et al. (ed.) Application of a regional water quality effort to meet national priorities - The Mississippi Delta Management Systems Evaluation Area (MDMSEA), Amer. Chem. Soc. Symp. Ser. 877.

Weaver, M.A., R.M. Zablotowicz, and M.A. Locke. 2005. Laboratory assessment of atrazine and

fluometuron degradation in soils from a constructed wetland. Chemosphere (in press).

**Fate of herbicides affected by surfactants and prior exposure:** Herbicides applied to crops and soil need to be effective in controlling weeds, but should have limited persistence to minimize the potential for non-target effects. ARS scientists and collaborators demonstrated the effects of various management practices on herbicide degradation in soil. Degradation of 2,4-D was initially more rapid with conventional tillage, but was more completely mineralized with subsoil tillage, suggesting that tillage-induced changes in soil microbial activity and physical properties could affect decomposition of herbicides. Surfactants to aid delivery of herbicides improved water solubility of herbicides in soil. Atrazine and cyanazine desorbed from soil to a greater extent with surfactant than without, suggesting that surfactants could enhance herbicide bioavailability for dissipation in soil. Cyanazine dissipation in soil was correlated with clay content and soil acidity, but was not affected by soil organic matter and potential microbial activity. This research demonstrated that factors controlling herbicide dissipation in soil are dependent upon application mixture, landscape position and certain soil characteristics. Atrazine degraded rapidly and completely to carbon dioxide in soils of the Mississippi Delta receiving as little as one to two previous applications of atrazine, which contrasted with slower degradation in soils that never received atrazine. Under conditions in Mississippi, soil microbial communities capable of accelerated atrazine degradation developed more rapidly than observed in other regions of the USA. Weed and soil scientists, ecosystem modelers, and agricultural practitioners will be able to use this information to formulate effective herbicide management strategies to mitigate the environmental effects of herbicides in aquatic and terrestrial ecosystems.

**Impact:** This research has advanced scientific understanding of herbicide degradation in soil. Input costs to obtain effective weed control could be affected by management strategy, which affects herbicide persistence.

**Documentation:**

Seifert, S., D.R. Shaw, R.M. Zablotowicz, R.A. Wesley, and W.L. Kingery. 2001. Effects of tillage on soil microbiological characteristics and herbicide degradation in a Sharkey clay soil. Weed Sci. 49:685-693.

Locke, M.A., K.N. Reddy, L.A. Gaston, and R.M. Zablotowicz. 2002. Adjuvant modification of herbicide interactions in aqueous soil suspensions. Soil Sci. 167:444-452.

Staddon, W.J., M.A. Locke, and R.M. Zablotowicz. 2004. Spatial variability of cyanazine variability from a conservation managed field. p. 179-193. *In* M.T. Nett et al. (ed.) Application of a regional water quality effort to meet national priorities - The Mississippi Delta Management Systems Evaluation Area (MDMSEA), Amer. Chem. Soc. Symp. Ser. 877.

Locke, M.A., R.M. Zablotowicz, and M.A. Weaver. 2005. Herbicide fate under conservation tillage, cover crop and edge-of-field management practices. (in press). *In* H.P. Singh et al. (ed.) Handbook of sustainable weed control, Haworth Press.

**Pesticides react with clay minerals and water chemistry to affect environmental fate:** Pesticides are an effective component of agriculture in the USA, but when transported away from intended locations, can have serious environmental consequences. Knowledge of reactions of pesticides with soils and sediments under various conditions is necessary to avoid environmental impacts. ARS scientists and cooperators demonstrated that soil clay minerals vary in their ability to adsorb pesticides and other organic molecules due to the nature of the organic molecule, surface properties of clay, type of saturating cation on clay, ionic strength of solution, and extent of clay swelling. Non-ionic surfactants found in pesticide formulations can inhibit sorption of pesticides by competing for the same sorption sites. Sorption of chlorpyrifos on clay and river sediment inhibited hydrolysis of chlorpyrifos. Sorption of chlorpyrifos on suspended humic colloids in water was toxic to fish. Hypochlorous acid, present in chlorinated tap water, reacted with chlorpyrifos to form chlorpyrifos-oxon, the bioactive form of chlorpyrifos, which is 1000 times more toxic than the parent compound. Soil scientists, biologists, environmental toxicologists, and environmental regulatory agencies will be able to use this information to (a) improve predictions of environmental fate of pesticides and (b) better assess regulations on pesticide usage.

**Impact:** This research has advanced fundamental scientific understanding of the mechanisms that control the fate of pesticides in soil environments. Pesticide regulations to increase environmental safety will result.

**Documentation:**

Hundal, L.S., M.L. Thompson, D.A. Laird, and A.M. Carmo. 2001. Sorption of phenanthrene by reference smectites. Env. Sci. Technol. 35:3456-3461.

Wu, J., and D.A. Laird. 2002. Hydrolysis of chlorpyrifos in aqueous and colloidal systems. Isr. J. Chem. 42:99-107.

Phillips, T.A., R.C. Summerfelt, J. Wu, and D.A. Laird. 2003. Toxicity of chlorpyrifos adsorbed on humic colloids to larval walleye (Stizostedion vitreum). Arch. Environ. Contam. Toxicol. 45:258-263.

Wu, J., and D.A. Laird. 2003. Abiotic transformation of chlorpyrifos to chlorpyrifos oxon in chlorinated water. Env. Tox. Chem. 22:261-264.

Chappell, M.A. 2004. Confounding factors and tertiary-phase control by a surfactive agent on smectite sorption of atrazine. Ph.D. diss. Iowa State Univ., Ames.

Li, H., B.J. Teppen, D.A. Laird, C.T. Johnston, and S.A. Boyd. 2004. Geochemical modulation of pesticide sorptin by smectite clay from aqueous solution. Environ. Sci. Technol. (in press).

Wu, J., and D.A. Laird. 2004. Interactions of chlorpyrifos with colloidal materials in aqueous systems. J. Environ. Qual. 33:1765-1770.

**Management limits transport of the herbicide, metolachlor:** Transport of herbicides from the site of application to ground water or surface water bodies is a serious environmental concern, because of the unintended detrimental effects on plants and herbivores that utilize this water. Scientists from Morris, Minnesota found that the acetamide herbicide, metolachlor, was transported <2 inches from the point of soil application during the winter. Lack of movement may have occurred due to ice formation that trapped metolachlor near the soil surface. Autumn application of this and similar herbicides should have minimal impact on the environment and have greatest effectiveness on targeted weeds. Abating soil erosion best controlled the transport of metolachlor from the point of application. Soil scientists, agronomists, environmental toxicologists, herbicide manufacturers, and agricultural practitioners will be able to use this information to effectively utilize herbicides without contamination of receiving water bodies. This research has increased the scientific understanding of herbicide transport in cropland.

**Impact:** Information can be transferred to crop producers, herbicide manufacturers, and environmental regulatory agencies for assessing the fate of metolachlor in cropland.

**Documentation:**

Sharratt, B.S., K. Sander, and D. Tierney. 2002. Fate of metolachlor during winter in the northern U.S. Corn Belt. *In* Agron. Abstr., CD-ROM, Am. Soc. Agron., Madison, WI.

Sharratt, B.S., K. Sander, and D. Tierney. 2003. Fate of autumn-applied metolachlor in a clay loam in the northern U.S. Corn Belt. J. Environ. Sci. Health (Part B) 38:37-48.

**Herbicides degraded in aquatic and anoxic environments:** Environmental health is threatened from the transport of herbicides to aquatic environments. Understanding the behavior of herbicides in aquatic environments will aid mitigation efforts to improve environmental quality. Earlier work implicated a role for reduced iron (microbially mediated) in the rapid deactivation of trifluralin and other dinitroaniline herbicides in wet soils and sediments. The presence of nitrate inhibited this degradation. ARS scientists from and cooperators demonstrated that reduced forms of soil minerals facilitated not only herbicide degradation, but also sorption processes. The herbicide, dimethenamid, was rapidly degraded (14-day half life) under anaerobic conditions, regardless of whether conditions were predominantly denitrifying, iron-reducing, or sulfate-reducing. Interactions of atrazine with the aquatic plant, hornwort, indicated that epiphytic organisms on the plant surface were responsible for some degradation of the herbicide. Soil scientists, environmental toxicologists, and environmental regulatory agencies will be able to use this information to (a) improve predictions of herbicide fate in anoxic and aquatic environments and (b) design and implement mitigation strategies to enhance herbicide degradation in aquatic environments.

**Impact:** This research has advanced the scientific understanding of herbicide fate in aquatic environments. Research with hornwort will be further explored to develop an alternative bioremediation approach to pesticide contamination of waterways.

**Documentation:**

Rupassara, S.I., R.A. Larson, and G.K. Sims. 2001. Biodegradation of atrazine in aquatic ecosystems. p. 181-188. *In* A. Leesonet al. (ed.) Phytoremediation, wetlands, and sediments, Proc. Sixth Int. In-Situ and On-Site Bioremed. Symp., Batelle Press, Columbus, OH.

Crawford, J.J., G.K. Sims, F.W. Simmons, L.M. Wax, and D.L. Freedman. 2002. Dissipation of the herbicide (14C) dimethenamid under anaerobic aquatic conditions in flooded soil microcosms. J. Agric. Food. Chem. 50:1483-1491.

Rupassara, S.I., R.A. Larson, G.K. Sims, and K.A. Marley. 2002. Degradation of atrazine by hornwort in aquatic systems. Bioremed. J. 6:217-224.

**Soil conditions control degradation of herbicides:** Herbicides are exposed to an enormous variety of conditions in soils across the USA and globally. Fundamental knowledge of how soil conditions affect herbicide degradation will aid the development of management strategies to mitigate any adverse effects of herbicides in the environment. ARS scientists and cooperators are unraveling the fate of a variety of herbicides under different physicochemical (temperature, nutritional status, pH) conditions in soil. A method was developed to quantitatively recover herbicide C and N incorporated into microbial proteins. Proteolytic activity of soil microorganisms was used to determine the effect of starvation on utilization of herbicide C and N. The labile herbicide, isoxaflutole, remained inactive due to sorption to soil under dry conditions, but the relatively stable decomposition product, diketonitrile, which is herbicidally active, was formed upon soil wetting. These transformations in soil helped explain the observation of reactivation of herbicide upon wetting of soil following dry periods. Prosulfuron can cause sporadic carryover injuries to plants due to soil moisture and pH differences. Uptake of herbicides by soil microorganisms was affected by ionization status, which is controlled by soil pH. Persistence and mobility of herbicides in the environment can be affected by soil pH. Soil scientists, environmental toxicologists, and herbicide manufacturers will be able to use this information to (a) predict the environmental behavior of herbicides and (b) reduce the threat of environmental damage caused by persistence of herbicides in soil.

**Impact:** This research has improved the scientific understanding of herbicide degradation in soil. Application of these findings can be used to help reduce negative environmental impacts of herbicides.

**Documentation:**


Sims, G.K., R.P. Hultgren, A.M. Cupples, and R.J. Hudson. 2001. Role of ionization in bacterial uptake and soil sorption of agrochemicals. p. 268-270. *In* Proc. 3rd Int. Conf. Groundwater Qual., Sheffield, UK.

Xu, J.C., J.W. Stucki, J. Wu, J.E. Kostka, and G.K. Sims. 2001. Fate of atrazine and alachlor in redox-treated ferruginous smectite. Environ. Toxicol. Chem. 20:2717-2724.

Hultgren, R.P., R.J.M. Hudson, and G.K. Sims. 2002. Effects of soil pH and soil water content on prosulfuron dissipation. J. Agric. Food Chem. 50: 3236-3243.

Sims, G.K., and M.M. Wander. 2002. Proteolytic activity under nitrogen or sulfur limitation. Appl. Soil Ecol. 19:217-221.

Taylor-Lovell, S., G.K. Sims, and L.M. Wax. 2002. Effect of moisture, temperature, and biological activity on the degradation of isoxaflutole in soil. J. Agric. Food Chem. 50: 5626-5633.

Marsh, K.L., R.L. Mulvaney and G.K. Sims. 2003. A technique to recover tracer as carboxyl-carbon and alpha-nitrogen from amino acids in soil hydrolysates J. Assoc. Analyt. Communities Int. 86:1106-1111.

Johnson, T.A., and G.K. Sims. 2004. Effects of carrier solvents on biodegradation of 2,4-dichlorophenoxyacetic acid in soil. Lett. Appl. Microbiol. (in press).


**Conservation tillage reduces agrochemical transport:** Transport of agrochemicals from the point of application across the landscape into riparian areas and streams is an economic loss for producers, reduces the effectiveness of the intended chemical, and threatens environmental health of the region. ARS scientists in Tifton, Georgia and cooperators demonstrated that strip tillage, a form of conservation tillage in the southeastern USA, was highly effective in controlling soil erosion and reducing pesticide transport in water runoff. Soil scientists, hydrologists, agronomists, environmental toxicologists, ecosystem modelers, and agricultural practitioners will be able to use this information to reduce soil erosion and the loss of agrochemicals to receiving water bodies. Soil scientists, hydrologists, agronomists, environmental toxicologists, ecosystem modelers, and agricultural practitioners will be able to use this information to reduce soil erosion and the loss of agrochemicals to receiving water bodies.

**Impact:** Data are being used to validate agrochemical runoff models for the USDA Conservation Effects Assessment Project in the Little River watershed of southern Georgia. This information will benefit NRCS as they assess the effectiveness of management practices used in conservation programs.

**Documentation:**

Potter, T.L., C.C. Truman, D.D. Bosch, D.D., and C. Bednarz. 2004. Fluometuron and pendimethalin runoff from strip and conventionally tilled cotton in the southern Atlantic Coastal Plain J. Environ. Qual. (In press).

Strickland, T.C., D.G. Sullivan, R.D. Wauchope, D.L. Bosch, and T.L. Potter. 2004. Using USDA-Agricultural Research Service long-term watershed hydrology/water quality observations to estimate the quality of model predictions of the Conservation Effects Assessment Program (CEAP). Picogram 67:75.

**Pesticide degradation is rapid in the warm, moist southeastern USA:** Pesticides applied to agricultural fields must be effective for a short period of time following application, but if they persist too long, loss of these pesticides to the surrounding environment could occur through leaching and runoff. Degradation of pesticides in soil is currently predicted using a nationwide-average approach that does not account for regional differences in climate. Collaborative research demonstrated the rapid degradation of pesticides applied to agricultural fields in the warm, moist region of the southeastern USA. A novel approach was developed to simulate multiple applications of pesticides to a single crop applied to agricultural fields, in which enhanced degradation of two common fungicides (chlorothalonil and tebuconazole) occurred. Ecosystem modelers, hydrologists, environmental toxicologists, soil scientists, and environmental regulatory agencies will be able to use this information to better predict pesticide degradation in different ecoregions.

**Impact:** This research has increased scientific understanding of environmental controls on pesticide degradation. Research methodology has been adopted by industry in risk assessment of new pesticides.

**Documentation:**

Potter, T.L., R.D. Wauchope, and A.K. Culbreath. 2001. Accumulation and decay of chlorothalonil and selected metabolites in surface soil following foliar application to peanuts. Environ. Sci. Technol. 35:2634-2639.

Potter, T.L., K.N. Reddy, E.P. Millhollen, C.W. Bednarz, D.D. Bosch, C.C. Truman, and T. Strickland. 2002. Dissipation of the defoliant, tribufos, in cotton producing soils. J. Agric. Food Chem. 50:3795-3802.
Wauchope, R.D., T.L. Potter, and A.K. Culbreath. 2003. Relating field dissipation and laboratory studies through modeling: Chlorothalonil dissipation after multiple applications in peanut. p. 287-303. *In* E.A. Arthur et al. (ed.) Terrestrial field dissipation studies: Purpose, design, and interpretation, Am. Chem. Soc. Symp. Ser. 842.
Strickland, T., T.L. Potter, and H. Joo. 2004. Tebuconazole dissipation and metabolism in Tifton loamy sand during laboratory incubation. Pest. Manage. Sci. 60:703-709.
Wauchope, R.D., T.C. Strickland, and M.A. Locke. 2004. National needs, regional solutions: The development of site-specific assessments of pesticides in water resources. p. 251-263. *In* M.T. Nett et al. (ed.) Water quality assessments in the Mississippi Delta - Regional solutions, national scope, Am. Chem. Soc. Symp. Ser. 877.

**Pesticide transport modeled:** Transport of agrochemicals through soil and across agricultural landscapes into nearby receiving bodies of water could threaten environmental quality. Better knowledge of if, when, where, and how pesticide transport might occur would help develop management strategies to reduce the impact of agrochemicals from agriculture to neighboring ecosystems. ARS scientists from several locations conducted collaborative research that demonstrated model prediction of pesticide transport within and across agricultural landscapes. The Root Zone Water Quality Model was used to describe pesticide runoff and leaching. Details and testing of algorithms were presented. Ecosystem modelers, hydrologists, soil scientists, environmental toxicologists, and agricultural practitioners will be able to use this information to better predict the fate and transport of pesticides under different management and environmental conditions of various ecoregions of the USA and globally.

**Impact:** Model applications are being utilized by industry and US-EPA to predict pesticide transport in agricultural landscapes.

**Documentation:**

Ma, Q., R.D. Wauchope, K.W. Rojas, L.R. Ahuja, L. Ma, and R.W. Malone. 2004. The pesticide module of the Root Zone Water Quality Model (RZWQM): Testing and sensitivity analysis of selected algorithms for pesticide fate and surface runoff. Pest Manage. Sci. 60:240-252.
Ma, Q., R.D. Wauchope, L. Ma, K.W. Rojas, R.W. Malone, and L.R. Ahuja. 2004. Test of the Root Zone Water Quality (RZWQM) model for predicting runoff of atrazine, alachlor and fenamiphos species from conventional-tillage corn mesoplots. Pest Manage. Sci. 60:267-276.
Malone, R.W., L.R. Ahuja, L. Ma, R.D. Wauchope, Q. Ma, and K.W. Rojas. 2004. Application of the Root Zone Water Quality Model (RZWQM) to pesticide fate and transport: An overview. Pest Manage. Sci. 60:205-221.
Malone, R.W., L. Ma, R.D. Wauchope, L. Ahuja, K.W. Rojas, Q. Ma, R. Warner, and M. Byers. 2004. Modeling hydrology, metribuzin degradation, and metribuzin transport in macroporous tilled and no-till silt loam using RZWQM. Pest Manage. Sci. 60:253-266.
Malone, R.W., J. Weatherington-Rice, M.J. Shipitalo, N. Fausey, L. Ma, L. Ahuja, R.D.

Wauchope, and Q. Ma. 2004. Herbicide leaching as affected by macropore flow and within-storm intensity variation: A RZWQM simulation. Pest Manage. Sci. 60:277-285.
Wauchope, R.D., L.W. Rojas, L.R. Ahuja, Q. Ma, R.W. Malone, and L. Ma. 2004. Documenting the pesticide processes module of the ARS RZWQM agoecosystem model. Pest Manage. Sci. 60:222-239.

## Productive and Sustainable Soil Management Systems Component

Most traditional soils research has focused on single issues such as erosion control, nutrient cycling, water use efficiency, or soil biology (i.e., the other components of this national program). Such efforts are needed to explain and advance the basic understanding of soil management, but specialized single-issue solutions cannot always be combined to form balanced, well-designed management systems. A systems research approach will be needed to integrate principles of soil biology, chemistry, and physics into soil management practices that optimize land use and are readily adoptable by landowners and operators. Systems can be defined at scales ranging from cellular to planetary, but within this National Program Component, the term is applied to resource management practices and decisions typically associated with fields, farms, or other defined land areas. The systems approach is characterized by a coordinated effort to balance all inputs and outputs and an effort to simultaneously address and assess multiple goals. In addition, soil management is site and resource-specific; therefore, to accommodate inherent space and time variability in soils, plants, climate, and human resources, research must be conducted at multiple locations throughout the U.S. The products of this research are strategies and recommendations to more effectively address multiple goals imposed by farmers and ranchers.

Research within the Productive and Sustainable Soil Management Systems Component of the Soil Resource Management National Program was conducted in three Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a workshop held at the start of the current 5-year National Program cycle. The three Problem Areas are: (Problem Area 17) Sustainable soil resource management strategies need to be developed, (Problem Area 18) Critical soil information needs to be developed and interpreted to guide site-specific management, and (Problem Area 19) Assessment and interpretation guidelines are needed to document the effects of current and alternative soil and crop management strategies on the Nation's soil resources.

Productive and sustainable soil management systems research is currently conducted by the following ARS locations: Akron, Colorado; Ames, Iowa; Auburn, Alabama; Beltsville, Maryland; Brookings, South Dakota; Columbia, Missouri; Florence, South Carolina; Ft. Collins, Colorado; Kimberly, Idaho; Las Cruces, New Mexico; Lincoln, Nebraska; Lubbock, Texas; Mandan, North Dakota; Morris, Minnesota; Oxford, Mississippi; Pullman, Washington; Riverside, California; Stoneville, Mississippi; Tifton, Georgia; and Watkinsville, Georgia.

## Soil Management Systems Component

**Problem Area 17: S**ustainable soil resource management strategies need to be developed.

**Background:** Most traditional soil research has focused on single issues such as erosion control, nutrient cycling, water use-efficiency, or soil biology (i.e., the other components of this national program). Such efforts are needed to explain and advance the basic understanding of soil management, but specialized single-issue solutions cannot always be combined to form balanced, well-designed management systems. The lack of complete, functional management systems can prevent landowners and operators from profitably meeting food, feed, and fiber needs and potentially result in adverse environmental impacts. Variation in soil physical, chemical, and biological properties can prevent adoption of optimum management practices when implemented in different locations. Developing "systems-oriented" management strategies often requires a different approach than component studies. However, by simultaneously addressing soil biological, chemical, and physical processes with a systems approach, strategies and recommendations can be developed that more effectively address multiple goals imposed by farmers and ranchers. Research in this problem area focused on combining the management of more than one of the following: tillage, crop residue, crop rotations, alternative crops including cover crops, grazing as well as other practices. The expected outcomes are innovative, user-friendly tools and techniques that identify and select optimum soil management practices for different soil, climate, and human resource situations.

The goals of this research were:

Develop a systems-approach to identify productive, profitable, and sustainable soil management systems that minimize negative environmental impact, require fewer nonrenewable resources, and optimize the inherent biological, chemical, and physical attributes of soils nationwide.

Develop science-based tools and decision aids that enable land managers to understand the effects of various combinations of animal, plant, soil, water, and pest management practices on soil biological, chemical, and physical conditions; and further, to understand the resultant productivity, profitability, sustainability, and environmental impact on our diverse soil resources.

Evaluate and quantify productivity, profitability, sustainability, and environmental impact of organic and conventional farming systems on national soil resources.

**Accomplishments:**

**No-tillage enhances sustainability of Northern Great Plains farming systems:** Cropping systems in the northern Great Plains must possess a resilient soil resource to be sustainable. Evaluation of a long-term cropping systems study indicated that soil in a continuous crop, no-till management practice provided more plant nutrients, withstood erosion, and facilitated water transfer better than a crop-fallow, conventional tillage management practice as indicated by increased soil organic matter, greater aggregate stability, and faster water infiltration rates. The use of no-till and minimum tillage at fertilization rates above 34 kg N/ha resulted in the highest crop yields, though yield response, nitrogen use, and plant-available water varied among years. The primary beneficiaries of this research are farmers in the northern Great Plains who can improve soil quality and agricultural sustainability by adopting production systems that employ continuous cropping practices with reduced tillage management.

**Impact:** With no-till or minimum till management, producers can adopt continuous cropping systems and thereby increase net annualized farm income. For example, a wheat-fallow production system only raises a crop on half of the land each year. A continuous cropping system allows for a crop each year, thus increasing net income.

**Documentation:**

Tanaka, D.L., and R.L. Anderson. 2003. Evolution and adaptation of cropping systems in the northern and central Great Plains. p. 105-113. In: Hanson, J.D., and J.M. Krupinsky (ed.), Proceedings of the Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismarck, ND.

Schepers, A., J.F. Shanahan, M.A. Liebig, J.S. Schepers, S.H. Johnson, and A. Luchiari, Jr. 2004. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agron. J. 96(1): 195-203.

**Converting to no-tillage and annually cropping increases dryland profit:** Precipitation use efficiency, economic return, and soil organic carbon (SOC) sequestration can be increased by converting dryland farming systems from crop-fallow to a more intensive practices (i.e. crop-crop-fallow or annual cropping). Adopting no-tillage increased N requirements for maximum grain yield when compared to conventional tillage practices. Nevertheless, economic returns were greater with minimum- or no-tillage annual cropping than with conventional tillage with either a spring wheat-fallow or annual cropping system. Reducing tillage and increasing cropping intensity also increased SOC sequestration, especially when compared to moldboard plowing. Farmers in the northern and central Great Plains who are converting to more intensive dryland cropping systems by using minimum- and no-till production practices are the primary beneficiaries of this research.

**Impact**: Converting to more intensive dryland cropping systems by using minimum- and no-tillage practices can increase profitability for producers in the central and northern Great Plains. Assuming an increased profit potential of $80 per hectare with minimum- and no-till annual cropping systems compared to spring wheat-fallow, the potential economic impact in North Dakota alone could be about $104 million per year with conversion of 1.3 million hectare of summer fallow to annual cropping. Increased SOC sequestration can also help mitigate global warming potential.

**Documentation**:

Halvorson, A.D., A.L. Black, J.M. Krupinsky, S.D. Merrill, B.J. Wienhold, and D.L. Tanaka. 2000. Spring wheat response to tillage and nitrogen fertilization in rotation with sunflower and winter wheat. Agron. J. 92:136-144.

Halvorson, A.D., A.L. Black, J.M. Krupinsky, S.D. Merrill, B.J. Wienhold, and D.L. Tanaka. 2000. Spring wheat response to tillage and nitrogen fertilization within a crop-fallow

system. Agron. J. 92(2):288-294.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2001. Tillage and nitrogen fertilization influence grain and soil nitrogen in an annual cropping system. Agron. J. 93:836-841.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2001. Tillage and nitrogen fertilization influences on grain and soil nitrogen in a spring wheat-fallow system. Agron. J. 93:1130-1135.

Halvorson, A.D., B.J. Wienhold, and A.L. Black. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Sci. Soc. Amer. J. 66(3):906-912.

Halvorson, A.D., G.A. Peterson, and C.A. Reule. 2002. Tillage system and crop rotation effects on dryland crop yields and soil carbon in the Central Great Plains. Agron. J. 94:1429-1436.

DeVuyst, Eric A., and Ardell D. Halvorson. 2004. Economics of Annual Cropping Versus Crop-Fallow In Northern Great Plains As Influenced by Tillage and Nitrogen. Agron. J. 96:148-153.

Saseendran, S.A., D.C. Nielsen, L. Ma, L.R. Ahuja, and A.D. Halvorson. 2004. Modeling nitrogen management effects on winter wheat production using RZWQM and CERES-wheat. Agron. J. 96:615-630.

Halvorson, A.D., D.C. Nielsen, and C.A. Reule. 2004. Nitrogen fertilization and rotation effects on no-till dryland wheat production. Agron. J. 96:1196-1201.

**No-tillage facilitates returning CRP land to cropland:** Management strategies are needed to help return approximately 10.7 million acres from the Conservation Reserve Program (CRP) to cropland in the Northern Great Plains. Runoff, erosion, and soil erodibility measured using a rainfall simulator for no-tillage, conventional-tillage, and undisturbed CRP converted to permanent hay land showed the cropped no-tillage land had the same low erodibility as the permanent hay land. Erodibility was increased six-fold by moderate pre-plant disking. Nitrogen fertilizer decreased the severity of leaf spot diseases on winter wheat grown in post-CRP fields. Producers, soil conservationists, and those interested in demonstrating the value of using no-tillage for a wheat-dominated continuous crop rotation are primary beneficiaries of this research.

**Impact:** This information is important for designing new management strategies for post-CRP lands and demonstrates importance of and methods for using no-tillage agricultural practices to reduce erodibility and soil degradation during conversion from CRP to cropland.

**Documentation**:

Krupinsky, J.M. and D.L. Tanaka. 2001. Leaf spot diseases on winter wheat influenced by nitrogen, tillage and haying after a grass/alfalfa mixture in the conservation reserve program. Plant Dis. 85:785-789

Tanaka, D.L., S.D. Merrill, and J.M. Krupinsky. 2002. Crop residue production after conversion from perennial vegetation to annual cropping. In: Annual Meeting Abstracts. Nov. 10-14, 2002. Indianapolis, IN, ASA-CSSA-SSSA, Madison, WI. (CD ROM)

Zheng, F., S. D. Merrill, C. Huang, and D. L. Tanaka. 2003. Runoff, sediment, and runoff water quality after conversion of CRP land. In: Annual Meeting Abstracts, Nov. 2-6, 2003. ASA-CSSA-SSSA, Madison, WI (CD-ROM)

**Conservation tillage positively affects soil organic matter amount and quality:** Coastal Plain soils often have low organic matter because high temperatures, intense rainfall, and tillage stimulate microbial processes and organic matter decomposition. Long-term conservation tillage increased the amount of organic matter and increased the proportion of less-reactive, longer-lasting compounds in the surface two inches (5 cm) compared to conventional tillage.

**Impact:** Adopting management practices that increase soil organic matter helps producers by reducing soil strength (need for deep tillage) and spatial variability while improving yields through increased water and nutrient holding capacities.

**Documentation:**

Ding, G.S., J.M. Novak, D. Amarasiriwardena, P.G. Hunt, and B. Xing. 2002. Soil organic matter characteristics as affected by tillage management. Soil Science Society of America Journal 66:421-429.

Ding, G.S., S. Herbert, J.M. Novak, and B. Xing. 2002. Long-term tillage effects on soil metolachlor sorption and desorption behavior. Chemosphere 48:897-904.

Hunt, P.G., P.J. Bauer, T.A. Matheny, and W.J. Busscher. 2004. Crop Yield and Nitrogen Accumulation Response to Tillage of a Coastal Plain Soil. Crop Science 44:1673-1681.


**Improved practices utilizing cover crops leads to an adoption of conservation tillage on 70-80% of Tennessee Valley farms:** Soil erosion from continuous cotton resulted in governmental regulations that forced many Tennessee River Valley producers in northern Alabama to try no-tillage in the early 1990's, but reduced yield prevented widespread adoption of this system. Non-inversion fall tillage to alleviate soil compaction and use of rye cover crops to reduce soil compaction, weed pressure and conserve soil water during periods of drought were successful and led to subsequent studies focused on improved nitrogen management, irrigation efficiency, site-specific practices, and controlled traffic technologies with automatic tractor steering in high-residue conservation systems. Growers, consultants, extension agents, and NRCS personnel are the primary beneficiaries of this research.

**Impact:** Conservation tillage has been adopted on more than 48,500 ha (120,000 acres) of land in the Tennessee River Valley, increasing profits and decreasing off-site environmental effects.

**Documentation:**

Raper, R. L., D. W. Reeves, and E. B. Schwab. 2000. Reducing compaction of Tennessee Valley soils in conservation tillage systems. J. Cotton Sci. 4:84-90 (http://www.jcotsci.org).

Raper, R. L., D. W. Reeves, C. H. Burmester, and E. B. Schwab. 2000. Tillage depth, tillage timing, and cover crop effects on cotton yield, soil strength, and energy requirements. Applied Eng. in Agric. 16(4):379-385.

Schwab, E.B., D.W. Reeves, C.H. Burmester, and R.L. Raper. 2002. Conservation tillage systems for cotton grown on a silt loam soil in the Tennessee Valley. Soil Sci. Soc. Am. J. 66:569-577.

Truman, C., W. Reeves, J. Shaw, A. Motta, C. Burmester, R. L. Raper, and E. Schwab. 2003. Tillage impacts on soil property, runoff, and soil loss variations from a Rhodic Paleudult under simulated rainfall. J. Soil Water Cons. 58(5):258-267.

**Better crop residue and tillage management and increased cropping intensity enhances precipitation capture, storage, and use-efficiency:** Water is the single most limiting factor in dryland crop production in the central Great Plains, and information is needed to quantify the effects of various crop residue management practices, residue types and orientation, and crop sequencing on precipitation storage efficiency and precipitation use efficiency. Harvesting a normal winter wheat crop at two-thirds of its height gave 80% of the maximum soil and water conservation protection, but when the crop was very short and sparse due to growing season water stress, harvesting with a stripper header increased soil and water conservation while minimizing harvest losses. Avoiding tillage during the fallow period in winter wheat-fallow cropping systems increased precipitation storage efficiency from 20 to 40%. Allowing sunflower stalks to stand over winter reduced erosion potential to nearly zero, increased snow capture by three to ten times, and recharged soil water by 10 cm. Adopting no-tillage increased water use efficiency (WUE) by 18%, but growing two crops in 3 years instead of one crop in 2 years increased WUE by 55%.

**Impact:** Managing crop residues improved precipitation capture, storage, and use efficiencies and subsequently increased winter wheat yield by 141 kg/ha for each additional centimeter of water stored in the soil before planting in the Central Great Plains.

**Documentation:**

McMaster, G.S., R.M. Aiken, and D.C. Nielsen. 2000. Optimizing wheat harvest cutting height for harvest efficiency and soil and water conservation. Agron. J. 92:1104-1108.

Nielsen, D.C. 2002. Water use efficiency, enhancing. p. 1399-1402. In: R. Lal and L. Ahuja (eds) Encyclopedia of Soil Science, Marcel Dekker, New York.

Nielsen, D.C. 2002. Crop rotation, soil water content and wheat yields. Conservation Tillage Facts #1-02. Central Great Plains Research Station, Akron, CO. (http://www.akron.ars.usda.gov/fs_croprotsoilwater.html).

Nielsen, D.C. M.F. Vigil, R.L. Anderson, R.A. Bowman, J.G. Benjamin, and A.D. Halvorson. 2002. Cropping system influence on planting water content and yield of winter wheat. Agron. J. 94:962-967.

Nielsen, D.C. 2003. Water in dryland cropping systems. p. A2-A6. Proc. 15th Ann. Winter Conf. Colorado Conservation Tillage Assoc., Feb. 4-5, Greeley, CO.

Aiken, R.M., D.C. Nielsen, and L.R. Ahuja. 2003. Scaling effects of standing crop residues on the wind profile. Agron. J. 95:1041-1046.

Nielsen, D.C. 2003. Stubble management effects on available soil water in dryland cropping systems. In. J. Davis (ed.) From the Ground Up, Agronomy News 23:20-21. Colorado State University Cooperative Extension, Ft. Collins. (http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/2003/Drought/drought.pdf).

**Retaining corn stubble improves soil properties and subsequent plant growth:** Soil temperature and erosion are important factors affecting crop production in the northern Corn/Soybean Belt. Leaving standing corn stubble rather than chopping or removing it increased snow capture and decreased frost penetration depth. This resulted in more rapid soil warming in the spring, decreased erosion potential, and enhanced soil biological processes that are sensitive to freezing. Less off-site silt and clay contamination of surface waters was an additional benefit of this research.

**Impact:** Soil resources were protected, crop yield potential was increased, and off-site water quality was protected by adopting conservation practices such as stubble retention. Producers and their advisors as well as state and federal action agencies will benefit from this research.

**Documentation:**

Sharratt, B.S. 2002. Corn stubble height and residue placement in the northern U.S. Corn Belt. Part I. soil physical environment during winter. Soil and Tillage Research. 64:243-252.

Sharratt, B.S. 2002. Corn stubble height and residue placement in the northern U.S. Corn Belt. part II. spring microclimate and wheat development. Soil Tillage Research. 64:253-261.

McIntosh, G.C., Sharratt, B.S. 2003. Over-winter stability and hydrology of macropores in the northern U.S. Corn Belt. Soil Science. 168:338-346.

Sharratt, B.S. 2003. Thermal environment of seasonally frozen soil affected by crop and soil management. Marcel Dekker, Inc. Encyclopedia of Soil Science. p.1321-1323.

**Alternative crops identified for dryland cropping systems:** The traditional wheat-fallow cropping system of the central Great Plains is subject to production problems of monoculture systems, (e.g., insect, weed, pathogen infestations) and to potential soil loss by wind erosion. Alternative crops need to be evaluated for their dryland production potential and after-harvest residue characteristics. Water use/yield functions for forage kenaf, chickpea, field pea, lentil, canola, crambe, sunflower, and corn were determined and productivity potential assessed from long-term weather records. Kenaf produced high-quality forage with dryland yields estimated to average 4534 kg/ha and more crude protein than dryland corn silage. Kenaf residue after harvest was effective for wind erosion control and trapping snow to recharge soil water. Estimated average seed yields for chickpea, field pea, and lentil were 2092, 1406, and 654 kg/ha, respectively. Producers interested in rotating these crops with winter wheat and agribusiness lenders are primary beneficiaries of this research.

**Impact:** Throughout the central Great Plains acreage of dryland corn increased from 10,000 to 350,000 acres and sunflower acreage increased from 0 to 315,000 since 1990. Information on the sunflower production function developed through this research was published in the High Plains Sunflower Production Handbook, which has had wide distribution throughout Kansas, Colorado, Nebraska, and Wyoming.

**Documentation:**

Nielsen, D.C. 2001. Production functions for chickpea, field pea, and lentil in the central Great Plains. Agron. J. 93:563-569.

Johnston, A.M., D.L. Tanaka, P.R. Miller, S.A. Brandt, D.C. Nielsen, G.P. Lafond, and N.R. Riveland. 2002. Oilseed crops for semiarid cropping systems on the northern Great Plains. Agron. J. 94:231-240.

Nielsen, D., J. Benjamin, and J. Schneekloth. 2002. Corn water use and yield under dryland rotations and limited irrigation. In. J. Davis (ed.) From the Ground Up, Agronomy News 22:3-4. Colorado State University Cooperative Extension, Ft. Collins. (http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/2002/Corn/corn.pdf). 2002.
Nielsen, D.C. 2004. Kenaf forage yield and quality under varying water availability. Agron. J. 96:204-213.

**Alternative crops show promise for semiarid Northern Great Plains:** The desire to improve water use efficiency, economic return, and soil quality created producer interest in crop rotations other than the traditional fallow-grain system. Wheat yield was limited by N when green manure was managed for minimum soil water consumption. Annual legume/grain-forage crops (e.g. oat-pea hay) had improved water use efficiency compared to traditional spring grains and retained high quality as biomass production increased. Deep tillage (subsoiling) effects on infiltration and water storage were very short-term (<1 season), but soil quality improvement may take several crop rotation cycles. Producers, extension agents, crop commodity groups and the NRCS were the primary beneficiaries of this research.

**Impact:** An economically and environmentally beneficial cropping system that fits the growing conditions and needs of producers in the northern Great Plains was developed.

**Documentation:**

Aase, J.K., J.L. Pikul Jr. 2000. Water use in a modified summer fallow system on semiarid northern Great Plains. Agric. Water Management. 43:345-357.
Pikul, Joseph L. Jr. and J. Kristian Aase. 2003. Water infiltration and storage affected by subsoiling and subsequent tillage. Soil Sci. Soc. Am. J. 67:859-866.
Pikul, J.L. Jr., J. K. Aase and V.L. Cochran. 2004. Water Use and Biomass Production of Oat-Pea Hay and Lentil in a Semiarid Climate. Agron. J. 96:298-304.

**Continuous dynamic cropping systems increase wheat yield in Northern Great Plains:** Information on crop synergy and the influence of previous crop residues on the many variables impacting crop growth and production is required in the northern Great Plains because of the diversity of crops. An evaluation of crop sequence effects of ten crops (barley, canola, crambe, dry bean, dry pea, flax, safflower, soybean, spring wheat, and sunflower) on crop seed yield, soil coverage by residue, soil water use, surface soil properties, and plant diseases showed that after one or 2 years of an alternative crop, wheat yield increased an average of 14% or 20% compared to continuous spring wheat. Depending upon the crops and crop sequence, the greatest yield increase one year after an alternative crop was 20% while after 2 years of an alternative crop it was 32%.

**Impact:** Adopting a dynamic cropping systems approach utilizing crop rotations increases wheat yields and provides producers management flexibility for developing their own long-term sustainable crop, soil, and land-use systems.

**Documentation:**

Johnston, A.M., Tanaka, D.L., Miller, P.R., Brandt, S.A., Nielsen, D.C., Lafond, G.P., Riveland, N.R. 2002. Oilseed crops for semiarid cropping system in the Northern Great Plains. Agron. J. 94:231-240.

Krupinsky, J.M., D.L. Tanaka, S.D. Merrill, M.A. Liebig, J.R. Hendrickson, J.D. Hanson, and R.E. Ries. 2002. Crop sequences for direct seeding. p. 68-78. In: Reduced Tillage Linkages, Direct Seeding Advantage, Proceedings of the Alberta Reduced Tillage Linkages, Edmonton, Alberta, November 19-20, Nisku, Alberta, Canada.

Ries, R.E., Tanaka, D.L., Anderson, R.L. 2002. Decline of weed densities in sunflower as affected by multiple tactics in a three-crop rotation. p. 166-170. In: Proceedings of the 24th Sunflower Research Workshop, January 23, 2002, National Sunflower Association, Bismarck, North Dakota.

Tanaka, D.L., J.M. Krupinsky, S.D. Merrill, and M.L. Liebig. 2003. Sunflower production as influenced by previous crop and crop residuesIn: Proceedings of the 25th Sunflower Research Workshop, January 16-17, Fargo, ND, National Sunflower Assoc. (Research Forum Papers located under Research & Statistics at http://www.sunflowernsa.com/research_statistics/research_workshop/), Bismarck, ND.

Karn, J.F., D.L. Tanaka, M.A. Liebig, R.E. Ries, S.L. Kronberg, and J.D. Hanson. 2003. Integrating crop and livestock enterprises to enhance farm productivity. p. 65-73. In: Proceedings of the Manitoba-North Dakota Zero Tillage Farmers Assoc. Jan. 28-29, 2003 Brandon, MB. Manitoba-North Dakota Zero Tillage Farmers Association, (www.mandakzerotill.org/links.htm).

**Dynamic cropping systems approach enhances producers' management flexibility:** Producers are challenged to integrate a vast array of information to make management decisions that are influenced by numerous factors many that are not under their control. A dynamic cropping systems approach, which is a strategy of annual crop sequencing that optimizes crop and soil use options to attain production, economic, and resource conservation goals, was developed. A crop by crop residue matrix was developed as a research tool to help evaluate multiple crop sequences and synergistic effects in the same project under similar weather and soil conditions.

**Impact:** The dynamic cropping systems approach, with its appropriate sequencing of crops, provides producers important information that allows them to reduce their risk and attain production, economic, and resource conservation goals by using sound ecological management principles with management flexibility for developing their own long-term sustainable crop, soil, and land-use systems.

**Documentation:**

Hanson, J.D., Tanaka, D.L., Krupinsky, J.M., Merrill, S.D., Ries, R.E., Hendrickson, J.R., Liebig, M.A., Johnson, H.A. 2001. Dynamic Cropping Systems for the Northern Great Plains: A Team Approach. In: Annual Meeting Abstracts, October 21-25, 2001, Charlotte, NC, ASA-CSSA-SSSA, Madison, WI, No. 194953-P, CD-ROM.

Tanaka, D.L., J.M. Krupinsky, M.A. Liebig, S.D. Merrill, R.E. Ries, J.R. Hendrickson, H.A. Johnson, and J.D. Hanson. 2002. Dynamic Cropping Systems: An adaptable approach to crop production in the Great Plains. Agron. J. 94:957-961.

Hanson, J.D. and J.M. Krupinsky (eds.). 2003. Proceedings of Dynamic Cropping Systems: Principles, Processes, and Challenges, Bismarck, ND. (Hardcopy and CD). 295p. (see www.mandan.ars.usda.gov for more details)
Hanson, J.D., J.R. Hendrickson, J.M. Krupinsky, D.L. Tanaka, M.A. Liebig, S.D. Merrill, and H.A. Johnson. 2003. Introduction to dynamic cropping systems as part of integrated agricultural systems. p. 1-8. In: Proceedings of Dynamic Cropping Systems: Principles, Processes, and Challenges. Aug. 5-7, 2003.Bismarck, ND.
Krupinsky, J.M., D.L. Tanaka, S.D. Merrill, M.A. Liebig, J.R. Hendrickson, J.D. Hanson, and R.E. Ries. 2003. Crop Sequences and Dynamic Cropping Systems. p. 58-61 In: Direct Seeding, Knowledge Based Farming, Proceedings of 15th Annual Meeting, Conference, and Trade Show of the Saskatchewan Soil Conservation Assoc. Feb. 19-20, 2003. Prairieland Park, Saskatoon, Saskatchewan. Saskatchewan Soil Conservation Assoc., Indian Head, Sask.

**Crop sequence calculator facilitates evaluating alternative crop sequences:** In a dynamic cropping system, agricultural producers need timely information relevant to their crop production systems to successfully manage risk and develop their own sustainable crop, soil, and land-use systems. The Crop Sequence Calculator, an interactive CD-ROM for viewing crop sequencing information and calculating returns was developed and distributed to help producers assess crop production and the potential returns of ten crops in a no-till diverse cropping system. Expected crop prices can be input into the computer program to provide rapid calculations of potential returns. The program contains information on crop production and economics, crop water use, plant diseases, weeds, insects, and surface soil properties to aid producers in their evaluation of management risks associated with different crop sequences. Crop consultants, producers, researchers, and persons interested in developing user-friendly technology transfer tools designed to help producers reduce risks and develop their own dynamic crop production systems are the primary beneficiaries of this research.

**Impact:** Since its first release (January, 2001), over 10,000 copies of the Crop Sequence Calculator have been distributed (as of July, 2004) to help producers assess crop production and the potential returns of ten crops in a no-till diverse cropping system. This number of requests for the Crop Sequence Calculator alone demonstrates the impact of this tool.

**Documentation:**
Krupinsky, J.M., D.L. Tanaka, J.S. Fehmi, S.D. Merrill, J.R. Hendrickson, R.E. Ries, M.A. Liebig, S. Wright, and J.D. Hanson. 2001. A computer program to assist sunflower producers. p. 83-84. In: Proc. of the 23rd Sunflower Research Workshop, Jan. 17-18, 2001, National Sunflower Assoc, Bismarck, ND, 185 pp.
Krupinsky, J.M., D.L. Tanaka, J.S. Fehmi, S.D. Merrill, J.R. Hendrickson, R.E. Ries, M.A. Liebig, S. Wright, and J.D. Hanson. 2001. A computer program to assist safflower producers. p. 219-222 In: Proc. of the Fifth International Safflower Conference, North Dakota State Univ., Williston, ND, 328 p.
Fehmi, J.S., Krupinsky, J.M., Tanaka, D.L., Merrill, S.D., Hendrickson, J.R., Ries, R.E., Liebig, M.A., Hanson, J.D. 2001. A Crop Sequence Calculator for Designing Dynamic Cropping Systems: Translating Science into Practice. In: Annual Meeting Abstracts, October 21-

25, 2001, Charlotte, NC, ASA-CSSA-SSSA, Madison, WI.
Krupinsky, J. M., D.L. Tanaka, S.D. Merrill, M.A. Liebig, J.R. Hendrickson, J. Hanson, J. Fehmi, D. Archer, R. Anderson, J. Knodel, P. Glogoza, L Charlet, S. Wright, and R. Ries. 2002. Crop Sequence Calculator, v. 2.0. Northern Great Plains Research Laboratory, Mandan, North Dakota. CD ROM.
Krupinsky, J.M., Tanaka, D.L., Fehmi, J.S., Merrill, S.D., Liebig, M.A., Hendrickson, J.R., Hanson, J.D., Anderson, R.L., Archer, D., Knodel, J., Glogoza, P.A., Charlet, L.D., Wright, S., Ries, R.E. 2002. Crop Sequence Calculator, v. 2, A revised computer program to assist producers. p. 63-66. In: Proceedings of the 24th Sunflower Research Workshop, National Sunflower Association, Bismarck, North Dakota.
Krupinsky, J.M., D.L. Tanaka, J.D. Hanson, S.D. Merrill, M.A. Liebig, and J.R. Hendrickson. 2003. p. 174-178. In: Dynamic cropping systems and the distribution of research information: Crop sequence calculator. Proceedings of Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismarck, ND.

**Cover crops provide environmental benefits in the northern corn/soybean belt:** Effluent from agricultural drainage tiles and erosion from fields in corn-soybean rotations contribute nitrate, sediment, and phosphorus contaminants to surface waters. Incorporating small grain cover crops into the corn-soybean rotation in the upper Midwest significantly reduced rill and inter-rill erosion, increased water infiltration, and reduced nitrate leaching. Producers as well as persons interested in recreation and other surface water uses are the beneficiaries of this research.

**Impact:** Wide use of cover crops in the upper Midwest could dramatically reduce nitrate, sediment and phosphorus loss to surface waters in this region, decreasing drinking water treatment cost and enhancing safe and enjoyable recreation opportunities.

**Documentation:**

Johnson, T.J., T.C. Kaspar, K.A. Kohler, S.J. Corak, and S.D. Logsdon. 1998. Oat and rye overseeded into soybean as fall cover crops in the upper Midwest. J. Soil Water Conserv. 53(3):276-279.
Kaspar, T.C., J.K. Radke, and J.M. Laflen. 2001. Small grain cover crops and wheel traffic effects on infiltration, runoff, and erosion. J. Soil Water Conserv. 56:160-164.
Logsdon, S.D., T.C. Kaspar, D.W. Meek, and J.H. Prueger. 2002. Nitrate leaching as influenced by cover crops in large soil monoliths. Agron. J. 94:807-814.

**Improved rollers for terminating cover crops:** Cover crops have been shown to provide environmental protection, weed control, water conservation, nutrient retention and other benefits, but can interfere with subsequent primary crop establishment and growth. Crop rollers effectively and economically killed cover crops, providing an alternative to chemical control with the added benefit of providing a flat, unidirectional mat of residue cover for planting. Designs that reduce vibration and allow producers to traverse fields at higher speeds were identified. Producers, Cooperative Extension personnel, and implement manufacturers striving to develop improved conservation systems for row-crop production are the primary beneficiaries of this research.

**Impact:** A patent application has been filed with the U.S. Patent Office on this newly developed technology, which has been highlighted in numerous popular press articles.

**Documentation:**


Ashford, D. L., D. W. Reeves, M. G. Patterson, G. R. Wehtje, and M. S. Miller-Goodman. 2000. Roller vs. herbicides: an alternative kill method for cover crops. p. 64-69. In: Proc. 23rd Annual Southern Conservation Tillage Conference for Sustainable Agriculture, June 19-21, 2000, Monroe, LA. Louisiana State University Agric. Exper. Stn., Baton Rouge, LA.

Ashford, Dana and Wayne Reeves. 2002. Rolling and Crimping – Scientists Study Alternative Cover Crop Kill Method. Highlights On-Line at: http://www.ag.auburn.edu/resinfo/highlightsonline/fall01/fall-ashford.html Ala. Agric. Exper. Stn. (AAES), Auburn, AL.

Ashford, D.L., and D.W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. *American Journal of Alternative Agriculture* 18(1):37-45.

Raper, R.L., P.A. Simionescu, T.S. Kornecki, A.J. Price, and D.W. Reeves. 2004. Cover crop rollers: a new component of conservation tillage systems. Applied Engineering in Agriculture (accepted 04/20/2004).


**Regional assessment shows cropping systems improve soil properties in the Great Plains:** Traditional semiarid Great Plains cropping practices (tillage, fallow, and monocropping) have resulted in substantial soil degradation during the last century. Nitrogen fertilization, crop rotation, and reduced tillage significantly increased yields, reduced annual variability, and decreased risk to Great Plains producers. Soil quality indicator assessments for potential N mineralization, microbial biomass, and particulate organic matter were found to be sensitive, accurate, and did not require sophisticated equipment. The Soil Management Assessment Framework (SMAF) and AgroEcosystem Performance Assessment Tool (AEPAT) were useful for comparing soil attribute response to management. The NRCS, producers, and crop consultants are the primary beneficiaries of this research.

**Impact:** This multi-location study, by ARS scientists and their cooperators throughout the Great Plains, documented that reduced tillage intensity, reduced incidence of fallow, and more diverse crop rotations can reverse soil degradation that has occurred with traditional management practices. It also demonstrated the utility of several soil quality indicator measurements and two assessment tools.

**Documentation:**


Gajda, A.M., J.W. Doran, T.A. Kettler, B.J. Wienhold, J.L. Pikul, Jr., and C.A. Cambardella. 2001. Soil quality evaluations of alternative and conventional management systems in the Great Plains. pp. 381-400. In: Lal, R. et al. (ed). Assessment methods for soil carbon. Lewis Publ., Boca Raton, FL.

Helmers, G.A., C.F. Yamoah, and G.E. Varvel. 2001. Separating the impact of crop diversification and rotations on risk. Agron. J. 93:1337-1340.

Liebig, M.A., G. Varvel, and J. Doran. 2001. A simple performance-based index for assessing multiple agroecosystem functions. Agron. J. 93:313-318.

Liebig, M.A., G.E. Varvel, J.W. Doran, and B.J. Wienhold. 2002. Crop sequence and nitrogen fertilization effects on soil properties in the Western Corn Belt. Soil Sci. Soc. Am. J. 66:596-601.
Pikul, J.L., Jr., R. Schwartz, J. Benjamin, L. Baumhardt, and S. Merrill. 2003. Soil physical characteristics of contrasting cropping systems in the Great Plains: Preliminary findings. pp. 205-209. In: Proc. Dynamic Cropping Systems Symposium, Mandan, ND.
Varvel, G.E. 2000. Crop rotation and nitrogen effects on normalized grain yields in a long-term study. Agron. J. 92:938-941.
Varvel. G., W. Riedell, E. Deibert, B. McConkey, D. Tanaka, M. Vigil, and R. Schwartz. 2003. Assessment of cropping system effects on soil quality in the Great Plains: Introduction. pp. 197-204. In: Proc. Dynamic Cropping Systems Symposium, Mandan, ND.
Wienhold, B.J., J. Pikul, Jr., M. Liebig, M. Vigil, G. Varvel, and J. Doran. 2003. Cropping system effects on soil quality in the Great Plains: summary from a regional project. pp. 215-219. In: Proc. Dynamic Cropping Systems Symposium, Mandan, ND.

**Winter-annual grazing requires tillage before cotton or peanuts:** Integrating livestock with cotton - peanut rotations may offer profitable alternatives for producers, but could result in excessive soil compaction that can severely limit yields. Winter grazing provided a net return of $158 to $205 per ha per year ($64 to $83 per acre per year), but increased soil compaction in the upper 10 cm (4 inches). Tillage (conventional surface tillage or deep tillage) alleviated the compaction and increased soil water removal by subsequent cotton or peanut crops. Strict no-tillage resulted in 23% lower cotton and 39% lower peanut yield than with tillage. Non-inversion deep tillage was required to maximize crop yields with no-(surface) tillage. Producers with both animal and crop production enterprises were the primary beneficiaries of this research.

**Impact:** Integrating livestock grazing on cotton - peanut rotations and using non-inversion deep tillage enables mid-South producers to increase profit during winter months without reducing subsequent cotton or peanut yields.

**Documentation:**

Siri-Prieto, G., D.W. Reeves, R.L. Raper. 2003. Conservation tillage systems for cotton and peanut following winter-annual grazing. p. 1143-1148. In: Proceedings of the 16th ISTRO Conference, July 14-19, 2003, Brisbane, Australia (on CD-ROM).
Siri-Prieto, G., D.W. Reeves, R.L. Raper, D. Bransby, and B.E. Gamble. 2003. Integrating winter annual grazing in a cotton-peanut rotation: forage and tillage system selection. P. 104-115. In: Proceedings of Sod Based Cropping Systems Conference, Feb. 20-21, 2003, Quincy, FL. (on CD-ROM). Also available at http://nfrec.ifas.ufl.edu/sodrotation/postconference.htm
Siri-Prieto, G., D.W. Reeves, D. Bransby, R.L. Raper, B.E. Gamble. 2003. Integrating livestock in cotton production in the coastal plain: influence of pasture and tillage. In: Proc. Beltwide Cotton Conf., January 6-10, 2003. p. 2056-2057. Nashville, TN. National Cotton Council. 2003. (on CD-ROM). Also available at http://www.cotton.org/beltwide/proceedings/index.cfm
Siri-Prieto, G., D.W. Reeves, R.L. Raper, and B.E. Gamble. 2004. Impact of winter annual grazing and conservation tillage on soil properties and crop productivity in a cotton-

peanut rotation in the coastal plain. p. 2507-2508. In: Proc. 2004 Beltwide Cotton Conferences, January 5-9, 2004, San Antonio, TX.

**Bamboo provides forage and improves soil in Appalachian silvopastoral systems:** Small farm systems in hill-land Appalachia need management options that diversify income opportunities, can be integrated into traditional and new livestock management strategies, and help maintain or improve soil quality. Cell wall fiber concentrations in temperate bamboo species were lowest in young leaves collected in July, increasing as they aged to reach highest levels in over-wintered leaves. Leaf crude protein decreased from July to September, but was relatively constant through the winter. Concentrations of fiber and protein were similar to those reported for other browses such as black locust, willow, and oak, and sufficient to meet maintenance needs of browsing sheep or goats. Producers, rural development organizations, and Appalachian community leaders were the primary beneficiaries of this research.

**Impact:** Temperate bamboo appears to have potential as a winter feed in central Appalachia because it remains green and maintains its quality throughout the winter. It may also increase stocks of soil and standing biomass C in pastures and control erosion by stabilizing stream banks. With development, bamboo could become a valuable multiple-use crop, suitable for increasing income of small low-input farm operations and easily adaptable to goat production systems.

**Documentation:**

Halvorson, J.J., K.A. Cassida and K.E. Turner. 2004. Nutritive Quality of Bamboo Browse for Livestock. P. 417. In: Cassida, K. et al (eds.) American Forage and Grassland Council Conference Proceedings Vol 13, American Forage and Grassland Council, Georgetown, Texas.

**Systems approaches facilitate development of sustainable soil management practices on integrated crop-animal farm:** Long-term field-scale watershed studies on deep loess soils showed that after more than 20 years of continuous corn production, weed pressure was very high and dominated by foxtail (*Setaria*) species. Ridge-tillage reduced runoff, increased infiltration, reduced water loss due to evaporation and increased grain yield, thus increasing water use efficiency, but also resulted in higher baseflow N concentrations from the site because N fertilization rates exceeded average annual grain removal. An on-farm study demonstrated that grazing corn crop residues can provide a low-cost source of feed for beef cattle without having a major impact on subsequent soybean yields. A regional assessment of Monsanto Center of Excellence (COE) studies showed that although no-tillage practices may not always increase yield, profitability is often increased because of fewer trips across the field and lower equipment investment. Producers and crop consultants are the primary beneficiaries of this research.

**Impact:** This research demonstrates the importance of increased cropping system diversity, balancing both N and water use efficiencies, and how animal and crop production operations can be integrated to provide more sustainable and profitable farming systems. It also provides information enabling Corn/Soybean Belt producers to make more informed and sustainable soil and crop management decisions.

**Documentation:**

Karlen, D.L., Kramer, L.A., James, D.E., Buhler, D.D., Moorman, T.B. and Burkart, M.R. 1999. Field-scale watershed evaluations on deep loess soils: I. Topography and agronomic practices. J. Soil Water Conserv. 54:693-704.

Logsdon, S.D., Karlen, D.L., Prueger, J.H. and Kramer, L.A. 1999. Field-scale watershed evaluations on deep loess soils: III. Rainfall and fertilizer N use efficiencies. J. Soil Water Conserv. 54:711-716.

Clark, J.T., Russell, J.R., Karlen, D. L., Singleton, P.L., Busby, W.D., and Peterson, B.C. 2004. Soil surface property and soybean yield response to corn stover grazing. Agron. J. (accepted 04-02-04)

Buman, R.A., Alessi, B.A., Hatfield, J.L., and Karlen, D.L. 2004. Profit, yield, and soil quality effects of tillage systems in corn/soybean rotations. J. Soil Water Conserv. (accepted 08-11-04)

**Long-term management effects on soil properties:** It is necessary to understanding long-term management effects on soil properties to determine the relative sustainability of cropping systems. ARS scientists from the Great Plains and the Western Corn Belt and cooperators determined the effects of long-term management practices on soil properties. They found that increased nitrogen-rate resulted in greater organic C, total nitrogen, and particulate organic matter, but lower soil pH and lesser microbial biomass in the western Corn Belt. Four-year crop sequences possessed more potentially mineralizable nitrogen and a greater percentage of particulate organic matter present as soil organic matter than shorter-term and less diverse crop sequences. Longer and more diverse crop sequences enhance nutrient cycling efficiency relative to continuous corn. Cropping systems in the western Corn Belt with extended rotations fertilized with moderate levels of nitrogen perform at least as well as continuous corn when both agronomic and environmental attributes are taken into consideration. In the northern Great Plains, N fertilization effects on soil pH were modest at high, medium, and low N treatments resulting in decreases in soil pH of 0.67, 0.33, and 0.15, respectively. Acidification was limited to the 0 to 7.6 cm depth, thereby negating the possibility of carbon loss by acid decomposition in this long-term cropping systems experiment. Below 15.2 cm, soil pH increased over the 16 yr period, indicating the possibility for formation of calcium carbonate at lower depths. Throughout the Great Plains, alternative cropping systems characterized by continuous cropping, diverse crop sequences, and/or reduced tillage enhanced microbial biomass and potentially mineralizable nitrogen, indicating a greater capacity of the soil to supply plant-available nitrogen in these systems. Dynamic agricultural systems benefit producers and their advisors including NRCS and university extension on the Northern Great Plains.

**Impact:** Sustainability of our natural resources has been increased through agricultural systems that offer producers a choice of alternative management options – and are therefore inherently dynamic. The agronomic and environmental performance of cropping systems is enhanced through improvements in management with reduced tillage, increased diversity of crop rotations, reduced use of fallow, and judicious application of plant nutrients to improve soil functions.

**Documentation:**

Wienhold, B.J., and D.L. Tanaka. 2001. Soil property changes during conversion from perennial vegetation to annual cropping. Soil Science Society of America Journal.65:1795-1803.

Liebig, M.A., G.E. Varvel, J.W. Doran, and B.J. Wienhold. 2002. Crop sequence and nitrogen fertilization effects on soil properties in the Western Corn Belt. Soil Science Society of America Journal. 66:596-601.

Liebig, M.A., S. Wright, L.Jawson, D.L. Tanaka, J.M. Krupinsky, S.D. Merrill, J.R. Hendrickson, R.L. Anderson, R. Ries, and J.D. Hanson. 2002. Northern Great Plains Cropping Systems: Influences on Soil Properties Associated with Soil Quality. p. 20-26. *In*: Proceedings of the 24th annual Manitoba-North Dakota Zero Tillage Farmers Association Workshop. Manitoba-North Dakota Zero Tillage Farmers Association. Minot, North Dakota.

Liebig, M.A., and G.E. Varvel. 2003. Effects of western Corn Belt cropping systems on agroecosystem functions. Agronomy Journal. 95:316-322.

Liebig, M., L. Carpenter-Boggs, J.M.-F. Johnson, S. Wright, and N. Barbour. 2003. Soil biological characteristics of contrasting cropping systems in the Great Plains: Summary of preliminary findings. *In*: Proceedings of Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismarck, North Dakota. p. 210-214.

Wienhold, B., J. Pikul, M. Liebig, M. Vigil, G. Varvel, and J. Doran. 2003. Cropping system effects on soil quality in the Great Plains: Summary from a regional project. p. 215-219. *In*: Proceedings of Dynamic Cropping Systems: Principles, Processes, and Challenges. Bismarck, North Dakota.

Mikha, M. M., M. F. Vigil, M. Liebig, B. Wienhold, R. Bowman, B. McConkey, E. Deibert, and J. Pikul. 2003. Great Plains soil quality assessment project: Soil chemical properties. *In*: Abstracts of the Annual Meeting of the American Society of Agronomy. November 2-6, 2003. Denver, Colorado. CD-ROM.

Pikul, Jr., J.L., R. Schwartz, J. Benjamin, L. Baumhardt, and S.D. Merrill. 2003. Assessment of cropping systems in the Great Plains on soil quality: Physical properties. *In*: Abstracts of the Annual Meeting of the American Society of Agronomy. November 2-6, 2003. Denver, Colorado. CD-ROM.

Wienhold, B., J. Pikul, M. Liebig, M. Vigil, G. Varvel, and J.W. Doran. 2003. Cropping system effects on soil quality in the Great Plains. *In*: Abstracts of the Annual Meeting of the American Society of Agronomy. November 2-6, 2003. Denver, Colorado. CD-ROM.

**Surface soil properties characterized under long-term cropping and grass systems in a dry, cold environment:** Degradation of soil and water resources with cropping can be a perceived and real problem throughout the world. A collaboration between scientists from the US and Canada evaluated soil indicators of erosion resistance, soil fertility, and biophysical complexity under permanent grass cover and under 3-year wheat crop rotations under no-tillage management. Soil properties were improved at the end of 11 years under permanent grass cover compared with wheat cropping systems, but differences of <15% were less than typically observed had the wheat been cultivated with conventional inversion tillage rather than with no tillage. This information is beneficial to producers, agricultural consultants, and environmental organizations in fostering and developing agricultural systems in the semiarid regions that incorporate sod-based rotations with no-tillage management for protection and improvement of soil and water quality.

**Impact:** These results favor recommendation of two economically viable production alternatives for producers (hay harvest and grain production with no tillage) capable of saving millions of dollars to tax payers and nature enthusiasts by avoiding environmental degradation of the landscape and its surface waters.

**Documentation:**

Arshad, M.A., G.W. Clayton, A.J. Franzluebbers, N.Z. Lupwayi, and Y.K. Soon. 2001. Impact of conservation tillage on soil quality and crop yield in the cold region of northwestern Canada. First World Congress on Conservation Agriculture. October 1-5, 2001. Madrid, Spain.

Arshad, M.A., and A.J. Franzluebbers. 2002. Soil structure, C, and N changes under different management systems in northern Alberta, Canada. Abstracts of Annual Meetings of the American Society of Agronomy. November 10-14, 2002. Indianapolis Indiana. CD-ROM.

Arshad, M.A., A.J. Franzluebbers, and R.H. Azooz. 2004. Surface-soil structural properties under grass and cereal production on a Mollic Cryoboralf in Canada. Soil and Tillage Research. 77:15-23.

**Effects of silvopastoral pasture establishment on soil microclimate, processes and forage establishment:** Silvopastoral management strategies in hill-land Appalachia seek to expand spatial and temporal boundaries of forage production and promote ecosystem integrity through a combination of tree thinning and establishment of understory pastures. However, subsequent changes to the microclimate may affect rates of decomposition, nutrient cycling and retention of soil organic matter and forage establishment may be impacted by competition with trees for light or water or by the physical and chemical effects of deciduous tree litter. Soils were warmer in open pastures during much of the growing season but edges of cleared areas were warmer in late summer. Soils were wetter near cleared edges and drier under forest canopy than in open pasture. Silvopastoral thinning treatments had little effect on decomposition rates of yellow poplar or maple litter but rates for white oak and white pine litter were least in open sites, intermediate in thinned sites and greatest under unthinned canopies. After one year in the field, mass loss for litter samples first exposed in the fall were similar to samples initially exposed in the spring. These results suggest average decomposition rates in silvopastoral systems may be faster than in open pasture and slower than under an unthinned forest canopy but do not account for disturbance effects on soil organic C, typically high in forest soil organic horizons. Leaf extracts applied to soil inhibited white clover growth to a greater degree than did those of yellow poplar and red maple. Leaf extracts also delayed seed germination for several forage species, especially legumes, but germination resumed soon after washing the extract from the seeds. Scientists actively studying Appalachian silvopastoral systems are the direct beneficiaries of this research.

**Impact:** Development of management strategies that compensate for and ameliorate soil-based limits in pasture systems is aided. Forage production is extended into the understory of wooded sites through silvopastoral systems, land use efficiency is increased, and extremes in the growing or grazing season are buffered in microsite conditions that restrict optimal plant productivity.

**Documentation.**

Halvorson, J.J., D.P. Belesky, and C.M. Feldhake. 2002. Influence of forest canopy on microclimate, growth and quality of a cool season perennial grass. Ecological Society of America Abstracts. p.360.

Belesky, D.P., J. J. Halvorson, J.M. Ruckle, and C.M. Feldhake. 2002. Production and nutritive value of orchard grass along a gradient from open pasture to woodland. Abstracts of the Annual Meetings of the American Society of Agronomy. November 10-14, 2002. Indianapolis Indiana. CD-ROM.

Halvorson, J.J., D.P. Belesky, and H.W. Godwin. 2003. Inhibition of seed germination and early development by leaf litter extracts. Ecological Society of America Abstracts. pp. 136-137. Halvorson, J. J. 2004. Silvopastoral thinning effects on rates of surface decomposition of leaf litter. Annual Meeting of the Ecological Society of America Abstracts.

## Soil Management Systems Component

**Problem Area 18:** Critical soil information needs to be developed and interpreted to guide site-specific management.

**Background:** Soil resources vary greatly over time and space. This occurs because of differences in the parent material, topography, climate, vegetation, time of formation, and long-term management histories. Soil variability ranges in scale from subtle differences within an individual field to entirely different soil types if the scale is large and different land areas or regions are being compared. At the field scale, subtle differences in water and nutrient balance need to be quantified so they can be readily measured and interpreted for use with the engineering technologies being developed or marketed as components of "precision farming" or site-specific management. Within the past 5 years, crop yield monitors and global positioning systems (GPS) have become more available, and yield maps showing variability over different areas are being used to make soil management decisions such as location of drainage tile; irrigation methods and practices; and tillage, fertilizer, insecticide, pathogen, and weed control options. Various soil-sampling strategies have been tried, but none have proven to be economically feasible or consistently effective for quantifying variability in soil biological, chemical, and physical properties and processes over space and time. Appropriate interpretational criteria are needed that account for known inherent soil variation and use all available information to make management decisions. The focus in this Problem Area will be to conduct site-specific soil management or precision farming research within a systems context to develop decision aids, computer simulation models, and other information technologies.

The goals of this research were:

Determine optimum soil sampling and interpretation strategies to provide the biological, chemical, and physical information needed to implement site-specific technologies.

Develop quantitative approaches for evaluating the environmental and economic benefits of site-specific soil management strategies.

**Accomplishments:**

**Assessment package developed for soil salinity surveys:** Soil salinization is a major problem, causing decreased crop production in irrigated lands of arid and semiarid regions of the world, but a major limitation to managing salinity has been the lack of technology to rapidly assess, map, and interpret conductivity information. Technology for using electromagnetic induction sensors (EM) to measure electrical resistance to map soil salinity was developed, implemented on a mobile platform (typically a modified spray tractor) with a global positioning system (GPS) and an on-board computer, and used to rapidly and remotely collect soil conductivity data across a field. A web site (www.ussl.ars.usda.gov/lcrsan/lcrhome.htm), providing detailed information on salinity assessment technology for non-network users was also developed. Technical specialists with the US Bureau of Reclamation (USBR), Natural Resources Conservation Service (NRCS), irrigation districts, university extension specialists, research scientists, and producers in saline regions throughout the world are the primary beneficiaries of this research.

**Impact:** The ARS ESAP software package provides a comprehensive assessment of salinity, processes and interprets conductivity data, provides the user with optimal soil sampling plans, as well as field scale salinity inventory statistics, spatial salinity maps, estimates crop yield loss based on salt tolerance, and provides recommended leaching management plans to reduce salinity while minimizing water use.

**Documentation:**

Lesch, S.M., J.D. Rhoades and D.L. Corwin. 2000. The ESAP-95 version 2.01R user manual and tutorial guide. USSL Research Report No. 146.

Lesch, S.M. and D.L. Corwin. 2001. Practical salinity assessment techniques via EM38 survey information. Conf. Proceedings: EM Techniques for Ag Resources Management, Yanco, NSW, Australia. Australian Soc. Soil Sci. Inc. pp:8-24.

Barnes, E.M., K.A. Sudduth, J.W. Hummel, S.M. Lesch, D.L. Corwin, C. Yang, C.S.T. Daughtry and W.C. Bausch. 2003. Remote- and ground-based sensor techniques to map soil properties. J. Photogrammetric Engineering & Remote Sensing . 69(6):619-630.

Lesch, S.M. and D.L. Corwin. 2003. Using the dual-pathway parallel conductance model to determine how different soil properties influence conductivity survey data. Agron. J. 95:365-379.

**Field-mobile NIRS developed for on-the-go soil analysis:** Rapid, quantitative spatial analysis of surface soil properties will facilitate development of improved site-specific management practices and monitoring of changes in soil quality and/or carbon sequestration. Near infrared diffuse reflectance spectroscopy (NIRS) techniques for rapidly quantifying soil organic carbon, total N, cation exchange capacity, soil moisture and many other soil properties were evaluated and a prototype field mobile on-the-go NIRS spectrometer system was built and tested.

**Impact:** This research led to the development of commercial, field-mobile NIRS systems and a Cooperative Research and Development Agreement (CRADA) between ARS and a small private company.

**Documentation:**

Chang, C.W., D.A. Laird, M.J. Mausbach, and C.J. Hurburgh. 2001. Near infrared reflectance spectroscopy-principal component regression analyses of soil properties. Soil Sci. Soc. Am. J. 65:480-490.

Chang, C.W. and D.A. Laird. 2002. NIRS analysis of soil C and N. Soil Sci. 167:110-116

Christy, C., E. Lund, and D.A. Laird. 2003. Mapping Soil Carbon with On-The-Go Near Infrared Spectroscopy. In: Proc. CASMGS Carbon Measurement and Monitoring Forum, Kansas State University in Manhattan, KS, October 15-17. http://www.oznet.ksu.edu/ctec/Fall%20Forum%20pdf%20files/Papers_Abstracts/Christy_Veris.pdf

Christy, C.D., P. Drummond and D.A. Laird. 2003. An On-The-Go Spectral Reflectance Sensor for Soil. Paper No. 031044 p. 1-7. In: Proc.2003 ASAE Annual International Meeting. July 27-30, 2003. Las Vegas, Nevada.

**Management zones accommodate spatial variability in soil properties:** Inherent spatial variability strongly influences soil functions including nutrient availability and water retention or movement within and between fields. Management zones within fields exhibiting similar soil properties were delineated using apparent electrical conductivity, landscape attributes, and aerial photographs and correlated with crop production and seasonal rainfall. Cooperative Extension personnel, producers, soil and crop management consultants, and agri-chemical dealers are the primary beneficiaries of this research.

**Impact:** Use of management zones can improve input use efficiency and profit while reducing the potential for environmental contamination due to agricultural production.

**Documentation:**

Johnson, C.K., J.W. Doran, H.R. Duke, B.J. Wienhold, K.M. Eskridge, and J.F. Shanahan. 2001. Field-scale conductivity mapping for delineating soil condition. Soil Sci. Soc. Am. J. 65:1829-1837.

Johnson, C.K., K.M. Eskridge, B.J. Wienhold, J.W. Doran, G.A. Peterson, and G.W. Buchleiter. 2003. Using electrical conductivity classification and within-field variability to design field-scale research. Agron. J. 95:602-613.

Johnson, C.K., D.A. Mortensen, B.J. Wienhold, J.F. Shanahan, and J.W. Doran. 2003. Site-specific management zones based on soil electrical conductivity in a semiarid cropping system. Agron. J. 95:303-315.

Schepers, A.R., J.F. Shanahan, M.A. Liebig, J.S. Schepers, S.H. Johnson, and A. Luchiari, Jr. 2004. Appropriateness of management zones for characterizing spatial variability of soil properties and irrigated corn yields across years. Agron. J. 96:195-203.

**Understanding landscape position effects facilitates tillage system transition:** Identifying management zones and the limiting soil properties in each can facilitate use of manure as a soil amendment and the transition from conventional to conservation systems. Soil survey, topography, and electrical conductivity maps were used to define management zones that included knolls, severely eroded side-slopes, and valleys. Conservation systems using no-tillage and high-residue producing cover crops minimized drought stress, reduced economic risks from yield variations, and increased cotton yields.

**Impact:** This research enables producers to take immediate advantage of increased yields when converting their row-crop production system from conventional tillage to conservation tillage and benefits the general public by encouraging more rapid adoption of conservation tillage.

**Documentation:**

Terra, J.A., D.W. Reeves, J.N. Shaw, R.L. Raper, E. van Santen, and P.L. Mask. 2003. Spatial variation of cotton yield: influence of soil management and terrain attributes. p. 2029-2030. In: Proc. 2003 Beltwide Cotton Conference, Jan. 7-11, 2003. Nashville, TN. (on CD-ROM) Also at: http://www.cotton.org/beltwide/proceedings/2003/2003Session14.cfm

Terra, J.A. D.W. Reeves, J.N. Shaw, R.L. Raper, E. van Santen, P.L. Mask. 2003. Soil management, terrain attributes and soil variability impacts on cotton yields. p. 1217-1222. In: Proc. 16th ISTRO Conference, July 14-19, 2003. Brisbane, Australia. (on CD-ROM)

Terra, J.A., D.W. Reeves, J.N. Shaw, E. van Santen, P.L. Mask, and R.L. Raper. 2004. Conservation system impacts on cotton water relationships and productivity at the landscape level. P. 2581-2582. In: Proc. 2004 Beltwide Cotton Conference, Jan. 5-9, 2004. San Antonio, TX. (On CD-ROM) Also at: http://www.cotton.org/beltwide/proceedings/getPDF.cfm?year=2004&paper=K021.pdf

Terra, J. A., J.N. Shaw, D.W. Reeves, R.L. Raper, E. van Santen and P.L. Mask. 2005. Soil carbon relationships with terrain attributes, electrical conductivity surveys and soil map units in a coastal plain landscape. Soil Sci. (accepted 08/05/04).

**Landscape position and long-term management affect soil properties:** Quantifying spatial variability in soil properties is important for determining how to collect, interpret, and use site-specific soil management information to increase productivity and minimize the potential for environmental contamination. Geostatistical analyses showed that long-term conventional (corn-soybean rotation) and an alternative 5-year (corn-soybean-corn-oat-meadow) rotation resulted in different spatial patterns for soil properties in adjacent fields. Terrain analyses showed that differences in backslope and shoulder landscape positions were the primary factors influencing soil quality in long-term conventional- and ridge-tillage watersheds.

**Impact:** Understanding spatial dependence of soil properties facilitates design of simplified soil sampling systems for analyses within and between fields and watersheds.

**Documentation:**

Cambardella, C.A. and D.L. Karlen. 1999. Spatial analysis of soil fertility parameters. Prec. Agric. 1:5-14.

Dieleman, J.A., D.A. Mortensen, D.D. Buhler, C.A. Cambardella, and T.B. Moorman. 2000. Identifying associations among site properties and weed species abundance. Part. I. Multivariate analysis. Weed Science 48:567-575.

Cambardella, C.A., T.B. Moorman, S.S. Andrews, and D.L. Karlen. 2004. Watershed-scale assessment of soil quality in the Loess Hills of Southwest Iowa. Soil and Tillage Research 78:237-248.

Moorman, T.B., C.A. Cambardella, D.E. James, D.L. Karlen, and L.A. Kramer. 2004. Conventional and ridge tillage effects on soil carbon in small Iowa watersheds. 78:225-236.

Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework: a quantitative soil quality evaluation method with case studies. Soil Sci. Soc. Am. J. 68:1945-1962.

**Spatial variability influences herbicide fate, weed control, nutrient availability and plant disease:** Quantifying and understanding spatial variability is critical for developing site-specific management practices. Crop management and landscape position significantly affected the distribution of soil biological, chemical, and physical properties, herbicide fate, and population dynamics of the aflatoxin-producing fungus *Aspergillus flavus*. Sorption of the herbicide Fluometuron, its half-life, and the accumulation of metabolites were positively correlated with clay content and soil organic matter (SOM). Weed density was highest in soils with more than 30% clay and 1.6% SOM. Nitrate concentrations were about 50% higher in a conventionally tilled field, while phosphate was about 3-fold higher in the no-till field that had a winter wheat cover crop. Nitrate was negatively correlated with soil pH and sand content, while phosphate positively correlated with pH and clay content. *A. flavus* populations were higher following corn than either cotton or wheat, and although initially distributed randomly throughout fields, they became spatially dependent after several years of no-tillage.

**Impact:** Understanding spatial and temporal relationships among agronomic production factors and landscape position facilitates development of site-specific management practices, resulting in better weed control, reduced aflatoxin contamination in corn, and reduced N and P loss.

**Documentation:**


Gaston, L.A., M.A. Locke, R.M. Zablotowicz, and K.N. Reddy. 2001. Spatial relationships among soil properties and weed populations in Beasley Lake watershed. p. 100-104. In: Mississippi Delta Management Systems Evaluation Project, 1995-2000. R.A. Rebich and S.S. Knight (eds.) Mississippi Agricultural and Forestry Experiment Station Information Bulletin 377. Mississippi State, MS.

Locke, M.A., W.J. Staddon, R.M. Zablotowicz, and S.M. Dabney. 2001. Nutrient distribution in reduced tillage and conservation tillage cotton soils. p. 144-148. In: Mississippi Delta Management Systems Evaluation Project, 1995-2000**.** R.A. Rebich and S.S. Knight (eds.). Mississippi Agricultural and Forestry Experiment Station Information Bulletin 377. Mississippi State, MS.

Locke, M.A., R.M. Zablotowicz, and L.A. Gaston. 2002. Environmental fate of fluometuron in a Mississippi Delta watershed. Terrestrial field dissipation studies: Purpose, design and interpretation. p. 206-225. In: C. Barefoot, E.L. Arthur, and V. E. Clay (Eds.), Amer. Chem. Soc. Symp. Series 842, Washington D.C.

Abbas, H.K., R.M. Zablotowicz, and M.A. Locke. 2005. Spatial variability of *Aspergillus flavus* soil populations under different crops and corn grain colonization and aflatoxins. Can. J. Botany. (accepted 8/2004).


**Delineation of site-specific management units improves efficiency and profitability:** Conventional farming is not as efficient as it could be because fields are currently managed uniformly, ignoring the inherent spatial variability within and between them. Guidelines and protocols to delineate site-specific management units (SSMUs) for irrigated, arid zone soils were developed using yield monitor data and geospatial electromagnetic induction measurements of apparent soil electrical conductivity ($EC_a$) to direct soil sampling. This information benefits producers and their advisors including extension and NRCS personnel.

**Impact:** This research demonstrates the techniques for defining SSMUs. In arid-zone soils available soil water and salinity play a dominant spatio-temporal role influencing crop yield indicating the need for variable-rate, on-demand irrigation water application. Knowledge of spatial variability and its influence on crop yield helps producers know what, where, when, and how many inputs to apply on a site-specific basis for optimum efficiency and profitability.

**Documentation:**

Corwin, D.L., S.M. Lesch, P.J. Shouse, R. Soppe, J.A. Jobes, J. Fargerlund, and J.E. Ayars. 2003. Identifying soil properties that influence cotton yield using soil sampling directed by apparent soil electrical conductivity. Agronomy Journal. 95(2):352-364.

Corwin, D.L., and S.M. Lesch. 2003. Application of soil electrical conductivity to precision agriculture: Theory, principles and guidelines. Agronomy Journal. 95(3):455-471.

Corwin, D.L., and S.M. Lesch. 2004. Apparent soil electrical conductivity measurements in agriculture. Computers and Electronics in Agriculture. (accepted 7/16/04).

Kaffka, S.R., S.M. Lesch, K.M. Bali, and D.L. Corwin. 2004. Relationship of geo-referenced electromagnetic induction measurements, soil properties, and sugar beet yields in salt-affected fields for site-specific management. Computers and Electronics in Agriculture. (accepted 7/14/04).

Johnson, C.K., K.M. Eskridge, and D.L. Corwin. 2004. Apparent soil electrical conductivity: Applications for designing and evaluating field-scale experiments. Computers and Electronics in Agriculture. (accepted 8/02/04).

Corwin, D.L., and R.E. Plant. 2004. Applications of $EC_a$ measurements in precision agriculture. Computers and Electronics in Agriculture. (accepted 6/25/04).

**Soil electrical conductivity and terrain attributes explain spatial yield patterns:** New approaches need to be devised to interpret yield variability data and exploit this information for improved field management. Rapidly collected soil electrical conductivity, coupled with easily measured terrain attributes derived from elevation data collected with GPS, explained much of the spatial yield patterns within a farmer's field using simple multi-linear regression or factor analysis techniques provided the multi-year yield data were first segregated into years with either above or below growing season precipitation. Including soil properties in the analyses, improved our understanding somewhat, with pH being the most important soil factor. Producers and crop management consultants are the primary beneficiaries of this research.

**Impact:** This research illustrates the importance of growing season precipitation on relationships between soil and terrain properties and spatial yield variability in rain-fed fields and will have its greatest impact if constructed yield zones are coincident with management zones for farm inputs.

**Documentation:**

Bakhsh, A., Colvin, T.S., Jaynes, D.B., Kanwar, R.S., and Tim, U.S. 2000 Using Soil Attributes and GIS for Interpretation of Spatial Variability in Yield. Trans. ASAE. 43(4):819-828.

Bakhsh, A., Jaynes, D.B., Colvin, T.S., and Kanwar, R.S. 2000. Spatio-temporal Analysis of Yield Variability for a Corn-soybean Field in Iowa. Trans. ASAE. 43(1):31-38.

Jaynes, D.B., Kaspar, T.C., Colvin, T.S., and James, D.E. 2003. Cluster Analysis of

Spatiotemporal Corn Yield Patterns in an Iowa Field. Agron. J. 95:574-586.
Kaspar, T.C., Colvin, T.S., Jaynes, D.B., Karlen, D.L., James, D.E., and Meek, D.W. 2003. Relationship Between Six Years of Corn Yields and Terrain Attributes. Precision Agriculture. 4:87-101.
Brevik, E.C., Fenton, T.E., and Jaynes, D.B. 2003. Evaluation of the Accuracy of a Central Iowa Soil Survey and Implications for Precision Soil Management. Precision Agriculture. 4:331-342.
Kaspar, T.C., Pulido, D.J., Fenton, T.E., Colvin, T.S., Karlen, D.L., Jaynes, D.B., and Meek, D.W. 2004. Relationship of Corn and Soybean Yield to Soil and Terrain Properties. Agron. J. 96:700-709.

**Nitrogen use-efficiencies help characterize spatial variability in Pacific Northwest:** Strategies for improving N management are needed to achieve desired grain yield and protein concentrations in wheat, optimum fertilizer use efficiency and minimum impact on the environment. Calculating nitrogen use efficiency components and indices (which varied from 20 to 60% across the field) proved to be an effective technique for evaluating wheat grain yield-protein relationships and to diagnose field areas with over or under application of fertilizer N, poor N utilization or uptake efficiencies, or significant N loss. Producers and crop management consultants who develop nitrogen requirements and management strategies to use with precision agriculture are the primary beneficiaries of this research.

**Impact:** Improving N use efficiency will improve profitability and reduce the potential for negative environmental impact of agriculture in the Palouse and elsewhere.

**Documentation:**
Huggins, D.R. and Pan, W.L. 2003. Key indicators for assessing nitrogen use efficiency in cereal-based agroecosystems. Co-published simultaneously in J. of Crop Prod. 8 (1-2):57-86 and pp. 157-186 in A. Shrestha (ed.) Cropping Systems: Trends and Advances. The Haworth Press, Inc. Binghamton, NY.
Baker, D.A., Young, D.L., Huggins, D.R., and Pan, W.L. 2003. Economically optimal nitrogen fertilization for yield and protein in hard red spring wheat. Agron. J. 96:116-123.
Mamo, M., Malzer, G.L., Mulla, D.J., Huggins, D.R., and Strock, J. 2003. Spatial and temporal variation in economically optimum N rate. Soil Sci. Soc. Am. J. 95:958-964.
Fuentes, J. P., Flury, M., Huggins, D.R., and Bezdicek, D.F. 2003. Soil water and nitrogen dynamics in dryland cropping systems of Washington State, USA. Soil and Tillage Research 71:33-47.

**Remote sensing tools and techniques developed for weed and water stressors:** Tools and data analysis techniques are needed to enable producers and their advisors to evaluate the status of a crop with respect to weed infestation, moisture status, and herbicide injury. Signature analysis (SA), discrete wavelet transformations (DWT) and indices are analysis techniques applied to baseline data collected with a handheld spectroradiometer. This information will be used to design airborne sensors for assessing crops more quickly and efficiently, saving producers valuable time and money. Researchers are the primary beneficiary of this research because it is still in the early developmental phase.

**Impact:** Use of hyperspectral, remotely sensed crop data will ultimately enable producers and crop advisors to distinguish between weeds and crops under a variety of conditions and measure stressors such as herbicide drift or moisture stress.

**Documentation:**

Henry, W.B., D.R. Shaw, K.R. Reddy, L.M. Bruce, and H.D. Tamhankar. 2004. Remote sensing to detect herbicide drift on crops. Weed Technol. 18(2):358-368.

Henry,W.B., D.R. Shaw, K.R. Reddy, L.M. Bruce, and H.D. Tamhankar. 2004. Remote sensing to distinguish soybean (*Glycine max*) from weeds following herbicide application. Weed Technol. (accepted 05/01/2004).

Henry, W.B., D.R. Shaw, K.R. R.Reddy, L.M. Bruce, and H.D. Tamhankar. 2004. Remote sensing to distinguish soybean from weeds grown with varying soil moisture. Weed Sci. 52:788-796.

**Weed infestations identified with remote sensing:** Locating the occurrence of leafy spurge in western rangeland and patches of marijuana remotely is important for implementing control measures and for reducing cost of search efforts. Collaborative research involving ARS scientists and cooperators demonstrated the potential for (a) identifying extensive geographical distribution of the noxious weed, leafy spurge, using satellite remote sensing and (b) future identification of the illicit field production of marijuana from recently developed spectral signatures combined with computer software utilization. Mixture-tuned matched filtering, a specialized type of spectral mixture analysis, was used to estimate leafy spurge canopy cover and map leafy spurge distribution. The advanced-image processing technique detected >95% of leafy spurge patches near Devils Tower National Monument. The remote sensing signature of leafy spurge was related to carotenoid concentration in the plant. The spectral signature of marijuana was derived from a combination of diffuse reflectance from the leaf interior plus a specular reflectance associated with leaf surface features. Specular reflectance may be exploitable for detection. Textural features in high spatial resolution images also provided new forms of information that may be exploitable for detecting specific plants. Plant architecture was quantified, modeled, and analyzed using L-Systems software. Rangeland scientists, government regulatory agencies, law enforcement, and ecosystem modelers will be able to use this information to better control the spread of noxious and illicit weeds.

**Impact:** Leafy spurge infests >1.2 Mha (3 million acres) in the USA and Canada, rendering these lands unsuitable for livestock grazing. The remote-sensing technique developed will be used to construct maps of leafy spurge abundance and to prioritize control practices by local weed and pest districts to minimize economic impacts of leafy spurge on livestock. Remote sensing of marijuana will aid law enforcement agencies worldwide. Aerial spotter training classes for law enforcement officers resulted in a better understanding of airborne marijuana detection issues and site characteristics important for marijuana sensing research. Future development of aerial or satellite sensing of marijuana in conventional cultivated crops appears possible.

**Documentation:**

Walthall, C.L., and C.S.T. Daughtry. 2001. Detecting marijuana using optical wavelength remote sensing. p. 648-656. *In:* Proc. ONDCP Int. Technol. Symp, 25-28 June 2001, San Diego, CA.

Parker-Williams, A.P., and E.R. Hunt, Jr. 2002. Estimation of leafy spurge cover from hyperspectral imagery using mixture tuned matched filtering. Remote Sens. Environ. 82:446-456.

Walthall, C.L., C.S.T. Daughtry, V. Vanderbilt, M. Higgins, T. Bobbe, J. Lydon, and M. Kaul. 2003. What do we know about the spectral signatures of illegal Cannabis cultivation? *In* Proc. ONDCP Int. Technol. Symp., San Diego, CA.

Hunt, E.R., Jr., J.H. Everitt, J.C. Ritchie, M.S. Moran, D.T. Booth, G.L. Anderson, P.E. Clark, and M.S. Seyfried. 2003. Applications and research using remote sensing for rangeland management. Photogramm. Eng. Remote Sens. 69:675-693.

Hunt, E. R., Jr., J.E. McMurtrey, III, A.E. Parker-Williams, and L.A. Corp. 2004. Spectral characteristics of leafy spurge (Euphorbia esula) leaves and flower bracts. Weed Sci. 52:492-497.

Pachepsky, L., M. Kaul, C. Walthall, C. Daughtry, and J. Lyndon. 2004. Need and feasibility of applying L-System models in agricultural crop modeling. Chap. 10. *In* M.N. Novak (ed.) Proc. Fractional 2004 Conf., Thinking in Patterns: Fractals and Related Phenomena in Nature, River Edge, World Scientific Publ.

Parker-Williams, A.P., and E.R. Hunt, Jr. 2004. Accuracy assessment for detection of leafy spurge with hyperspectral imagery. J. Range Manage. 57:106-112.

Pachepsky, L., M. Kaul, C. Walthall, J. Lydon, H. Kong, and C. Daughtry. 2004. Soybean growth and development visualized with L-systems simulations: Effects of temperature. Int. J. Biotronics. (in press).

# Soil Management Systems Component

**Problem Area 19:** Assessment and interpretation guidelines are needed to document the effects of current and alternative soil and crop management strategies on the Nation's soil resources.

**Background:** The concept of soil quality has received substantial discussion and become a major focal point for the NRCS and other groups interested in soil resource management. It is also important to recognize that the concept of soil quality and the tools and techniques being evaluated for its assessment are not the same as those developed for soil survey, which are intended to measure inherent soil characteristics. Soil quality or soil health evaluations focus on the dynamic soil condition, which is more temporal and often directly affected by recent and current land use decisions. To evaluate soil quality, measurement protocols and indexing techniques are needed for easy identification of the soil properties, processes, or functions that are affected by long-term crop production or any other land use. These tools must be sensitive and responsive to soil properties and processes that respond to changes in soil management practices and land use decisions. They should determine input needs and help land owners and operators select or develop more environmentally sound management practices while providing the food, feed, and fiber needed to satisfy increasing human needs. Soil quality assessment and interpretation techniques should help determine appropriate land use and the inputs required based on the physical, chemical, and biological conditions of the soil resource. Finally, these tools should be designed to help landowners and managers prioritize among soil resource problems that need to be addressed. Improved soil management and not soil quality assessment *per se* is the focus of this research. A fundamental knowledge gap with regard to soil quality assessment and evaluation is the interpretation and linking of various proposed biological, chemical, and physical indicators. Evaluation tools need to be developed that account for differences in inherent soil conditions among various geographic and physiographic regions and their response, both positive and negative, to management practices.

The goals of this research were:

Identify appropriate soil physical, chemical, and biological indicators or measures of soil quality, reliable assessment and monitoring tools and techniques, and the spatial and temporal variability associated with each indicator.

Establish appropriate baselines, expected ranges, and interpretation criteria for each soil quality indicator and the variability over space and time associated with various soil orders and climatic regions throughout the U.S.; and determine whether they can be quantitatively related to soil management inputs or outcomes.

Quantify the impacts of various land management practices at field, landscape, farm, watershed, regional, and ecosystem scales on indicators of soil quality.

**Accomplishments:**

**No-tillage and cover crops influence soil quality indicators:** The effects of cover crops and reduced tillage on soil properties and weed control needed to be quantified to encourage adoption of conservation practices that are economically and environmentally more sustainable than those currently used. Fatty-acid, methyl-ester (FAME) profiles indicated that microbial community composition was significantly influenced by tillage and cover crop, with fungi, gram-negative bacteria and gram-positive bacteria being dominant contributors to community structure. Temporal dynamics were different in no-tillage and conventional-tillage treatments, with the greatest FAME diversity in the no-tillage plus cover crop treatment. A balansa clover (*Trifolium balansae*) cover crop increased bacterial and fungal propagule number, enzyme activity and nitrate concentration, decreased weed density, but had no effect on cotton yield. No-tillage soils had higher organic carbon and nitrate concentrations than conventionally tilled soils with legume cover crops.

**Impact:** This research demonstrates that legume cover crops and no-tillage practices enrich soil ecosystems, but additional refinement is needed to capture those benefits through increased crop yield.

**Documentation:**

Locke, M.A., K.N. Reddy, and R.M. Zablotowicz. 2002. Weed management in conservation crop production. Weed Biol. Management. 2:123-132.

Reddy, K.N., R.M. Zablotowicz, M.A. Locke, C. Koger. 2003. Cover crop, tillage, and herbicide effects on weeds, soil properties, microbial populations, and soybean yield in the lower Mississippi delta**.** Weed Sci. 51:987-994.

Locke, M.A. and R.M. Zablotowicz. 2004. Pesticides in soil: benefits and limitations to soil health. p. 239-260. In: P. Schjonning, S. Elmholt, and B.T. Christensen (eds.), Managing soil quality-Challenge for modern agriculture, CABI International, Wallingford, U.K.

Zablotowicz, R.M. M.A. Weaver, K.N. Reddy, and A. Mengistu. 2004. Soil microbial populations and community structure as affected by tillage and cover crops. Proc. S. Regional Amer Soc. Agron. Mtg., Biloxi, MS, CD-ROM.

**Characterizing spatial variability facilitates soil quality assessment:** Characterizing spatial variability of soil properties is essential to understand any soil-related, landscape-scale process ranging from solute transport modeling to soil quality assessment or even precision agriculture. Protocols were developed to measure geospatial soil properties, including salinity, water content, texture, organic matter, bulk density, and pH through apparent soil electrical conductivity ($EC_a$), to document changes in forage yield and soil quality on a sodic soil where drainage water reuse was being evaluated as an alternative for reducing drainage water volumes. Developing relationships between soil electrical conductivity and these other soil parameters enables multiple soil properties to be evaluated by just measuring soil electrical conductivity, which is easier to measure than these other parameters.

**Impact:** The developed protocols represent a significant advance in establishing standardized guidelines for conducting and interpreting field surveys of $EC_a$ to assess and map soil quality while also characterizing soil spatial variability.

**Documentation:**

Lark, R. M., S. R. Kaffka, and D. L. Corwin. 2003. Multiresolution analysis of data on electrical conductivity of soil using wavelets. J. Hydrology. 272:276-290.

Barnes, E. M., K. A. Sudduth, J. W. Hummel, S. M. Lesch, D. L. Corwin, C. Yang, C. S. T. Daughtry, and W. C. Bausch. 2003. Remote- and ground-based sensor techniques to map soil properties. J. Photogrammetry & Remote Sensing. 69(6):619-630.

Corwin, D. L., S. R. Kaffka, J. D. Oster, J. Hopmans, Y. Mori, J. W. van Groenigen, C. van Kessel, and S. M. Lesch. 2003. Assessment and field-scale mapping of soil quality of a saline-sodic soil. Geoderma 114(3-4):231-259.

Corwin, D.L., and S.M. Lesch. 2004. Characterizing soil spatial variability with apparent soil electrical conductivity: I. Survey protocols. Computers and Electronics in Agriculture. 2004. (accepted 6/15/04).

Corwin, D.L., and S.M. Lesch. 2004. Characterizing soil spatial variability with apparent soil electrical conductivity: II. Case study. Computers and Electronics in Agriculture. 2004. (accepted 6/15/04).

**Soil organic matter stratification ratios useful indicator of soil quality:** Assessment strategies are needed to quantitatively evaluate the effects of various management practices across a variety of soils and environments. Stratification ratios of various soil organic C and N pools were calculated for soils managed under conventional and conservation tillage practices and successfully related to various soil functions such as water transmission, erosion, nutrient cycling, and overall biological activity. Stratification ratios were generally higher where conservation tillage rather than conventional practices were being used, but showed the largest difference when conservation tillage was being used on inherently poor soil resources (i.e. sandy rather than clayey soils and those in warm-humid regions rather than those in cold-semiarid regions).

**Impact:** Soil organic matter stratification ratios may be a useful indicator of soil quality.

**Documentation:**

Franzluebbers, A.J. 2002. Soil organic matter stratification ratio as an indicator of soil quality. Soil and Tillage Research. 66:95-106.

Franzluebbers, A.J., Grose, B., Hendrix, L.L., Wilkerson, P.K., Brock, B.G. 2003. Surface-soil properties in response to silage cropping intensity under no tillage on a Typic Kanhapludult. p. 444-451. In: Proc. 16$^{th}$ International Soil Tillage Research Organization, July 13-18, 2003. Brisbane Australia. (available on CD-ROM)

**Soil quality assessment quantifies soil management effects:** The soil quality concept was developed to more effectively evaluate the integrated long-term biological, chemical, and physical effects of various soil management practices. A multi-state project showed that several soil quality indicators were improved by placing highly erodible cropland into perennial grass through the Conservation Reserve Program (CRP). It also demonstrated that biological indicators were often more sensitive than either chemical or physical indicators. Soil quality assessment was successfully used to discriminate subtle differences between supplemental carbon management treatments and alternative vegetable production systems in the Central Valley of California. The Natural Resources Conservation Service (NRCS), producers, and others striving for greater recognition of the importance of soil resources in federal land use programs were all primary beneficiaries of this research.

**Impact:** This research has provided a science-based approach for incorporating soil quality assessment in inter-agency projects such as the Conservation Effects Assessment Program (CEAP) and premier conservation programs such as the Conservation Security Program (CSP).

**Documentation:**

Karlen, D.L., M.J. Rosek, J.C. Gardner, D.L. Allan, M.J. Alms, D.F. Bezdicek, M. Flock, D.R. Huggins, B.S. Miller, and M.L. Staben. 1999. Conservation Reserve Program Effects on Soil Quality Indicators. J. Soil Water Conserv. 54:439-444.

Andrews, S.S., J.P. Mitchell, R. Mancinelli, D.L. Karlen, T.K. Hartz, W.R. Horwath, G.S. Pettygrove, K.M. Scow, and D.S. Munk. 2002. On-farm assessment of soil quality in California's central valley. Agon. J. 94:12-23.

Andrews, S.S., D.L. Karlen, and J.P. Mitchell. 2002. A comparison of soil quality indexing methods for vegetable production systems in northern California. Agric. Ecosys. & Environ. 90(1):25-45.

Andrews, S.S., C.B. Flora, J.P. Mitchell, and D.L. Karlen. 2003. Growers' perceptions and acceptance of soil quality indices. Geoderma 114:187-213.

**Soil quality assessment confirms reduced tillage and fallow benefits in Great Plains soils:** For many years, loss of soil organic matter (SOM) in the Great Plains has been associated with tillage and summer fallow. Particulate organic matter (POM), EC, pH, inorganic N, total N (TN), and SOM measured for (CON) conventional (summer fallow, with tillage, and/or monocropping) and (ALT) alternative (reduced or conservation tillage, reduced fallow, and/or extended crop rotations) at eight locations throughout the U.S. and Canadian Great Plains showed that ALT treatments improved soil TN, $NO_3$-N, SOM, POM, EC, and pH in the 0 to 7.5 cm increment at most study locations. Treatment differences in the lower two depths were observed at Fargo (1.71 Mg N $ha^{-1}$ in the CON treatment vs. 2.03 Mg N $ha^{-1}$ in the ALT treatment) and Swift Current (1.72 Mg N $ha^{-1}$ in the CON treatment vs. 1.97 Mg N $ha^{-1}$ in the ALT treatment) for the 7.5 to 15 cm increment. At Bushland, a similar trend in total N at the deeper soil depths (15-30 cm increment) was observed (1.77 Mg N $ha^{-1}$in the CON treatment vs 2.03 Mg N $ha^{-1}$ in the ALT treatment). Particulate organic matter (POM) was greater in the 0 to 7.5 cm depth of the ALT treatment than the CON treatment at Mandan, Sidney, and Swift Current. In addition, POM was 44% greater in soils from the ALT treatment than in soils from the CON treatment at Fargo ($P = 0.06$). Soil $NO_3$-N and EC in the 0 to 7.5 cm depth were positively correlated ($r = 0.79$). In general, chemical soil properties measured in this study generally exhibited values more conducive to crop production and environmental quality in the ALT treatment than in the CON treatment. Improvements in soil chemical properties in the ALT treatment were attributed to a reduction in tillage intensity and incidence of fallow. Differences between the two treatments were usually only detected in the surface 7.5 cm, underscoring the importance of sampling this near-surface soil depth for assessing management effects on soil chemical properties.

**Impact:** Alternative soil and crop management systems led to an improvement in several soil quality indicators. These alternative soil and crop management systems thus should be more sustainable for producers than conventional management practices across the entire Northern Great Plains region.

**Documentation:**

Mikha, M.M., M.F. Vigil, M.A. Liebig, R.A. Bowman, B. McConkey, E.J. Deibert, and J.L. Pikul, Jr. 2004. Cropping system influences on soil chemical properties and soil quality in the Great Plains. Renewable Agriculture & Food Systems (In review).

Wienhold, B.J., J.L Pikul, Jr., M.A. Liebig, M.M. Mikha, G.E. Varvel, J.W. Doran, and S.S. Andrews. 2005. Cropping system effects on soil quality in the Great Plains: Summary from a Regional Project. Renewable Agriculture & Food Systems (In review).

**Soil management assessment framework (SMAF) developed to evaluate soil quality:** Methods for measuring and assessing soil management effects on soil quality are needed to balance productivity with potential environmental impacts of agricultural production. Total organic carbon (TOC), total N (TN), and water stable aggregation (WSA) were the most sensitive regional-scale soil quality indicators in the Central and Southern High Plains. Potentially mineralizable N (PMN), microbial biomass carbon (MBC), WSA and TOC were the most discriminating attributes among land uses in the Northern Mississippi Valley Loess Hills, while TOC and TN were the most sensitive indicators for the Palouse and Nez Perce Prairies. A framework consisting of indicator selection, interpretation, and integration into an index was developed to facilitate assessment of how soil management affected various soil functions. The results were demonstrated to be transferable to a variety of climates, soil types, and soil management systems. The primary beneficiaries of this research are the Natural Resources Conservation Service (NRCS) who is responsible for assessing the status of the nation's soil resources and producers who now have an integrative tool for evaluating the combined biological, chemical, and physical effects of their management decisions on their soil resources.

**Impact:** The concept of soil quality and its use as a tool for assessing the effects of various soil management practices was developed and evaluated through these research efforts. This enabled the NRCS to move aggressively in establishing soil quality as being equal to water quality in projects such as the Conservation Effects Assessment Project (CEAP) and the Conservation Security Program (CSP).

**Documentation:**

Brejda, J. J., T.M. Moorman, J.L. Smith, D.L. Karlen, D.L. Allan, and T.H. Dao. 2000. Distribution and variability of surface soil properties at a regional scale. Soil Sci. Soc. Am. J. 64:974-982.

Brejda, J. J., T.M. Moorman, D.L. Karlen, and T.H. Dao. 2000. Identification of regional soil quality factors and indicators. I. Central and southern High Plains. Soil Sci. Soc. Am. J. 64:2115-2124.

Brejda, J. J., D.L. Karlen, J.L. Smith, and D.L. Allan. 2000. Identification of regional soil quality factors and indicators. II. Northern Mississippi Loess Hills and Palouse Prairie. Soil Sci. Soc. Am. J. 64:2125-2135.

Andrews, S.S., D.L. Karlen, and C.A. Cambardella. 2004. The soil management assessment framework: a quantitative soil quality evaluation method. Soil Sci. Soc. Am. J. 68:000-000 (accepted 06/02/04)

**Soil quality contradictions and potential implementation pitfalls identified:** The soil quality concept is seen by some in the soil science community as a means of promoting improved soil stewardship through development of soil property monitoring indices to track management effects and as a communication and education tool for farmers and the lay public. However, other soil scientists believe the soil quality concept has conceptual contradictions, definitional failures and potential implementation pitfalls. Several renowned soil scientists and agronomists explored the extent and depth of concern about the soil quality concept, itemizing more that twenty specific technical and conceptual problems with extensive examples and documentation from the scientific literature. The soil science community at large and action agencies are the primary beneficiaries, having been given an organized and considered list of concerns that can serve as a basis for concept refinement and alert concept users to potential sources of conflict arising from unresolved facets of the concept.

**Impact:** This discussion has been one of the most important dialogues in soil science in recent years.

**Documentation:**

Sojka, R.E. and D.R. Upchurch. 1999. Reservations regarding the soil quality concept. Soil Sci. Soc. Am. J. 63:1039-1054.

Sojka, R.E. and D.R. Upchurch. 1999. Challenges for identifying best management practices--integrating emerging modern technologies and philosophies. In Best soil management practices for production. p. 11-25. In: L.D. Currie, M.J. Hedley, D.J. Horne and P. Loganathan (eds.). Occasional Report No. 12. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand.

Singer, M.J., and R.E. Sojka. 2002. Soil quality. p. 312-314. In: E. Geller, et al. (eds). McGraw-Hill Yearbook of Science & Technology, McGraw-Hill, Inc., New York.

Sojka, R.E., D.R. Upchurch, and N.E. Borlaug. 2003. Quality soil management or soil quality management: Performance versus semantics. Advances in Agronomy 79:1-68.

Letey, J., R.E. Sojka, D.R. Upchurch, D.K. Cassel, K.R. Olson, W.A. Payne, S.E. Petrie, G.H. Price, R.J. Reginato, H.D. Scott, P.J. Smethurst, and G.B. Triplett. 2003. Deficiencies in the soil quality concept and its application. J. Soil Water Conserv. 58(4):180-187.

Price, G.H., P.J. Smethurst, L.A. Sparrow, and R.E. Sojka. 2004. Soil Quality - to regulate or to manage? p. 938-942. In: Proc. International Soil Tillage Research Organization 16th Triennial Conf. Soil Management for Sustainability. July 13-18, 2003, Brisbane, Australia.

**Soil quality changes with no-till take longer in low rainfall zones:** Growers in the United States and worldwide are adopting no-tillage (no-till) cropping to reduce soil erosion, improve soil quality, increase water infiltration, and reduce number of passes with farm equipment over their fields. Long-term no-till increased organic carbon over time, although response is variable, and also increased the proportion of aggregates in the larger (> 50 micron) size fractions. Soil quality changes during transition to no-till were less perceptible and more variable in the low (150 to 300 mm annual) precipitation zones compared to the higher (300 to 550 mm annual) precipitation zones. Lower disturbance with direct seeding had more impact on soil quality measurements than surface residue management. This information provides growers in the Inland Pacific Northwest and scientists with practical information regarding soil quality changes associated with soil and crop management practices.

**Impact:** These long-term experimental results will allow scientists and growers to better assess the productivity and quality of soils in the dryland cropping regions especially in no-till cropping systems.

**Documentation:**

Petersen, S.O., P.S. Frohne and A.C. Kennedy. 2002. Dynamics of a soil microbial community under spring wheat. Soil Sci. Soc. Amer. J. 66:826-833.

Kennedy, A.C. and W.F. Schillinger. 2003. Soil quality changes with no-till management adoption for wind erosion control. p. 67-73. In W.L. Schillinger and B. Sharratt (eds.) Northwest Columbia Plateau Wind Erosion/Air Quality Project Research Reports -2003. Washington State University, Pullman, WA. (Technical Report)

Kennedy, A.C., T.L. Stubbs and W.F. Schillinger. 2004. Soil and crop management effects on soil microbiology. pp 295-326. In F. Magdoff and R.R. Weil (eds.) Soil Organic Matter in Sustainable Agriculture. Advances in Agroecology Series, CRC Press. Boca Raton, FL. 2004.

**Qualitative soil quality indicators developed for rangeland assessments:** Rangeland assessments based solely on vegetation often fail to correctly identify the critical processes associated with ecosystem degradation and recovery. A suite of qualitative soil quality indicators was developed, integrated with vegetation indicators, and used to produce a technical reference that is being widely applied by the NRCS, Bureau of Land Management (BLM), private consultants, and by international researchers and practitioners in Mexico, Canada and China.

**Impact:** These indicators are being used to help land managers decide where to allocate scarce management and monitoring resources by providing information on which areas are in greatest need of management action and which processes (e.g. erosion or invasive species) need to be addressed.

**Documentation:**

Pellant, M., P. Shaver, D. Pyke and J.E. Herrick. 2000. Interpreting Indicators of Rangeland Health, Version 3. Interagency Technical Reference 1734-6. Bureau of Land Management, Denver, Colorado.

Pyke, D.A., J.E. Herrick, P. Shaver, M. Pellant. 2002. Rangeland health attributes and indicators for qualitative assessment. Journal of Range Management 55:584-597.

Pyke, D.A., J.E. Herrick, P. Shaver and M. Pellant. 2003. What is the standard for rangeland health assessments? Proceedings of the IV$^{th}$ International Rangeland Congress, Durban, South Africa (compact disk).

Pellant, M., P. Shaver, D. Pyke and J.E. Herrick. 2005. Interpreting Indicators of Rangeland Health, Version 4. Interagency Technical Reference 1734-6. Bureau of Land Management, Denver, Colorado. (accepted 09/01/2004)

**Quantitative soil quality indicators developed for rangeland inventory and monitoring:** Rangeland assessments and monitoring based solely on vegetation indicators often fail to detect degradation until it is too late for management intervention. A suite of new easily measured soil quality indicators was developed for use on rangeland. These indicators are generated using three new tools: a soil stability kit, impact penetrometer and infiltrometer. These tools generate more sensitive and/or more cost effective data than previously existing tools, and are now being manufactured by at least one company (http://www.countgrass.com/tools.htm). The soil stability kit is the only quantitative soil protocol for the NRCS NRI and has been adopted as a standard monitoring tool by several individuals working with the BLM, DOD, Nature Conservancy, and other organizations.

**Impact:** Developing these soil quality indicators enabled rangeland managers to generate more useful information on the status and changes of both private and public rangeland. This information can be used to improve rangeland policy and management changes.

**Documentation:**

Herrick, J.E., W.G. Whitford, A.G. de Soyza, J.W. Van Zee, K.M. Havstad, C.A. Seybold, M. Walton. 2001. Soil aggregate stability kit for field-based soil quality and rangeland health evaluations. CATENA 44: 27-35.

Herrick, J.E. and T.L. Jones. 2002. A Dynamic cone penetrometer for measuring soil penetration resistance. Soil Science Society of America Journal 66: 1320-1324.

Herrick, J.E., J.R. Brown, A. Tugel, P.L. Shaver and K.M. Havstad. 2002. Application of soil quality to monitoring and management: paradigms from rangeland ecology. Agronomy Journal 94: 3-11.

Spaeth, K.E., F.B. Pierson, J.E. Herrick, P.L. Shaver, D.A Pyke, M. Pellant, D. Thompson, and R. Dayton. 2003. New proposed National Resources Inventory protocols on nonfederal rangelands. Journal of Soil and Water Conservation 53: 18A-23A.

**CRP and reduced tillage improves semi-arid soils:** The benefits of and best management strategies for conservation tillage and the Conservation Reserve Program (CRP) in semi-arid regions need to be documented to encourage landowners and operators to adopt these practices. Irrigated no-tillage and perennial pasture systems were found to have higher levels of soil C, soil enzymes important in nutrient cycling processes, and aggregate stability than conventionally-tilled irrigated or dryland cotton systems, even when a cover crop was included in the system. Long-term CRP (dryland grassland condition) positively influenced these soil properties, but not to the extent of native grassland.

**Impact:** Converting from conventional- to reduced- or no-tillage practices have resulted in many benefits to agricultural producers in humid and sub-humid environments. These include: reduced wind and water erosion, increased infiltration and soil water retention, decreased evaporation, increased nutrient cycling efficiencies, and decreased production costs.

**Documentation:**

Acosta-Martinez V., S. Klose, and T.M. Zobeck. 2003. Enzyme activities in semiarid soils under conservation reserve program, native rangeland, and cropland. J. Plant Nutr. Soil Sci. 166: 699-707.

Acosta-Martinez V., T.M. Zobeck, T.E. Gill, A.C. Kennedy. 2003. Enzyme activities and microbial community structure in semiarid agricultural soils. Biol. Fertil. Soils 38:216-227.

Acosta-Martinez V., T.M. Zobeck, and V. Allen. 2004. Soil microbial, chemical and physical properties in continuous cotton and integrated crop-livestock systems. Soil Sci. Soc. Am. J. (accepted 02/02/2004).

Bronson, K.F., Zobeck, T.M., Chua, T.T., Acosta-Martinez, V. and Booker, J.D. 2004. Carbon and Nitrogen Pools of Southern High Plains Cropland and Grassland Soils. Soil Sci. Soc. Am. J. 68:1695-1704.

**Ridge-tillage and crop rotation improve soil health:** Management practices that balance corn and soybean production, economic returns, and soil health can be complex in the northern U.S. Corn/Soybean Belt because of cool and wet conditions. Corn and soybean yield, nitrogen use, water use, and soil nitrate accumulation showed very little difference between ridge-tillage and chisel-plow treatments, but after 9 years of ridge-tillage soil organic carbon was 34% higher indicating an improvement in soil health. Continuous corn returned 2.3 times as much plant carbon to the soil as a 4-year corn-soybean-wheat-alfalfa rotation, but after 10 years of conventional tillage there was a net loss of soil carbon from the top 15 cm (6 inches) of soil for both rotations. Regarding N use efficiency, the 4-year rotation without fertilizer yielded only 9% less than continuous corn having sufficient available inorganic N (average soil and fertilizer N was 185 kg N/ha) to yield 8,500 kg/ha (135 bu/acre).

**Impact:** Soil quality can be improved without sacrificing economic return by adopting reduced tillage in the northern Corn/Soybean Belt. Increased crop diversity resulted in grain yield that was competitive with continuous corn but did not require any supplemental N fertilizer. These results confirm that producers are not increasing their risk or facing a loss of profit by adopting ridge-tillage, a crop production system that promotes soil conservation.

**Documentation:**

Carpenter-Boggs, L., J.L. Pikul, Jr., M.F. Vigil, and W.E. Riedell. 2000. Soil nitrogen mineralization influenced by crop rotation and nitrogen fertilization. Soil Sci. Soc. Am. J. 64:2038-2045.

Pikul, J.L. Jr., L. Carpenter-Boggs, M. Vigil, and W.E. Riedell, T.E. Schumacher. 2000. Crop yield and soil condition under ridge and chisel-plow tillage in South Dakota, USA. In J. E. Morrison, Jr (ed) Proceedings 15th International Soil and Tillage Research Organization (ISTRO) Fort Worth, Texas, USA. July 2-7, 2000. (Available on CD ROM,

Published by P. Dyke, Texas Agricultural Experiment Station, Temple, Texas USA.)
Gajda, A.M, J.W. Doran, T.A. Kettler, B.J. Wienhold, J.L. Pikul Jr., and C.A. Cambardella. 2001. Soil Quality Evaluations of Alternative and Conventional Management Systems in the Great Plains. p. 381-400. In: R. Lal, J.F. Kimble, and R.F. Follett, (eds.) Assessment methods for soil carbon. CRC Press, Boca Raton, FL.
Pikul, J.L. Jr., L. Carpenter-Boggs, M. Vigil, T.E. Schumacher, M.J. Lindstrom, and W.E. Riedell. 2001. Crop yield and soil condition under ridge and chisel-plow tillage in the northern Corn Belt, USA. Soil & Tillage Research. 60:21-33.
Pikul, J.L. Jr., T.E. Schumacher, and M. Vigil. 2002. Nitrogen Use and Carbon sequestered by Corn Rotations in the Northern Corn Belt, U.S. p. 707-713. In: J. Galloway, E. Cowling, J.W. Erisman, J. Wisniewski, and C. Jordan. (eds.) Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection. A.A. Balkema Publishers, Lisse, The Netherlands.
Pikul, J.L. Jr., S.F. Wright, L. Jawson, M.M. Ellsbury. 2002. Soil carbon and glomalin concentration under crop and tillage management in eastern South Dakota. p. 342-344. In: Proc. 20th International Humic Substances Society Conference. Northeastern University, Boston, Massachusetts.
Archer, D.W., J.L. Pikul Jr., W.E. Riedell. 2002. Economic risk, returns and input use under ridge and conventional tillage in the northern Corn Belt, USA. Soil & Tillage Res. 67:1-8.

**Organic amendments, crop residues, and minimum tillage improve claypan soil quality:** Soil and crop management practices cannot be optimized to improve soil function without basic knowledge of the relationships between agricultural practices and biological processes. Respiration, enzyme activity, and microbial community profiles in claypan soils in northeast Missouri were generally higher when soil organic matter levels were improved by adding organic amendments, retaining crop residues and adopting minimum tillage practices. Producers and others interested in manipulating the soil biological environment to enhance the quality and productivity of soil resources are the primary beneficiaries of this research.

**Impact:** Relatively simple and inexpensive soil management tactics that can improve overall productivity and functioning of claypan soils have been identified. These types of soils are found on a total area of about 4 million ha (10 million acres) in the Midwestern United States.

**Documentation:**
Kremer, R.J. and Li, J. 2003. Developing weed suppressive soils through improved soil quality management. Soil Tillage Research 72:193-202.
Means, NE., Starbuck, C.J., Kremer, R.J., and Jett, L. 2004. Effects of a food-waste-based soil conditioner on soil properties and plant growth. Compost Science and Utilization (accepted August 12, 2004).
Kremer, R.J. and Park, K. 2004. Soil amendment with organic materials for improved soil quality. p. 72. In: Proceedings of the Sustainable Land Application Conference, Univ. FL. Institute of Food & Agricultural Sciences (IFAS), Gainesville, FL. (Abstract)

**Organic production systems influence soil quality:** Organic production systems are dependent upon manures and/or compost, tillage, crop rotation, residue decomposition, and nutrient cycling. Evaluations of crop, soil, weed, and insect parameters in two, three, and four-year organic cropping systems demonstrated that grain crops can be successfully produced in the early transition years to organic management with good economic return without reducing soil organic carbon content or overall soil quality. Producers, Cooperative Extension personnel, other researchers, and organic cooperatives investing in this rapidly expanding market are the primary beneficiaries of this research.

**Impact:** The interdisciplinary systems approach has facilitated active communication among scientists and producers and provided the means for immediate feedback on research results. It has also led to several invited workshops, seminars, and field day or classroom presentations on the topic of soil quality in organic agriculture.

**Documentation:**

Gajda, A. M., J. W. Doran, T. A. Kettler, B. J. Weinhold, J. L. Pikul, and C. A. Cambardella. 2000. Soil quality evaluations of alternative and conventional management systems in the Great Plains. p. 381-400. In: Lal, R., J. M. Kimble, R. J. Follett, and B. A. Stewart (eds.), Assessment Methods for Soil Carbon. Lewis Publishers/CRC Press, Boca Raton, FL.

Delate, K., C. A. Cambardella, and D. L. Karlen. 2002. Transition strategies for post-CRP certified organic grain production. Crop Management. (available on-line) http:///www.plantmanagementnetwork.org/pub/cm/research/postcrp.

Delate, K., C. A. Cambardella, and D. L. Karlen. 2002. Soil Quality in Organic Agricultural Systems. ISU Extension Publication PM 1882. Iowa State University, Ames, IA. 8 p.

Delate, K. and C. A. Cambardella. Agroecosystem performance during transition to organic grain production. Agronomy J. (accepted 4/10/ 2004).


**Soil quality indicators respond positively to no-tillage and manure:** Soil organic matter is an important source of nutrients and a major binding agent that stabilizes soil aggregates, thus reducing soil erosion and improving soil structure, plant growth, and soil water infiltration. No-tillage and manure individually significantly increased soil aggregation especially macroaggregate >2000 μm size fraction (13.2 *v.s* 4.8 g 100 $g^{-1}$ soil for no-tillage (NT) and conventional-tillage (CT), respectively, and 11.5 *vs* 6.6 g 100 $g^{-1}$ soil for manure (M) and fertilizer (F), respectively). The same pattern was observed with aggregate-associated C after 10-yr of treatment were it was significantly greater with NT (35 g C $kg^{-1}$ sand-free aggregate) than CT (24 g C $kg^{-1}$ sand-free aggregate) and with M (33 g C $kg^{-1}$ sand-free aggregate) than F (25 g C $kg^{-1}$ sand-free aggregate), but when combined (*i.e.* manure plus no-tillage) soil aggregation and aggregate-protected C and N (measured using 28-d laboratory incubations) improved even more. The combination of NT and M improved soil aggregation (especially macroaggregate >2000 μm size fraction) by 1.6 and 2.5 fold compared with NT-F and CT-M treatments, respectively. However, aggregate labile C and N were greater with NT-M than CT-M by 1.1 and 1.9 fold, respectively.

**Impact:** This research quantifies the benefits of no-tillage and manure on soil organic matter, aggregation and nutrient cycling, thus providing information needed to encourage the adoption and use of these soil management practices.

**Documentation:**

Mikha, M.M., and Charles W. Rice. 2004. Tillage and manure effects on soil and aggregate-associated carbon and nitrogen. Soil Science Society of America Journal 68:809-816.

# Soil Resource Management National Program Projects Output (2001 –present)

Direct comparisons between locations and projects are complicated by:

- Vacancies
- Nature of the projects
- Whether output was prorated to include only those most applicable to the Soil Resource Management National Program or includes the complete output of the project.

Some units provided information only if their project was primarily coded (>60%) to the Soil Resource Management National Program while others provided this information regardless of coding percentage. Accomplishment statements were provided by units not represented in this table.

| Project Location[1] | Number of Scientists[2] | Soil NP %[3] | Peer-Reviewed Publications | Technology Transfer Publications | Invited Presentations | CRADAs[4] | Patents | Graduate Students Mentored | Postdocs Mentored | Extramural Grants Funded[5] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Akron, CO** | 6.0 | 100 | 96 | 11 | 109 | 1 | 0 | 2 | 2 | 2 |
| **Ames, IA** | 2.6 | 100 | 21 | 9 | 48 | 0 | 0 | 8 | 3 | 29 |
| **Ames, IA** | 2.5 | 30 | 33 | 13 | 7 | 2 | 0 | 8 | 2 | 5 |
| **Auburn, AL** | 7.0 | 70 | 25 | 89 | 117 | 1 | 1 | 20 | 2 | 21 |
| **Auburn, AL** | 1.2 | 40 | 25 | 20 | 7 | 0 | 0 (one application) | 3 | 0 | 7 |
| **Beltsville, MD (SASL)** | 2 | 100 | 26 | 1 | 10 | 0 | 1 | 1 | 1 | 1 |
| **Beltsville, MD (HRSL)** | 3.5 | 60 | 44 | 21 | 31 | 1 | 0 | 8 | 1 | 11 |
| **Beltsville, MD (EQL)** | 1.95 | 70 | 18 | 22 | 10 | 0 (one in negotiation) | 0 | 4 | 2 | 5 |
| **Beaver, WV** | 5.0 | 70 | 32 | 0 | 5 | 0 | 0 | 0 | 0 | 1 |
| **Brookings, SD** | 2.0 | 60 | 17 | 54 | 14 | 0 | 0 | 1 | 0 | 1 |

| Project Location[1] | Number of Scientists[2] | Soil NP %[3] | Peer-Reviewed Publications | Technology Transfer Publications | Invited Presentations | CRADAs[4] | Patents | Graduate Students Mentored | Postdocs Mentored | Extramural Grants Funded[5] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Bushland, TX** | 2.05 | 70 | 36 | 5 | 3 | 0 | 0 | 6 | 0 | 3 |
| **Columbia, MO** | 5.0 | 30 | 13 | 0 | 15 | 0 | 0 | 7 | 3 | 4 |
| **Florence, SC** | 1.2 | 70 | 12 | 10 | 2 | 0 | 0 | 0 | 0 | 1 |
| **Ft. Collins, CO (SPNL)** | 3.9 | 70 | 85 | 49 | 62 | 0 | 0 | 4 | 1 | 6 |
| **Ft. Pierce, FL** | 1.0 | 30 | 6 | 0 | 3 | 0 | 0 | 1 | 0 | 2 |
| **Kimberly, ID** | 3.55 | 70 | 92 | 32 | 50 | 0 | 0 (4 applica-tions) | 2 | 1 | 5 |
| **Lincoln, NE** | 2.1 | 70 | 28 | 13 | 31 | 0 | 0 | 2 | 0 | 2 |
| **Lubbock, TX** | 2.05 | 60 | 8 | 5 | 10 | 0 | 0 | 3 | 0 | 4 |
| **Mandan, ND** | 3.6 | 60 | 36 | 79 | 64 | 0 | 0 | 1 | 0 | 5 |
| **Morris, MN** | 2.0 | 100 | 12 | 29 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Morris, MN** | 2.1 | 40 | 9 | 24 | 10 | 0 | 0 | 0 | 0 | 1 |
| **Orono, ME** | 1.8 | 30 | 16 | 2 | 2 | 0 | 0 | 3 | 1 | 1 |
| **Parlier, CA** | 2.9 | 30 | 6 | 4 | 10 | 0 | 0 | 1 | 0 | 0 |
| **Pendleton, OR** | 3.0 | 70 | 10 | 8 | 9 | 0 | 0 | 0 | 2 | 0 |
| **Pullman, WA** | 2.6 | 40 | 28 | 8 | 16 | 1 | 0 | 8 | 1 | 6 |
| **Riverside, CA** | 1.1 | 70 | 37 | 2 | 12 | 0 | 0 | 0 | 0 | 0 |
| **St. Paul, MN** | 0.5 | 60 | 8 | 10 | 15 | 0 | 0 | 3 | 2 | 5 |
| **St. Paul, MN** | 4.0 | 60 | 18 | 7 | 12 | 0 | 0 (one application) | 5 | 2 | 2 |

| Project Location[1] | Number of Scientists[2] | Soil NP %[3] | Peer-Reviewed Publications | Technology Transfer Publications | Invited Presentations | CRADAs[4] | Patents | Graduate Students Mentored | Postdocs Mentored | Extramural Grants Funded[5] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Salinas, CA** | 1.0 | 30 | 4 | 6 | 10 | 0 | 0 (one application) | 0 | 1 | 2 |
| **Stoneville, MS** | 2.0 | 70 | 20 | 5 | 10 | 1 | 0 | 1 | 1 | |
| **Temple, TX** | 3.3 | 60 | 11 | | 2 | 3 | 0 (3 applica-tions) | | | 2 |
| **Tifton, GA** | 2.04 | 70 | 22 | 1 | 12 | | | | | |
| **Urbana, IL** | 1.1 | 60 | 10 | 1 | 3 | 0 | 0 | 7 | 3 | 5 |
| **Watkinsville, GA** | 3.8 | 70 | 31 | 54 | 14 | 0 | 0 | 1 | 0 | 4 |
| **Weslaco, TX** | 3.3 | 30 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **West Lafayette, IN** | 2.4 | 70 | 22 | 10 | 5 | 0 | 0 | 15 | 1 | 0 |
| **Wyndmoor, PA** | 3.0 | 70 | 20 | 5 | 13 | 0 | 0 | 1 | 2 | 2 |

1. Site of research laboratory or unit with a Soil Resource Management National Program project. Some locations have more than one unit with a project in the Soil Resource Management National Program and some units have more than one Soil Resource Management National Program project.

2. Number of scientists assigned to this project. Scientists can be assigned to more than project with a research unit or location; thus, fractions of time are frequently indicated.

3. Projects can be coded to more than one National Program. This column indicates the percentage of coding that a project has to the Soil Resource Management National Program.

4. Cooperative Research and Development Act (CRADA) is a federal act to facilitate transfer of research to the private sector. CRADAs are often a step in transferring patentable results to the private sector, but not all CRADAs involve patents.

5. This column was intended to represent the number of extramural grants obtained by a project, but some locations appear to have interpreted this item to be the number of cooperative and other agreements they have funded with researchers outside their unit.