# Manure and Byproduct Utilization:

## ARS National Program 206

### Accomplishment Report 2003 – 2008

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# Introduction

## Background

Manure and Byproduct Utilization 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); Crop Production and Protection (CPP); Nutrition, Food Safety/Quality (NFSQ); and Natural Resources and Sustainable Agricultural Systems (NRSAS). The Manure and Byproduct Utilization National Program is part of NRSAS, but interactions also occur with researchers in the other three areas. The National Program structure allows ARS to link scientists in laboratories around the country to address research problems of regional and national interest.

According to the National Agricultural Statistics Service, over one billion tons of agricultural (e.g., manure), municipal (e.g. biosolids), and industrial (e.g. coal combustion products) wastes with potential uses in agriculture are generated annually in the United States. Many of these materials are spread, sprayed or otherwise applied to agricultural land because of the benefits they provide. These benefits include: providing a nutrient source for crops; improving soil chemical, physical and biological properties; improving soil water storage and use; reducing movement of contaminants to water and air; and reducing production costs and energy use. However, improperly managed manure and other byproducts can pose a threat to soil, water and air quality, and to human and animal health.

The goal of the Manure and Byproduct Utilization National Program is to effectively and safely manage and use manure and other byproducts while protecting the environment and human and animal health. This goal is achieved by characterizing potential hazards, developing treatment practices and systems to alleviate problems, and providing information and decision support tools for technology transfer to scientists, extension agents, action agencies, producers, regulators, and policy makers. Sustainable agriculture depends on effective management of manure and byproducts.

## Program Planning Process and Plan Development

Information from several sources is used to make this National Program relevant to interested parties including producers, technical service providers, regulators, policy makers, public interest groups and other scientists. Sources of information include the report from an Assessment Panel that reviewed ARS research accomplishments over the previous five years; input from a National Program Planning Workshop; and input from other activities such as USDA and interagency programs, committees, and meetings attended by ARS scientists and National Program Leaders. The Manure and Byproduct Utilization National Program Planning Workshop was held in April 2004. Approximately 150 participants including producers, commodity group representatives, public interest group representatives, scientists from universities, and scientists and administrators from ARS and other Federal and State agencies attended this workshop. The participants identified and prioritized problems that needed to be addressed in the next five years by this National Program. Four key areas of research (atmospheric emissions, nutrient

management, pathogens and pharmaceutically active compounds, and beneficial uses of municipal and industrial byproducts) were identified using input from the workshop and the other information sources mentioned previously. These four areas of research became the four Components of the Manure and Byproduct Utilization National Program.

ARS National Program Leaders and scientists synthesized information from all the sources to develop a framework for research (Action Plan) in the Manure and Byproduct Utilization National Program. The Action Plan identifies research focus areas, known as Problem Areas, within each of the four Components of the National Program. A program logic model approach was used to identify the desired outcomes of the research, the outputs or products needed to achieve the outcomes, and the resources (human and financial) available to develop these products for each of the Problem Areas in this Action Plan. ARS scientists at each of the laboratories participating in this and related National Programs (e.g., Water Quality and Management, Soil Resource Management, Air Quality, Animal Production, Food Safety, and Integrated Agricultural Systems) used this Action Plan to develop Project Plans that describe the research to be conducted in each laboratory. The Project Plans provide detailed information on objectives, anticipated products or information to be generated, the approach that will be used, roles and responsibilities of ARS scientists and their cooperators, and timelines and milestones to measure progress of the research. All Project Plans were reviewed for scientific quality by an independent panel of experts in the field. ARS scientists use input from the review panel to revise and improve their planned research. Cooperation occurs among ARS laboratories to develop the products and achieve the outcomes identified in the Action Plan. Cooperators from academia, other agencies, and industry are full partners in the research and in the outreach and technology transfer activities resulting from the research.

## Program Components

The following paragraphs provide a brief description of each component and a listing of the Problem Areas within each component.

**Atmospheric Emissions:** ARS research on air emissions from animal production operations and land application of manure and other byproducts is directed toward developing management practices, control technologies and decision tools that will allow producers and their advisors to reduce or eliminate emissions of particulate matter, ammonia, volatile organic compounds associated with odor and formation of tropospheric ozone, hydrogen sulfide, methane, oxides of nitrogen and pathogens. Research is conducted at swine, poultry, dairy cattle and beef cattle production operations and in the laboratory where processes that control emissions are investigated. Measurement and prediction of emissions from animal production operations will help provide the scientific background for State and Federal regulatory and management decisions. Problem Areas include: (1) Understanding biological, chemical and physical mechanisms affecting emissions; (2) Measurement of emissions from livestock facilities; (3) Control technologies and strategies for emissions reduction; and (4) Atmospheric fate and transport to receptors.

**Nutrient Management:** Movement of nutrients in excess amounts from manure and other byproducts to soil, water and air can cause significant environmental problems. Nutrient losses to the environment can occur at the production site, during storage, and during and after field

application. Nitrogen and phosphorus from manure and other sources have been associated with algal blooms and accelerated eutrophication of lakes and streams. Utilization of nutrients in manures in an environmentally sustainable manner is one of the critical management issues facing the U.S. livestock industry. ARS scientists are conducting research to develop management practices, control technologies, and decision tools for effective agricultural use of nutrients from manure and other byproducts, while protecting environmental quality, human health and animal health. Problem Areas include: (1) Animal feeding and management; (2) Innovative technology for collection, storage and treatment of manure; (3) Management tools for indexing and evaluating nutrient fate and transport; and (4) Farming systems and practices for efficient and balanced manure nutrient management.

**Pathogens and Pharmaceutically Active Compounds**: Pathogens and pharmaceutically active compounds in manure, biosolids, and other byproducts can be transmitted to animals and humans through food supplies, water, and possibly air. Livestock and poultry can be re-infected not only via water and air, but also from other vectors such as birds, rodents, and insects that can directly infect the animal or contaminate animal feeds or water. The protozoan parasites *Cryptosporidium parvum* and *Giardia duodenalis*, and the bacterial pathogens *Escherichia coli*, *Salmonella,* and *Campylobacter* are among the most significant of the manure-borne zoonotic pathogens. Large amounts of pharmaceutically active compounds such as hormones and antibiotics may be present in animal wastes (wastewater and manure) and disseminated in the environment. ARS scientists are investigating the processes that control the transport and persistence of pharmaceuticals and pathogens in livestock manure and the environment to accurately assess risks and vulnerabilities, and to develop control mechanisms. Problem Areas include: (1) Method assessment and development; (2) Fate and transport of pathogens; (3) Pharmaceutically active compounds; and (4) Treatment technologies for control of pathogens and pharmaceutically active compounds.

**Byproducts:** Agricultural, municipal and industrial byproducts are frequently considered to be wastes and are often disposed in landfills. However, many of these materials have characteristics that make them potentially useful to improve crop production, to reclaim and remediate degraded soils, to produce manufactured soils and composts, to promote clean air and water resources, and/or to lower energy inputs in agricultural systems. Research is being conducted to determine benefits and risks of the materials, to develop and demonstrate byproduct uses, to develop guidelines for appropriate uses of byproducts, and to provide information to regulatory and advisory agencies to allow agricultural and horticultural uses of the materials. Problem Areas include: (1) Phytoavailability and bioavailability of nutrients, trace elements and xenobiotics in byproducts; (2) Protocols and methodology for byproduct evaluation; (3) Byproduct utilization technologies; and (4) Energy from byproducts.

## How This Report was Constructed and What It Reflects

This Accomplishment Report consists of selected research accomplishments, in the five year period between 2003 and 2008 in the Manure and Byproduct Utilization National Program. The accomplishments included in this report provide a broad picture of the research conducted in the program. A majority of the research described in the report was conducted with scientific partners from universities and/or state and federal agencies. Many of the accomplishments represent a summary of several research projects conducted by multiple scientists from within and outside ARS. Individual laboratories are not identified in the report since the purpose of the

review is to assess the overall National Program, not individual scientists or laboratories. A potential or current impact is given with each accomplishment along with a representative example of publications or other documentation. The Accomplishment Report is organized into five sections including an Introduction plus a section for each of the four components. Each component contains a summary of the research findings followed by accomplishments organized under the Problem Areas in each component.

# Atmospheric Emissions

## Summary

Research within the Atmospheric Emissions Component was conducted in four Problem Areas include: (1) Understanding biological, chemical and physical mechanisms affecting emissions; (2) Measurement of emissions from livestock operations; (3) Control technologies and strategies for emissions reduction; and (4) Atmospheric fate and transport to receptors.

A combination of biological, chemical and physical processes control emission of gases and particulate matter from animal production facilities, manure storage areas and manure field application sites. Research was conducted to understand these processes to allow development of management practices and control technologies to reduce emissions and to develop predictive tools for emission and dispersion of gases and particulate matter. Microbial populations responsible for formation of hydrogen sulfide and skatole in swine manure and ammonia in poultry litter were identified. Managing feedlot surface moisture within a narrow range (20% to 40%) and minimizing accumulation of manure limited emissions from beef cattle feedlots. Below the moisture threshold high dust emissions occurred, while an overly wet surface increased emissions of ammonia, odorants and greenhouse gases. ARS scientists have shown that several physical and chemical parameters including solution ammonium concentration, solution temperature, solution pH, air turbulence, bubble formation in lagoons and surficial oxygen transfer to lagoons influence gaseous emissions. Wind-produced turbulence was found to be a major factor effecting gaseous emissions on a short-term basis, accounting for up to 70% of the transport influence. Over the longer term water temperature is a major factor, ammonia emissions were generally negligible regardless of turbulence or chemical factors if water temperatures were at or below 3 degrees Celsius. Research demonstrated that bubble formation in lagoons due to microbial activity increased ammonia losses. Surficial oxygen transfer into wastewater can cause dinitrogen gas rather than ammonia to be the predominant form of N emitted from lagoons.

Emissions from animal production operations need to be measured and subsequently predicted to assess and manage their impact on the environment. Research was conducted to develop methods to measure and predict emissions from livestock and poultry operations. New methods were developed to collect, store and analyze highly reactive volatile organic compounds associated with odor or that serve as precursors for ozone formation. Sampling techniques have been coupled with instrumentation such as GC/MS to identify and quantify individual compounds. Odorant data from the instrumental methods has been correlated with results from human olfactory panels to provide rapid, unbiased assessments of potential odor problems. An atmospheric dispersion model (backward Lagrangian Stochastic model) has been developed to estimate gas emission rates from a whole farm or components of a farm (housing, lagoon) using concentration data measured in the emission plume. Emission rates obtained using the backward Lagrangian Stochastic model were comparable to those obtained using a flux gradient micrometeorological method. Ammonia emission rates and N inputs and outputs were measured at beef cattle, dairy cattle, swine and poultry operations. These data will complement emissions data obtained in the EPA – livestock industry monitoring program and will contribute to the development of process based emission models. In experiments at beef cattle feedyards, approximately 50% of fed N was lost as ammonia and annual ammonia emissions ranged from

14 to 19 kg ammonia/animal fed. Annual ammonia emissions from swine production systems were 16% of total fed N. Dinitrogen gas rather than ammonia was the primary form of N lost from lagoons. Annual ammonia emissions from freestall dairies in Wisconsin were 7% of fed N. Combined ammonia losses from a broiler house (50 day grow-out), litter storage area and litter land application site averaged 46 g ammonia/bird harvested. Emission factors determined in these investigations were considerably less than the emission factors currently used by EPA.

Management practices and control technologies, from diet modification to complete systems for wastewater treatment, were developed and used to reduce emissions from animal production operations and manure field application sites. Reducing dietary crude protein in dairy and beef cattle diets reduced total manure N and the proportion of N excreted in urine, thereby lowering ammonia emissions. Increasing the content of condensed tannins in forage legumes in dairy cattle diets also reduced ammonia emissions. Distillers' grains in beef cattle diets increased P and N levels in manure, but decreased methane emissions. Application of ant-microbial plant oils to cattle and swine manure inhibited microbial metabolism and limited emissions of odorants, methane and ammonia. Research demonstrated that the common practice of tilling and chopping poultry litter between flocks can result in greater ammonia losses than leaving the litter cake undisturbed between flocks. Additions of acid forming compounds such as alum (aluminum sulfate) to poultry litter during composting reduces ammonia losses while increasing the agronomic value of the compost. A three stage (solids separation, biological N removal and P recovery) swine wastewater treatment was developed that reduced ammonia emissions by greater than 90%, greenhouse gas emissions by 97% and malodorous compounds by 98%. The system has been designated as "Environmentally Superior Technology" for wastewater treatment. The state of North Carolina has offered producers incentives to replace existing anaerobic lagoons with Environmentally Superior Technology. Alum treatment of poultry litter reduced ammonia emissions in poultry rearing facilities resulting in healthier birds with improved performance. The alum system is cost-effective; two dollars are made for every dollar spent. Each year approximately 700-800 million broilers are produced using alum treatment of litter. Related discoveries include: scrubbers that remove ammonia and dust from air exhausted from poultry facilities, a liquid alum spray system to reduce ammonia levels in laying hen houses, and an aluminum chloride treatment system to reduce ammonia emissions and P solubility in liquid waste handling systems. Rapid soil incorporation of land applied manures, through tillage or injection, reduced ammonia losses by 50-95% compared to unincorporated surface applications.

Research is needed to develop atmospheric transport models capable of estimating movement of gases and particulate matter from livestock facilities to downwind receptors. The research on processes controlling emissions, measurement of emissions and estimation of emission rates described in Problem Areas 1 and 2 will contribute atmospheric transport model development. Research conducted at a swine production facility demonstrated that large variations in emissions over time were related to turbulence generated (vertical air velocities varied from 1 to 5 meters/sec) by interaction of wind with buildings at the site. A simple tool was developed to allow emissions modelers to describe vertical wind speed variations under most atmospheric stability conditions. A light detection and ranging (LiDAR) system was used to measure particulate matter (PM) emissions and their dispersion from a swine production facility. Transport of dust and nutrients downwind of a beef cattle feedyard changed the vegetation from native perennial grasses to weedy annuals. Measurement of PM emissions from beef cattle feedyards and dairies indicated that these facilities are not significant generators of PM2.5, the respirable form of PM generally associated with human and animal health problems.

## Accomplishments

***Problem Area 1: Understanding the Biological, Chemical and Physical Mechanisms Affecting Emissions***

**Microbial populations associated with emissions**

- Identification of microorganisms associated with the production of important odorants such as hydrogen sulfide, ammonia, and skatole is crucial for understanding and interpreting the effects of management practices on these organisms and their impact on production of odorous emissions. Hydrogen sulfide is one of the more odorous and potentially health-threatening gases produced by anaerobic bacteria in stored swine manure. The primary producers of this compound are sulfate-reducing bacteria, but little is known about their presence in stored swine manure. ARS research resulted in the isolation and identification of sulfate-reducing bacteria from swine manure and development of real-time polymerase chain reaction (PCR) methods for the detection and quantitation of different groups of these bacteria. **Impact:** This approach is being used to assess the impact of diet formulations and manure treatments on the populations of sulfate-reducing bacteria in the swine gastrointestinal tract and stored swine manure.

  Cotta, M.A., Whitehead, T.R., Zeltwanger, R.L. 2003. Isolation, characterization, and comparison of bacteria from swine feces and manure storage pits. *Environmental Microbiology*. 5:737-745

- Anaerobic bacteria present in stored swine manure produce a major odorous compound, 3-methyl-indole, also known as skatole, Identification of the biochemical pathway for skatole production from the amino acid tryptophan, a crucial constituent of swine feed, is important for determining potential methods for intervening in this breakdown. ARS research resulted in the confirmation of the pathway of skatole production from tryptophan and indole acetic acid by *Bacteroides* sp. and acetogenic microorganisms and provided evidence for the presence of these bacteria in stored swine manure that can produce skatole. **Impact:** This research provided new insight into the identity and physiology of microorganisms responsible for skatole production and new information that will aid in the development of management practices and treatment technologies to reduce or eliminate production of this odor producing compound in livestock waste storage systems. These data are now being used as the basis for on-going studies to evaluate the link between skatole formation and native acetogenic populations in swine slurry.

  Cook, K.L., Rothrock Jr, M.J., Loughrin, J.H., Doerner, K. 2006. Characterization of skatole-producing microbial populations in enriched swine lagoon slurry. *Federation of European Microbiological Societies Microbiology*. 60:329-340

- Microbial activity in poultry litter produces odor causing chemical compounds. ARS scientists studied the number and community structure of microorganisms such as *urease*- and *uricase*-producers associated with ammonia production. They found spatial diversity in microbial community structure in the poultry house related to variability in litter moisture content and pH. Application of a litter treatment such as alum (aluminum sulfate), lowered litter pH and shifted the microbial population from one dominated by bacteria to one dominated by fungi. Ammonia emissions were greatly reduced in the treated litter

demonstrating that bacterial populations as well as pH contribute to ammonia emissions in untreated litter. **Impact:** Findings from these studies provide new insight into the kinds of organisms that contribute to ammonia production in poultry litter and should aid in the development of new methods to reduce or eliminate these organisms.

Lovanh, N., Cook, K., Rothrock, M., Miles, D., Sistani, K. 2007. Spatial shifts in microbial population structure within poultry litter associated with physicochemical properties. *Poultry Science*. 86:1840-1849.

**Impact of environmental physical and chemical properties and processes on emissions**

- Physical and chemical properties in the environment in which manure exists can influence biotic and abiotic processes that control emissions. Feedlot surface moisture is likely one of the dominant factors controlling emission of odorants, ammonia, greenhouse gases, and dust, but there is no information examining these emissions over a range of moisture levels. ARS scientists conducted research to identify the range of moisture contents where emissions were minimized. Moisture content was the primary controller of dust, but organic matter content also played a role in determining the amount of moisture required to control dust emissions. A clear moisture threshold was evident, with high dust emissions below the threshold, while an overly wet surface increased emissions of ammonia, odorants and greenhouse gases. Managing feedlot surface moisture within a narrow range (20% to 40%) and minimizing accumulation of manure limited emissions from beef cattle feedlots. Urine spots were a significant source of feedlot surface moisture and served as a major source of ammonia losses. Since these ammonia losses occurred rapidly, control measures must be present on the pen surface to be effective. **Impact:** This research information has been transferred to producers and their advisors and should contribute to the development of feedlot surface management practices that will reduce particulate matter and gaseous emissions. This research also resulted in the development of a simple method to estimate dust potential from a cattle feedlot surface.

Miller, D.N., Woodbury, B.L. 2003. Simple protocols to determine dust potentials from cattle feedlot soil and surface samples. *J. Environ. Quality* 32: 1634-1640.

Miller, D.N., Berry, E.D. 2005. Cattle feedlot soil moisture and manure content: I. Impacts on greenhouse gases, odor compounds, nitrogen losses, and dust. *J. Environ. Qual.* 34:644-655.

- ARS scientists have shown that several physical and chemical parameters including solution ammonium concentration, solution temperature, solution pH, air turbulence, bubble formation in lagoons and surficial oxygen transfer to lagoons influence gaseous emissions. In a study of gaseous emissions from swine wastewater lagoons ARS scientists found that the climatic effect of turbulence was the strongest factor effecting emissions on a short-term basis. Turbulence accounts for about 70% of the transport influence. Over a longer term, water temperature also was an important controller of ammonia emissions. At about 3 C, ammonia emissions were generally negligible regardless of turbulence or chemical factors. Solution concentration and pH both influenced the partial pressure of ammonia in solution, but these factors were relatively constant in steady-state waste processing lagoons. **Impact:** This research has stimulated other scientists to look at turbulence in greater detail when trying to explain emissions and their dispersion from livestock operations. Understanding the importance of climatic factors on ammonia emissions has led to the adoption of non-interference micrometeorological measurement techniques to determine gaseous emissions

from lagoons. This information has contributed to the development of process models for ammonia emissions.

Harper, L.A., Sharpe, R.R., Parkin, T.B., Visscher, A. de, van Cleemput, O., Byers, F.M. 2004. Nitrogen cycling in swine production systems: Ammonia, nitrous oxide and dinitrogen gas emissions. *J. Environ. Qual*. 33: 1189-1201.

- ARS scientists have developed an improved model for ammonia emissions from anaerobic treatment lagoons that incorporated the impacts of bubble formation in the lagoon due to microbial activity and varying wind speeds. The new model was tested against ammonia emissions data generated over a one year period in three swine lagoons with distinctly different manure management and water quality characteristics: (1) traditional lagoon, (2) partially treated lagoon that received liquid manure after liquid-solid separation, and (3) treated lagoon that received liquid manure after separation of solids and removal of N and P. Internal bubbling in the non-treated lagoon increased ammonia volatilization rate during the warm season. The new model accurately predicted the measured ammonia emissions in all three lagoons. **Impact:** These results show that ammonia emission from swine lagoons would be significantly under-estimated if bubbling-enhanced mass transport and variable wind speed were not taken into account. This information should be useful to EPA and others who need to develop process models to predict ammonia emissions from livestock operations.

  Ro, K.S., Szogi, A.A., Vanotti, M.B., and Stone, K.C. 2008. Process model for ammonia volatilization from anaerobic swine lagoons incorporating varying wind speeds and gas bubbling. *Trans. ASABE*. 51: 259-270.

- Surficial oxygen ($O_2$) transfer into wastewater lagoons plays an important role in biochemical and physical processes responsible for ammonia and dinitrogen gas ($N_2$) emission from lagoons. Scientists have generally thought that insufficient $O_2$ limited $N_2$ formation in lagoons. However, recent discoveries of large $N_2$ emissions from swine treatment lagoons have caused reconsideration of lagoon biochemical processes. ARS scientists have developed a new unified equation to predict the amount of atmospheric $O_2$ that could be absorbed into stationary water bodies. Using this equation, the maximum $N_2$ production potential per unit mass of $O_2$ transferred was calculated using the three most likely biochemical pathways for ammonia removal in treatment lagoons. Most observed $N_2$ emissions from lagoons were below the maximum $N_2$ emission potential calculated for the classical nitrification-denitrification pathway. This suggested that sufficient $O_2$ could be transferred into a wastewater lagoon to account for most observed $N_2$ emissions from lagoons. **Impact:** EPA should be interested in these results because they suggest that harmless $N_2$ gas rather than ammonia may be the major gaseous N form lost from lagoons. The new equation to predict $O_2$ absorbed into stationary water bodies has allowed ARS scientists and engineers to advance their understanding of $O_2$ transfer into lagoons. The equation is being used by other scientists and engineers worldwide including its use by the U.S. Geological Survey to estimate water-air oxygen fluxes for the San Francisco Bay oxygen dynamics study.

  Ro, K.S., Hunt, P.G., Poach, M.E. 2006. Wind-driven surficial oxygen transfer and dinitrogen gas emission from treatment lagoons. *J. Environ. Sci. & Health* 41:1627-1638.

Ro, K.S., Hunt, P.G., Poach, M.E. 2007. Wind-driven surficial oxygen transfer. *Critical Reviews in Environ. Sci. and Technol*. 37: 539-563.

### *Problem Area 2: Measuring Emissions from Livestock Operations*

### Methods for measuring and predicting gaseous emissions

- Traditional techniques to quantify volatile organic compounds associated with odor, such as dynamic dilution olfactometry, are inadequate due to loss of most odorous compounds through sorption and transformation during storage. Consequently, novel approaches are required to measure traces of these highly reactive volatile organic chemicals. New methods for assessing odor have been developed using odor intensity models, flux chamber measurements, and adaptation of existing gas chromatography-olfactometry (GC-O) techniques. These methods provided good correlation with both odor intensity and hedonic tone along with the ability to identify key odorous compounds. Field sampling methods also have been developed to probe both animal waste and ambient air for odorous compounds. These new sampling techniques include twister stir analysis of animal waste and whole air and selective pre-concentration analysis of odorants. These sampling techniques have been coupled with multi-dimensional GC and interfaced with mass spectrometers, olfactometers, and sulfur detectors to allow a number of key odorants to be quantified. **Impact:** These new methods have been used at livestock operations around the country to measure emissions of malodorus compounds and to assess the impact of treatments such as animal diet on emissions. Odorant data generated from instrumental techniques such as GC/MS have been correlated with results from human olfactory panels to provide rapid, unbiased assessments of potential odor problems. In addition, this research has contributed to improved odor management at composting and wastewater treatment facilities such as those operated by the District of Columbia Water and Sewer Authority.

  Kim, H., McConnell, L.L., Millner. P.D. 2005. Comparison of odorous volatile compounds from 14 different commercial composts using solid phase microextraction. *Trans. ASABE*. 2005, 48:315-320.

  Loughrin, J. 2006. Comparison of solid-phase microextraction and stir bar sorptive extraction for the quantification of malodors in wastewater. *J. Agric. Food Chem*., 54:3237-3241.

  Miller, D., Woodbury, B. 2006. A solid-phase microextraction chamber method for analysis of manure volatiles. *J. Environ. Qual*. 35:2383-2394.

  Trabue, S., Anhalt, J., Zahn, J. 2006. Bias of Tedlar™ bags in the measurement of agricultural odorants. *J. Environ. Qual*., 34:129-138.

- Measurement of gaseous emission rates from animal production operations is a complex and time consuming task. ARS scientists and their cooperators have developed and tested an atmospheric dispersion model (backward Lagrangian Stochastic model) that can be used to estimate gas emission rates from a source using time-average concentration data measured in the emission plume using an open path laser. The method was validated using controlled releases of methane gas under a range of micrometeorological conditions. Model estimates of methane emission rates were within 2% of the actual release rate, with a variability of 20-22% depending on micrometeorological conditions. Emission rates of ammonia and methane from a beef cattle feedlot estimated using the dispersion modeling approach were comparable, but much easier to obtain, than emission rates determined by the flux-gradient meteorological technique. **Impact:** Use of the dispersion modeling technique to determine air

quality and greenhouse gas emission rates will improve understanding of emissions from animal production operations and facilitate development of management practices to reduce emissions. The model software (WindTrax) was validated in these investigations and is now commercially available. This model is being widely used in the U.S. and abroad to estimate emission rates of ammonia and other gases from whole farms and from individual components (housing, lagoons) of the farm.

Flesch, T.K., Wilson, J.D., Harper, L.A., Crenna, B.P. 2005 Estimating gas emission from a farm using an inverse-dispersion technique. *Atmos. Environ.* 39:4863-4874.

**Measurement of emissions from beef cattle feedyards**

- Comprehensive and accurate ammonia emissions and nutrient balance data are needed to develop reliable emission factors and to test process based models. Annualized ammonia emissions from a beef cattle feedyard determined using a backward Lagrangian Stochastic dispersion model were 53% of fed N, with summer emission rates being approximately twice winter rates. The annual emission factor for the pen area of the feedyard was 19.3 kg ammonia/animal fed (equal to 70.2 kg of ammonia/Mg live weight gain) and the annual emission factor for the feedyard retention pond was 0.9 kg ammonia /animal fed (equal to 3.2 kg ammonia/Mg live weight gain).These results indicate that ammonia emissions from feedyard retention ponds are small compared to ammonia losses from feedyard pen surfaces. **Impact:** This data should have a major impact on beef cattle ammonia emission factors developed and used by EPA. These results were presented to federal and state regulators and consultants at the EPA sponsored 16th Annual International Emission Inventory Conference and to the EPA Science Advisory Board's Integrated Nitrogen Committee

  The reliability of measurement procedures for ammonia emissions needs to be evaluated. Multiple approaches to determine emissions (backward Lagrangian Stochastic model, a box model, and a flux-gradient micrometeorological method) were tested at a 45,000 head commercial beef cattle feedyard and compared to the results of a total N balance developed for the facility. The flux-gradient micrometeorological method and the backward Lagrangian Stochastic model gave results similar to a total nitrogen balance. A box model gave a higher degree of variability, but the average ammonia emissions were comparable to those obtained using a total nitrogen balance. Ammonia emissions averaged 44 to 60% of fed N during the summer and 15 to 40% of fed N during the winter. Annual ammonia emissions for this feedyard averaged 14.4 kg/animal fed, with 48% of fed nitrogen lost as ammonia. **Impact:** This is the most comprehensive set of beef cattle feedyard ammonia emission measurements available, and thus, will be valuable to EPA and other interested parties in development of ammonia emission models and emission factors that are applicable over a wide range of seasonal and environmental conditions.

  Flesch, T.K., Wilson, J.D., Harper, L.A., Todd, R.W., Cole, N.A., 2007. Determining ammonia emissions from a cattle feedlot with an inverse dispersion technique. *Agricultural and Forest Meteorology* 144: 139-155.

  Todd, R.W., Cole, N.A.,Clark, R.N. 2007. Ammonia emissions from an open lot beef cattle feedyard on the southern High Plains. In: Proc. 16th Annual International Emission Inventory Conference – Emission Inventories: "Integration, Analysis, Communication", May 14-17, 2007, Raleigh, NC. Available online at http://www.epa.gov/ttn/chief/conference/ei16/session5/todd.pdf (accessed 28Jun2007).

- In a lab-scale system test, ammonia flux measured using flux chambers with air exchange rates of 8 turnovers per minute or fewer, were less than 50% of the measured flux from an unimpeded surface. At exchange rates of 2 turnovers per minute, treatment differences could not be accurately measured. Different measurement methodologies can yield very different results for ammonia emissions from feedlots. The flux-gradient micrometeorological method and a backward Lagrangian Stochastic model appear to offer more reliable results than flux chambers. **Impact:** Results of this study and similar investigations have convinced most researchers that flux chambers are unlikely to be appropriate for obtaining accurate estimates of ammonia flux from retention ponds or pen surfaces.

  Cole, N.A., Todd, R.W., Auvermann, B., Parker, D. 2008. Auditing and assessing air quality in concentrated feeding operations. *The Professional Animal Scientist* 24: 1-22.

**Emissions from broiler houses**

- ARS scientists conducted research to determine ammonia emissions from four tunnel ventilated broiler houses equipped with ammonia sensors, anemometers and data-loggers to continuously record ammonia concentrations and ventilation for two years. Ammonia emissions during litter storage and following land application of litter also were measured. Total emissions from the poultry house were 37.4 g $NH_3$/bird marketed, and represented emissions of 28.3 g $NH_3$/ bird marketed during the grow-out (50 days) and 9.1 g $NH_3$/bird marketed between flocks. Emissions from the house increased with litter pH and moisture content. Litter treatments such as alum (described elsewhere in this report), sodium bisulfate and acidified clay can be used to reduce emissions. Ammonia emissions from stacked litter were equivalent to 0.17 g $NH_3$/bird. Broadcast application of litter to pastures at a rate of 2.5 tons/acre resulted in ammonia losses equivalent to 7.9 g $NH_3$/bird. Use of a new knifing technique for soil incorporation of litter (described elsewhere) reduced ammonia losses to essentially zero. The total ammonia emission factor for broilers which included house, storage and land application losses was 45.5 g $NH_3$/bird marketed. **Impact:** This study represents the first comprehensive measurement in the U.S. of ammonia emissions in rearing facilities, during storage and following land application. This information will complement data from the EPA-livestock industry monitoring study and will help EPA develop emission factors and emission models for ammonia emissions from poultry operations. The emission factor developed in this investigation was less than half the value currently used by EPA (100 g $NH_3$/ bird marketed).

  Moore, P.A., Jr., D.M. Miles, R.T. Burns, D.H. Pote, and K. Berg. 2006. Evaluation and management of ammonia emissions from poultry litter. In: *Proceedings of the Workshop on Agricultural Air Quality: State of the Science*, June 5-8, 2006, Potomac, Maryland. p. 304-310.

- In a related study ARS scientists developed an N budget for 42-day broilers by measuring N inputs in feed and chicks, N outputs in broilers and ammonia emissions, and the N increase in the litter. Approximately 13% of fed N was lost through ammonia emissions. These emissions were modest over the first 3 weeks, but increased over weeks 4-7 when 77% of the total ammonia losses occurred, due to the greater N excretions and a rise in litter pH and moisture. Total ammonia emissions from the confinement area averaged about 18.2g $NH_3$/

bird produced. **Impact:** This data also will provide EPA with information to develop $NH_3$ emission factors and process based $NH_3$ emission models.

Mitran, L., Harter-Dennis, J. M., and Meisinger, J. J. 2008. Determining the nitrogen budget and total ammoniacal nitrogen emissions from commercial broilers grown on used litter in environmental chambers. *Journal Applied Poultry Research* (in press).

- An understanding of the relationship between litter properties and gas fluxes is needed to develop alternative management strategies that control emissions while maintaining economically viable production systems. Gas fluxes from broiler litter, including ammonia, nitrous oxide, carbon dioxide, and methane, were measured along a set grid in a poultry house where 28 previous flocks had been grown on the litter. Chicks were placed in half the house, after one day the litter temperature was 3.3 C greater and $NH_3$ flux was 126 mg/$m^2$-hr greater in the brood half compared to the vacant half of the house. Brood litter temperatures were 4 C less than nonbrood litter temperatures at day 21 which produced a decrease in average $NH_3$ flux of 174 mg/$m^2$-hr for the brood area. The peak area for $NH_3$ flux at 21 days corresponded to an area with high pH, high litter moisture and high carbon dioxide flux. **Impact:** The importance of small environmental changes on ammonia emissions in broiler houses has been clearly shown. This information has been transferred to the poultry industry and is being used to develop management strategies to reduce ammonia emissions.

Miles, D.M., Owens, P.R. and Rowe, D.E. 2006. Spatial variability of litter gaseous flux within a commercial broiler house: Ammonia, nitrous oxide, carbon dioxide and methane. *Poultry Science* 85:167-172.

**Emissions from swine production operations**

- Better emissions inventories need to be developed to help understand nutrient cycling in animal production systems and to develop better management practices to reduce trace gas emissions. ARS scientists and their cooperators measured emissions of ammonia, $N_2$ and nitrous oxide from housing, treatment lagoons and manure field application sites at three North Carolina swine production systems to obtain a whole farm N balance. Total ammonia emissions only accounted for 16% of the N fed to swine. Harmless $N_2$ gas rather than ammonia was the primary form of N lost from lagoons. A previous accomplishment (Emissions Component, Problem Area 1) addresses the role of surficial oxygen in $N_2$ formation in lagoons. The estimates of ammonia emissions resulting from this investigation were much lower than regulatory agency estimates of feed N lost from the system as ammonia. **Impact:** These studies represented the first attempt to establish a total N balance for an entire animal feeding operation. Ammonia emissions from these systems were much less than previously thought. New measurement techniques were developed to measure, in the water column, N leaving the lagoon as $N_2$ gas. These findings can be used by the EPA and state environmental protection agencies to develop more appropriate and accurate emissions inventories.

Harper, L.A., R.R. Sharpe, T.B. Parkin, A. De Visscher, O. van Cleemput, and F.M. Byers. 2004. Nitrogen cycling in swine production systems: Ammonia, nitrous oxide, and dinitrogen gas emissions. *J. Environ. Qual*. 33:1189-1201.

**Emissions from dairy production operations**

- ARS scientists and their cooperators measured ammonia emissions during winter and summer from three dairy farms in Wisconsin. All three farms had freestall barns with nearby retention ponds for waste management. Ammonia concentrations were measured at several locations around the farm and lagoon using open path lasers with path lengths from 50 to 1000 meters. Three dimensional sonic anemometers provided meteorological data used along with the measured ammonia concentrations to calculate ammonia emissions using a backward Lagrangian Stochastic model. Over the course of the study instantaneous emission rates over a two hour period ranged from 0.2 to 21.4 kg $NH_3$ per farm per hour. The average wintertime and summertime ammonia emissions from the three dairies in Wisconsin were 1.5 % and 13.1% of feed N input, respectively. Average emission rates were approximately 12 g $NH_3$ per animal per day and 94 g $NH_3$ per animal per day in the winter and summer, respectively. The ammonia emissions found in this study were considerably less than the EPA National Emission Inventory estimate of ammonia emissions (65% of fed N emitted as ammonia) from this type of dairy operation. In addition, these dairy ammonia emissions were significantly less than emissions from beef cattle, swine and poultry animal feeding operations. **Impact:** These data provide emission rates for the whole farm as well as the housing and lagoon. This information should complement data generated in the EPA-livestock industry monitoring study and allow EPA to make a more accurate estimate of ammonia emissions from this type of dairy operation.

Flesch, T.K., J.D. Wilson, L.A. Harper, and B.P. Crenna. 2005. Estimating gas emission from a farm using an inverse dispersion technique. *Atmos. Enviro*n. 39:4863-4874.

Harper, L.A. and T.K. Flesch. 2007. Ammonia Emissions from Dairy Production Systems in Wisconsin. Quarterly Report to USDA-ARS, Sp. Coop. Agmt. Proj. No. 3655-12630-03S, September 30, 2007. 16pp.

***Problem Area 3: Control Technologies and Strategies for Emissions Reduction***

**Effect of animal diet on emissions**

- Dairy farmers are increasingly held accountable for ammonia emitted from their farms. ARS scientists and their cooperators have discovered that reduced dietary crude protein content decreased both total manure N excretion, the proportion of N excreted in urine, and ammonia emissions after manure land application. Increasing the content of condensed tannins in the forage legume component of the diet decreased the proportion of N excreted in urine and resulted in proportionally lower ammonia emissions from a barn floor. The ability of beddings to separate urine and feces, and the relative absorbance of beddings were the most important factors influencing ammonia emissions from dairy barn floors. Ammonia emissions were least from sand and pine shavings and greatest from chopped newspaper, recycled manure solids and chopped corn fodder. **Impact:** These studies illustrated the potential of dairy cattle diet and bedding type to help farmers comply with regulations aimed at abating ammonia emissions. These techniques provided a screening tool to identify promising treatments for further testing. In addition, these data can be used to develop ammonia emission factors for tie-stall dairy barns in the Midwest U.S.

Powell, J.M., Misselbrook, T.H., and Casler, M.D. Season and bedding impacts on ammonia emissions from tie-stall dairy barns. 2008. *Journal of Environmental Quality*. 37: 7-15.

Misselbrook, T.H. Powell, J.M, Broderick, G.A., Grabber, J.H. 2005. Dietary manipulation in dairy cattle: Laboratory experiments to assess the influence on ammonia emissions. *J. Dairy Science*. 88: 1765-1777.

- ARS scientists in cooperation with university partners used lab-scale *in vitro* experiments, and field trials to determine the effects of dietary protein concentration and source on animal performance and ammonia emissions from beef cattle feedlot surfaces. Decreasing dietary crude protein concentration from 13%, a value typically fed in the Southern Great Plains, to 11.5% decreased average daily gain by 5% and ammonia emissions by 25% due to decreased urinary N excretion. Decreasing dietary protein concentrations from 13 to 11.5% with 56 days left on feed (i.e. phase feeding) decreased average daily gain by 3% and potential ammonia losses by 22%. Oscillating dietary protein concentrations between moderately deficient and adequate concentrations at 48-hour intervals tended to improve cattle performance and to reduce potential ammonia losses by 15%. **Impact:** Decreasing dietary crude protein below 13% could potentially reduce ammonia loss by several hundred tons a year from a typical feedyard. The phase feeding approach may hold greater promise since oscillating dietary protein on a 48-hour cycle does not seem practical at this point.

Cole, N.A., Clark, R.N., Todd, R.W., Richardson, C.R., Gueye, A., Greene, L.W., McBride, K. 2005. Influence of dietary crude protein concentration and source on potential ammonia emissions from beef cattle manure. . *J. Anim. Sci*. 83:722-731.

Cole, N.A., P.J. Defoor, M.L. Galyean, G.C. Duff, and J.F. Gleghorn. 2006. Influence of phase-feeding of crude protein on performance, carcass characteristics, serum urea nitrogen concentrations, and manure nitrogen of finishing beef steers. *J. Anim. Sci.* 84:3421-3432.

- Distillers' grains from ethanol production are being used in cattle diets, but their benefits and risks need to be determined. ARS scientists studied the effect of increasing levels of wet distillers' grains with solubles (WDGS) in feedlot cattle diets on odorants and greenhouse gas emissions. Concentration of total P, N, and odorous compounds such as isobutyrate, isovalerate, caproate, heptanoate, phenol, and ammonia in cattle feces increased as the level of WDGS increased in the diet. Ammonia was also greater in urinary excretions from cattle fed WDGS compared to cattle fed diets without WDGS. Concentration of total volatile fatty acids and L-lactate in cattle feces decreased as WDGS increased in the diet, resulting in a linear increase in fecal pH. There was a linear decrease in methane production as levels of WDGS increased in the diet. **Impact:** These results will help producers and their advisors make decisions about using WDGS. Feeding WDGS to feedlot cattle may have potential negative effects on the environment due to higher nutrient levels excreted in manure and the subsequent loss of these nutrients to air and water. However, the use of WDGS in feedlot diets may decrease rumen methane production, which is a detrimental greenhouse gas.

Archibeque, S.L., Freetly, H.C., Cole, N.A., Ferrell, C.L. 2007. The influence of oscillating dietary protein concentrations on finishing cattle. II. Nutrient retention and ammonia emissions. *J. Anim. Sci.* 85:1496-1503.

Meyers, T.P., Luke, W.T., Meisinger, J.J. 2006. Fluxes of ammonia and sulfate over maize using relaxed eddy accumulation. *Agricultural and Forest Meteorology*. 136:203-213.

**Additives to reduce emissions**

- Microorganisms are the main agent responsible for the production of odor causing compounds from manure. ARS research showed that addition of antimicrobial plant oils (thymol, carvacrol, eugenol) to cattle and swine manure inhibited essentially all microbial metabolism in these manure slurries whereby limiting formation of volatile fatty acids, an indicator of odor, or gaseous products. Results from eugenol addition to cattle and swine manure were unique because eugenol stopped volatile fatty acid production, yet allowed lactate accumulation. This effect rapidly lowers pH, and will likely conserve nutrients such as ammonia in manure slurries. In a related investigation, thymol and a urease inhibitor were added to a 33,000-liter swine manure pit. Volatile fatty acid production was reduced by 64 to100% and methane production was reduced by 78 to 93%, depending on application rate. Plant oils increase the ability of urease inhibitors to conserve urea N. Thymol incorporated into a granule and applied to cattle feedlot pens reduced odor production by 58% and reduced fecal coliforms by 89%. **Impact:** The plant oils offer an effective biological agent that can be added to livestock manure to reduce odor, greenhouse gases, and pathogens. The process of using plant oils to control emissions and pathogens has been patented. Based on ARS research urease inhibitors have been sold as an amendment for livestock waste by Agrotain International.

Varel, V. H. 2005. Patent No. 6,902,726. Reduction of odor gases from waste using plant-derived oils.

Varel, V.H., Wells, J. 2007. Influence of thymol and a urease inhibitor on coliform bacteria, odor, urea, and methane from a swine production manure pit. *J. Environ. Quality* 36: 773-779

**Broiler litter cake management to reduce ammonia emissions**

- Broilers can experience reduction in weight gain of up to 25% when exposed to aerial ammonia concentrations greater than 25 ppm. ARS scientists found that management of the litter between flocks can impact ammonia emissions experienced by the subsequent flock. The common practice of tilling and chopping litter between flocks can result in greater ammonia losses than leaving the litter cake undisturbed between flocks. **Impact:** Extension agents and poultry industry personnel are encouraging growers to discontinue tilling and chopping litter between flocks. A 12% reduction in body weight for each flock on a farm with eight houses equates to an estimated $27,600 annual unrealized profit for the grower.

Miles, D.M. 2006. Broiler cake potential to emit ammonia. *Proceedings of the National Poultry Waste Management Symposium*, pages 59-63. Springdale, AR, October 23-25, 2006.

**Composting with acids to reduce ammonia emissions**

- Composting poultry litter reduces pathogenic bacteria, but results in significant losses of N through ammonia volatilization. Research was conducted by ARS scientists to see if the addition of acids such as phosphoric acid or alum (aluminum sulfate) either top-dressed or mixed into windrows of composting poultry litter would reduce ammonia emissions. Both products tested reduced the pH of the manure, and subsequently lowered ammonia losses. Runoff trials conducted after the composting studies were complete showed that P runoff was greater from composted litter than fresh litter, but additions of alum to compost significantly lowered P runoff losses. **Impact:** Treating poultry litter with alum or phosphoric acid prior to

composting provides a means to reduce atmospheric N loading, while increasing the agronomic value of the compost. Alum additions to composting litter also result in improved water quality, since P runoff is significantly reduced with this practice. USDA Natural Resources Conservation Service was interested in promoting this practice to reduce ammonia losses during composting.

Delaune, P.B., P.A. Moore Jr., and J.L. Lemunyon. 2006. Effect of chemical and microbial amendments on phosphorus runoff from composted poultry litter. *J. Environ. Qual*. 35:1291-1296.

**Swine waste water treatment system that reduces emissions of ammonia, greenhouse gases and odorants**

- Innovative, cost-effective and reliable emission control strategies and treatment technologies are needed to reduce emissions from animal production operations. A full-scale swine wastewater treatment system was designed and implemented to replace anaerobic lagoons with a three-stage process of solids separation, biological N removal, and P recovery. Scientists at ARS evaluated reduction in ammonia emissions using two manure treatment approaches. In one case, high-rate solid-liquid separation of the raw manure was the only treatment. In a second case, the treatment consisted of high-rate solid-liquid separation plus biological N removal. The studies were performed at a full-scale swine operation and compared with traditional anaerobic lagoon systems. In lagoons that received effluent treated with high rate solid-liquid separation only, total annual ammonia emissions were reduced by 73% with respect to those of the traditional anaerobic lagoon. In lagoons that received effluent treated with solid separation plus biological N removal, total annual ammonia emissions were reduced by 90%.

  Less greenhouse gas—and more carbon credits per pig—are the latest environment-friendly benefits derived from this wastewater treatment system. ARS researchers found that replacing conventional anaerobic lagoon practices with the new aerobic waste management system reduced greenhouse gas (GHG) emissions (both methane and nitrous oxide) by 97 percent. In a 4,360-head swine operation, this treatment system cut annual emissions from 4,972 tons of carbon dioxide equivalents to just 153 tons. This indicates the system may have a role in the fledgling carbon dioxide abatement trading market, which allows farmers to earn money based on how much carbon dioxide and other GHG they can prevent from entering the atmosphere using alternative technologies.

  Malodorous compounds and water quality parameters such as suspended solids and biological oxygen demand (BOD) were monitored at all three stages of the treatment process. Reduction in soluble BOD was highly correlated with odor reduction, over 90% of the reduction occurred after biological N treatment. Evaluation of the system included the analysis of six selected odor compounds that are known contributors to malodor in wastewater (phenol, p-cresol, p-ethylpheno, p-propylphenol, indole, and skatole). Results showed that the concentrations of malodorous compounds were reduced by almost 98%. The majority of this odor reduction occurred during the biological N treatment step.

  **Impact:** This technology was evaluated at a farm scale and designated by the state of North Carolina as "Environmentally Superior Technology" for wastewater treatment. The success of this research has enabled further development of a second generation system that will be

available to producers at a fraction of the cost of the original system. The state of North Carolina has offered incentives to producers to replace existing anaerobic lagoons with these new technologies.

This research showed that treatment technologies, alone or in combination, can substantially reduce ammonia emissions from confined animal production units and that treatment intensity can be varied depending on the ammonia removal needs of the producer. The reduction of GHG emissions can generate income through earned carbon dioxide equivalent abatement credits that will help alleviate installation costs associated with cleaner aerobic systems and facilitate producer adoption of cleaner technologies to replace current anaerobic lagoons in the U.S..

Loughrin, J.H., Szogi, A.A. and Vanotti, M.B. 2006. Reduction of malodorous compounds from a treated swine anaerobic lagoon. *J. Environ. Qual*. 35:194-199.

Vanotti, M.B., A.A. Szogi, and P. G. Hunt. 2003. U.S. Patent 6,893,567. "Wastewater treatment system."

Vanotti, M.B., Szogi, A.A., and Vives, C.A. 2008. Greenhouse gas emission reduction and environmental quality improvement from implementation of aerobic waste treatment systems in swine farms. *Waste Management* 28:759-766.

- ARS scientists are paving the way for new, cost-efficient and large-scale methods of removing ammonia from livestock wastewater using an innovative bacterial process. The technology, anaerobic ammonium oxidation (anammox), uses recently discovered anaerobic bacteria to convert nitrite and ammonium to harmless dinitrogen gas. The process is more energy-efficient than traditional biological N-removal systems. The planctomycetes bacteria used in the anammox process have been isolated from animal wastewater. Anammox has commercial potential because it removes N from wastewater at higher rates and at a lower cost than conventional methods. **Impact:** This process should be of significant interest to livestock producers worldwide. The process is more efficient and four times less expensive than conventional biological N removal methods. The process has been patented and partial funding for the research has been provided by USDA Foreign Agricultural Service and the government of Brazil, where cooperative research is being conducted.

  Vanotti, M.B., and Szogi, A.A. 2006. Anaerobic ammonium oxidation for high-ammonia wastewater treatment. Invention Disclosure Docket No. 0103.06 B USDA-ARS-OTT.

- Adaptation of nitrification to high N load and cold weather are important considerations for stabilized performance of manure treatment systems. High ammonia-tolerant bacteria were isolated from manure and used to treat concentrated animal wastewater. These bacteria enabled fast ammonia removal using aeration treatment without the problem of ammonia volatilization. Nitrification activity was not severely affected by low water temperatures (3-5 C), indicating excellent acclimation to winter conditions. The nitrification culture was used to seed a full-scale system for swine wastewater treatment; the biological process removed >95% of the ammonia from wastewater containing 1000-2000 ppm ammonia. Thus, the technology is well suited for nitrification of high-ammonia livestock wastewater under cold weather conditions. **Impact:** Use of specialized bacteria cultures for high strength animal wastewaters and cold temperatures will facilitate effective use of animal wastewater treatment systems over a broad range of conditions. Results of this research have been

incorporated in Lesson 25: Manure Treatment Options of the Livestock and Poultry Environmental Stewardship (LPES) curriculum. Targeted uses of the curriculum include mandated environmental certification programs for producers and advisors, Cooperative Extension programs for producers, and clientele training for the NRCS Environmental Quality Incentives Program.

Szogi, A.A., Vanotti, M.B., Rice, J.M., Humenik, F.J., and Hunt, P.G. 2004. Nitrification options for pig wastewater treatment. *New Zealand J. Agric. Res*. 47:439-448.

**Alum treatment to reduce ammonia emissions from poultry operations**

- ARS scientists discovered that addition of alum (aluminum sulfate) to poultry litter greatly reduced ammonia volatilization, resulting in lower in-house ammonia concentrations and lower emissions. Lower ammonia levels in poultry rearing facilities resulted in healthier birds with improved performance including better weight gains (0.15 lbs.), improved feed conversion (6 points), lower condemnation (0.5%) and lower mortality (0.3%). Heating costs during winter months were significantly lower (11%) since less ventilation was required to remove ammonia. Alum-treated poultry litter was also a better fertilizer because much of N normally lost via ammonia volatilization was retained in the litter. In addition, alum use protects water quality by reducing P in runoff. Alum is not used in liquid manure handling systems since the sulfate in alum may be reduced to toxic hydrogen sulfide. An aluminum chloride treatment has been developed, tested, patented and licensed to reduce ammonia emissions and phosphorus solubility in liquid waste handling systems. **Impact:** Alum use in poultry litter is very cost-effective, for every one dollar spent, two dollars are made. Each year approximately 700-800 million broilers are produced using alum treatment of litter. This technology not only results in vast improvements in poultry production, it results in less pollution of our nation's air and water resources. A number of patents have been obtained for alum use in poultry production systems. General Chemical Corporation has licensed the technology and markets alum. Several of the nation's largest poultry companies are cost-sharing this practice with their growers mainly because of improvements in feed conversion and condemnation.

Gilmour, J.T., M.A. Koehler, M.L. Cabrera, L. Szajdak, and P.A. Moore, Jr. 2004. Alum treatment of poultry litter: Decomposition and nitrogen dynamics. *J. Environ. Qual*. 33:402-405.

Smith, D.R., P.A. Moore, Jr., C.V. Maxwell, B.E. Haggard and T.C. Daniel. 2004. Reducing phosphorus runoff from swine manure with dietary phytase and aluminum chloride. *J. Environ. Qual*. 33:1048-1054.

- ARS scientists developed, tested and patented an ammonia scrubber that removes ammonia and dust from air exhausted from poultry facilities. This system utilizes a dilute alum solution to capture ammonia N that would otherwise be lost to the atmosphere. This N can be utilized by the farmer to grow crops. The aluminum in the solution has the added benefit of reducing soluble P, which will reduce P in runoff. **Impact:** Each ammonia scrubber can capture up to 5 pounds of N per day that would normally be lost to the atmosphere. A poultry production facility with four houses and two scrubbers per house would be able to annually capture 12,000 pounds of nitrogen which could be used as a fertilizer.

Moore, P.A., Jr. 2007. U.S. Patent 7,194,979. Method and device for scrubbing ammonia from air exhausted from animal rearing facilities.

- ARS scientists developed, tested and patented a liquid alum delivery system that can be used to control ammonia levels in high-rise laying hen houses. These facilities have the highest levels of ammonia of all animal rearing facilities. Due to logistical constraints, it is not possible to apply dry alum in these barns as is done in broiler houses. A system was developed that scrubs ammonia from the air of a high-rise layer house using a spray of liquid alum. The system was shown to reduce ammonia levels from over 90 ppm to less than 10 ppm. **Impact:** The alum liquid spray technology protects worker and bird health while improving egg production and feed conversion. Improved hen performance using the liquid alum delivery system resulted in a net weekly return of $426/hen house.

**Ammonia loss from land applied manure**

- University and ARS scientists evaluated the magnitude and temporal pattern of ammonia volatilization from surface-applied liquid dairy manure, showing that slurries lose 40% to 80% of their ammonium-N within 24 to 48 hours after surface application. Solid manures, such as poultry litter, had smaller losses of 10% to 30% over approximately one week. A practical method to manage ammonia from land applied manures is with rapid soil incorporation by tillage or injection, common tillage implements reduce losses from 50% to 95% compared to unincorporated surface applications. Crop canopies also can influence ammonia capture and release. Dry deposition of ammonia in a corn canopy was measured during the growing season and showed periods of both ammonia deposition and emission. If atmospheric ammonia concentrations were above 2μg $m^{-3}$ the corn canopy absorbed ammonia, if they were below this value the corn canopy emitted ammonia. Thus, ammonia cycling within the corn canopy is quite dynamic. **Impact:** The results of this and other research were used to develop recommendations for estimating crop N availability from manure. Data from these studies formed the basis for an ammonia volatilization decision support tool that is being used to update ammonia loss estimates in Nutrient Management Programs in the Northeastern U.S.

Meyers, T.P., Luke, W.T., Meisinger, J.J. 2006. Fluxes of ammonia and sulfate over maize using relaxed eddy accumulation. *Agricultural and Forest Meteorology*. 136:203-213.

***Problem Area 4: Atmospheric Fate and Transport to Receptors***

*The research on processes controlling emissions, measurement of emissions and estimation of emission rates described in Problem Areas 1 and 2 will provide data needed to develop atmospheric transport models capable of estimating the movement of gases and particulate matter from livestock facilities to downwind receptor sites. Additional studies that link emissions and their transport are given in this section along with a couple examples of transport of emissions to receptors.*

**Impact of turbulence on emissions from livestock operations**

- Wind produces turbulence facilitating exchange of gases between animal production operations and the atmosphere. A study was conducted at a swine grow-finish facility to link the extreme variability of ammonia emissions over time with turbulence induced by buildings at the production site. A particulate matter and water vapor light detection and ranging

(LiDAR) system was used to measure plumes emitted from the facility. Plume emissions were linked to turbulence data generated from sonic anemometers at several locations around the site. The data indicated that vertical air velocities at the site ranged from 1 to 5 meters per second, accounting for large differences in emissions over time. **Impact:** These data provide insights needed to develop guidelines for measuring emission rates from animal production buildings and to quantify atmospheric exchanges adjacent to buildings for coupling with dispersion models. The information contributes to the knowledge base needed by air quality regulators to understand the extreme variation in emissions that can occur over time around swine production units.

Prueger, J., Eichinger, W., Hipps, L., Hatfield, J., Cooper, D. 2008. Turbulence statistics in the flow field of a confined animal feeding operation. *Atmospheric Environment* (in press).

**Prediction of wind speed variation**

- Wind speed is an important parameter for predicting gas exchanges, but wind speeds vary continuously and standardized procedures for monitoring and characterization of wind speeds are lacking. ARS scientists conceived and documented that the logarithmic vertical wind speed profile could be used for most atmospheric stability conditions. This was done by obtaining and analyzing an extensive set of wind speed distributions and logarithmic wind profile data. Results of this wind dynamics study allows scientists and engineers to expand the use of historical micrometeorological data for better emission predictions. **Impact**: This research provides emissions modelers with a simple tool to describe vertical wind speed variations irrespective of atmospheric stability conditions. ARCADIS, Inc., one of the world's largest engineering firms, relative to gas emission measurements, has modified their patented Radial Plume Mapping method (listed as EPA's OTM-10) and offered optional logarithmic profile-derived RPM outputs to customers.

Ro, K.S., and Hunt, P.G. 2007. Characteristic wind speed distributions and reliability of the logarithmic wind profile. *J. Environ. Engr.* 133:313-318.

**Measurement and tracking of particulate matter emissions from livestock operations**

- Particulate matter (PM) emissions from animal feeding operations (AFOs) can contribute to overall PM levels that exceed air quality limits and may pose a threat to human health. Methods are needed to measure PM emissions, particle size distribution, and dispersion of PM from AFOs. ARS scientists and their cooperators have conducted research to determine the feasibility of using light detection and ranging (LiDAR) equipment to evaluate PM emissions from AFOs. Field tests conducted at a swine production facility in Iowa showed that the LiDAR system could generate a two dimensional image of the PM plume dispersion and transport across the landscape. High frequency turbulence was measured in the approach, within the building complex and in the recovery space surrounding the AFO. Coupling of LiDAR measurements with micrometeorological data should allow determination of PM emission rates. A LiDAR system with three lasers allowed PM particle size distribution to be calculated. **Impact:** Data generated by the LiDAR system can be used to identify other source(s) of PM emissions in the vicinity of the AFO, to document the effectiveness of management practices and control technologies for PM emissions reduction, and to follow PM emissions offsite. This system has subsequently been used in California to document PM

emissions from cotton gins, field preparation and harvesting operations; and to assess the effectiveness of management practices for reducing PM emissions from these operations.

Prueger, J., Eichinger, W., Hipps, L., Hatfield, J., Cooper, D. 2008. Turbulence statistics in the flow field of a confined animal feeding operation. *Atmos. Environ.* (in press).

**Transport of dust and nutrients from a beef cattle feedyard**

- Land near beef cattle feedyards can be impacted by fugitive dust or ammonia deposition that may induce changes in nutrient-sensitive ecosystems. ARS researchers extensively characterized soil fertility, dust deposition, and vegetation composition on a native shortgrass prairie downwind of a beef cattle feedyard. Ammonia concentrations at heights of 1 and 3 m decreased approximately 15% for each 100 m downwind and approached background concentrations 800 m downwind. Phosphorus and N loading by dust from the feedyard severely impacted vegetation within 300 m of the feedyard, changing it from native perennial grasses to weedy annuals. However, vegetation and soil fertility were not affected 500 m from the feedyard. **Impact:** The data provide a basis for defining control guidelines to limit the spatial impacts of deposited ammonia on surrounding ecosystems.

Todd, R.W., Guo, W., Stewart, B.A., Robinson, C. 2004. Vegetation, phosphorus, and dust gradients downwind from a cattle feedyard. *Journal of Range Management.* 57:291-299.

- Research was conducted to determine transport of dust particles (PM10 and PM2.5) and bioaerosols from four feedyards and four dairies in the Southern Great Plains. PM10 levels exceeded National Ambient Air Quality Standards (NAAQS) on a few occasions near animal housing structures. PM10 concentrations were greater downwind than upwind of the production facilities. PM10 concentrations were approximately 2.5 times greater than PM2.5 concentrations. Concentrations of PM2.5 were similar in upwind and downwind locations and did not exceed NAAQS. A number of bioaerosol pathogens were identified (*E. coli* O157:H7, *H. influenza*, *S. uberus*) in the samples collected. The potential effects of these dusts and bioaerosols on cattle and worker health will need to be determined. **Impact:** These results suggest that beef cattle feedyards and dairies are not significant generators of PM2.5, the respirable form of PM generally associated with human and animal health problems. These results should be of interest to EPA as they revise PM air quality standards.

Purdy, C.W., Clark, R.N., Straus, D.C. 2007. Analysis of aerosolized particulates of feedyards located in the Southern High Plains of Texas. *Aerosol Science and Technology*. 41:497-509.

Purdy, C.W., Straus, D.C., Parker, D.B., Wilson, S.C., Clark, R.N. 2004. Comparison of microorganisms and concentration of endotoxin in the air of Southern High Plains feedyards. *American Journal of Veterinary Research* 65:45-52.

# Nutrient Management

## Summary

Research within the Nutrient Management component was conducted in four Problem Areas: (1) Animal feeding and management; (2) Innovative technology for collection, storage and treatment of manure; (3) Management tools for indexing and evaluating nutrient fate and transport; and (4) Farming systems and practices for efficient and balanced manure nutrient management.

Livestock and poultry diets were found to have a significant influence on the amount and form of N and P excreted in manure and the amount subsequently lost to the environment. Supplemental P routinely added to livestock and poultry feed resulted in elevated levels of total P and soluble P in manure, thus increasing the potential for P losses to surface water. Lowering or eliminating P supplementation in feed greatly reduced this problem without degrading animal performance. Withholding supplemental Ca and P from swine and poultry diets allowed endogenous phytase activity to hydrolyze phytate in the feed, therefore eliminating the need to add phytase enzyme supplements or use low phytate grains in the feed. Lowering crude protein levels in beef cattle diets increased N use-efficiency and lowered ammonia emissions, but in some cases the practice decreased weight gain especially if the cattle were on a highly fermentable high concentrate diet. Feeding distillers' grains from ethanol production to beef cattle lowered feed costs, but N, P and S dietary requirements were exceeded and the potential loss of manure N and P to water and air was increased.

Several innovative treatment systems to manage nutrients in manure and wastewater were developed and evaluated. A runoff control and treatment system consisting of a grass approach, a terrace with a debris basin and a vegetative treatment area was shown to be effective for managing runoff from small feedlot operations (< 6000 head capacity). The system will provide producers with a lower-cost alternative technology to meet EPA permit regulations and effluent guidelines. An algal scrubber system, based on nutrient uptake into algal biomass, was found to provide effective removal of N and P from dairy and swine effluent. The harvested algal biomass can be used as a fertilizer source or as a bioenergy feedstock. A method based on alum treatment of poultry litter reduced ammonia emissions and decreased losses of P to surface water. Approximately 700 – 800 million broilers are produced annually in poultry houses using alum litter treatment. The technology reduces air and water pollution while producing healthier broilers at a lower cost. A treatment system that removes nutrients, greatly reduces ammonia emissions and kills pathogens in swine wastewater has been developed and evaluated. The system has been designated as "Environmentally Superior Technology" through independent evaluation under the North Carolina Attorney General – Smithfield Foods Consent Agreement. The system is currently being used to replace anaerobic lagoons on swine production operations in North Carolina.

Methods and techniques are needed to measure and predict amount, forms and transformations of manure nutrients over time to make effective use of this resource and to protect the environment. Instruments to make rapid determination of nutrients in manure and soil have been developed to provide producers and their advisors information to make appropriate manure application decisions. These instruments range from a handheld reflectometer to estimate P in manure slurry

to x-ray fluorescence methods that can simultaneously measure multiple nutrients and trace elements in feed, manure and soil. Portable instruments based on near-infrared spectroscopy have been designed to measure total N and forms of N, and total C and forms of C in manure and soil. A ligand-based enzymatic assay has been developed to estimate bioavailable P fractions in manure, soil and wastewater. It may be possible to use this assay for evaluation of whole-farm accumulation of environmentally sensitive P forms. A risk assessment tool, the P Index, has been developed to identify areas on a farm or in a watershed that are susceptible to P losses to surface water. The P Index has been adopted by NRCS and used throughout the country to design nutrient management plans. Individual states have modified the original P Index to match their specific conditions and needs. Predictive tools to estimate plant available N release from manure over time (N mineralization) were developed. This research will lead to a decision support system to predict manure N mineralization across a range of soils, climate and manure composition.

Management practices and guidelines for efficient use of manure nutrients were designed and tested. Guidelines were developed to use broiler litter for fertilization of cotton. Complete or partial replacement of commercial; fertilizers with broiler litter will result in substantial savings to producers and will help alleviate the problem of litter overload on forage and pasture lands near poultry houses. Management practices for most efficient use of poultry litter and swine effluent nutrients in forage production in the southeastern U.S. were developed and transferred to NRCS. The information was used by NRCS to revise Code 590 (Nutrient Management) and Code 633 (Waste Utilization) guidelines that will determine management practices producers will use for environmental protection and improvement in forage and livestock systems. Two new poultry litter application methods were developed that incorporated litter into the soil, thereby reducing nutrient losses by 80 – 95% compared to surface application of manure. A web site for N management on dairy farms in the northeastern U.S. was designed to aid producers in the development of nutrient management plans. Manure nutrient losses in runoff were found to be much greater from grazed than hayed pastures. Renovation of grazed pastures using aerators increased infiltration and reduced runoff and nutrient losses. Long-term application of alum treated poultry litter to fescue pastures improved soil properties and significantly reduced P losses in runoff compared to untreated litter and ammonium nitrate fertilizer.

## Accomplishments

***Problem Area 1: Animal Feeding and Management***

**Dairy cattle diets to make more efficient use of nutrients and to protect the environment**

- Manure nutrient excretion, availability of nutrients to crops and environmental losses of manure nutrients are controlled by many factors, including what and how livestock are fed. ARS scientists and their cooperators used lactation trials, manure-soil incubations and greenhouse trials to discover that dietary forage and crude protein (CP) options are available that satisfy nutritional requirements of high-producing lactating dairy cows and produce manure with desirable characteristics for crop nutrition and environmental protection. Most tested diets had negligible impacts on milk production, but after application to soil, feces from cows fed on either high CP or alfalfa silage-based diets contributed to higher plant yields, N uptake and plant-available N than feces from corn silage-based diets. In related

studies, reducing P feed levels to NRC-recommended levels lowered manure P concentration of lactating dairy cows and resulted in lower P losses from rain simulation-generated runoff. If rainfall was delayed from two to five days after manure application, large decreases in the concentration of total and dissolved P in the runoff were observed. Based on these results, dairy farmers can reduce nutrient pollution from manure application by lowering or eliminating P supplementation of feed and by timing manure application to occur when runoff-producing rain is not expected for five or more days. **Impact:** Dairy nutritionists have started to incorporate this information into feeding trials to revaluate impacts of dairy cattle diet on milk production, manure nutrient excretions and environmental impacts. Dairy nutrition consultants with national and international responsibilities have requested this information for incorporation into their public presentations.

Powell, J.M., Wattiaux, M.A., Broderick, G.A., Moreira, V.R., and Casler, M.D. 2007. Dairy diet impacts on fecal chemical properties and nitrogen cycling in soils. *Soil Science Society of America Journal*, 70:786-794.

Hanrahan, L.P., W.E. Jokela, and J.R. Knapp. 2008. Dairy diet phosphorus and rainfall timing effects on runoff p from land-applied manure. *Journal of Environmental Quality* (in press).

**Poultry diets to make more efficient use of nutrients and to protect the environment**

- Research was conducted to evaluate the impact of lowering dietary calcium (Ca), phytase addition, and using low phytate grains in broiler diets on total and water soluble phosphorus (P) excreted. The study demonstrated that modified diets enhanced P retention in the birds, reduced total P in manure up to 63% and reduced water soluble P in manure up to 73%, thereby reducing the potential for P losses to surface waters. In a related study, endogenous phytase activity did not influence phytate excretion from either swine or poultry; in fact, both species had sufficient endogenous phytase activity to hydrolyze phytate in feedstuffs when supplemental Ca and P were not added to diets. **Impact:** These results will provide producers with dietary options that will allow livestock and poultry to make more efficient use of P in feed and result in greater protection of the environment. Based on the number of broilers produced annually (approximately 9 billion birds), feeding diets optimal in Ca and P would result in a 21,000 ton reduction in P excretion.

Leytem, A.B., P.W. Plumstead, R.O. Maguire, P. Kwanyuen, and J. Brake. 2007. What aspect of dietary modification in broilers controls litter water soluble phosphorus: Dietary phosphorus, phytase, or calcium. *J. Environ. Qual*. 36:453-463.

- Fecal P was determined for broilers grown under different house temperatures and dietary P levels (including modified diets incorporating phytase enzyme and high available P corn). Land application of litter from these treatments indicated that rearing temperature had no effect on soluble P in soil and runoff while diet modification resulted in a small reduction in water soluble P. Alum treatment of litter was more effective than diet modification in reducing P loss from litter. A related study with swine and poultry showed that the combination of phytase in the diet and manure treatment with alum or aluminum chloride resulted in the most effective use of P in the diet and lower levels of P in runoff. **Impact:** The research results have been transferred to the poultry industry and are being used to improve use of P in feed and to protect surface water quality. The alum process has been

patented and subsequently licensed by General Chemical. Approximately 10% of the broilers produced in the U.S. are grown using alum litter treatments.

Miles, D.M., Moore, P.A., Smith, D.R., Rice, D.W., Stillborn, H.L., Rowe, D.E., Lott, B.D., Branton, S.L., and Simmons, J.D. 2003. Total and water-soluble phosphorus in broiler litter over three flocks with litter treatment and dietary inclusion of high available phosphorus corn and phytase supplementation. *Poultry Science* 82:1544-1549.

Smith, D.R., Moore, P.A., Jr., Miles, D.M., Haggard, B.E., and Daniel, T.C. 2004. Decreasing phosphorus runoff losses from land-applied poultry litter with dietary modifications and alum addition. *Journal of Environmental Quality* 33:2210-2216.

**Effect of distillers' grain in beef cattle diet on nutrient excretion**

- ARS scientists studied the effect of increasing levels (0, 20, 40, or 60%) of wet distillers' grains with solubles (WDGS) in cattle diets on nutrients excreted, odorants, and persistence of coliforms in manure slurries. Nitrogen, P, and S were significantly greater in manure slurries from cattle fed WDGS. When no WDGS was in the diet, or a typical finishing corn diet (82%) was fed, the concentration of L-lactate was significantly greater and the pH was significantly lower in the manure slurries, compared to diets containing WDGS. The high L-lactate concentration and low pH in these slurries inhibited microbial activity, reduced persistence of generic *E. coli* and lowered methane production. Although feeding WDGS to feedlot cattle currently has a cost benefit compared to feeding corn, it could have a potential negative impact on the environment**. Impact:** The dietary requirements of the animal are often exceeded when WDGS is fed. Excess nutrients including N, P, and S are excreted. These nutrients have the potential to increase ammonia and odor emissions, increase P run-off, and prolong pathogen persistence in the environment.

Archibeque, S.L., Freetly, H.C., Cole, N.A., Ferrell, C.L. 2007. The influence of oscillating dietary protein concentrations on finishing cattle. II. Nutrient retention and ammonia emissions. *J. Anim. Sci*. 85(6):1496-1503.

**Beef cattle diets to make more efficient use of nutrients and to protect the environment**

- ARS scientists tried two methods to improve N use efficiency**,** oscillating dietary protein and phase feeding of dietary protein. The efficiency of utilization of dietary N might be improved in finishing beef cattle if a greater proportion of N were recycled among segments of the digestive system. Oscillating dietary crude protein concentration at 48 hour intervals from 13% to 11.5% increased N recycling and in some cases increased N retention and decreased potential ammonia emissions; however, the results were highly dependent upon dietary protein source and dietary energy concentration. Protein requirements (as a % of dietary dry matter) of finishing beef cattle tend to decrease as animals mature; thus, it might be possible to conserve N without adversely affecting animal performance by decreasing the dietary protein concentration late in the feeding period (i.e. phase-feeding). Decreasing dietary protein concentrations during the last 56 days of the feeding period when cattle were fed a steam-flaked corn-based diet decreased apparent ammonia losses by 1 to 3 kg per steer; however, phase feeding also depressed animal weight gain because of a decrease in dry matter intake. In a related study, phase feeding did not depress weight gain when the cattle were fed dry-rolled corn-based diets. **Impact:** Although oscillating dietary crude protein

concentrations is not practical at the present time, it may potentially lead to new feed management techniques that improve N utilization and decrease ammonia emissions. The phase feeding results appear to be dependent on diet suggesting that phase-feeding may be limited when cattle are fed a highly fermentable high-concentrate diet.

Archibeque, S.L., Freetly, H.C., Cole, N.A., Ferrell, C.L. 2007. The influence of oscillating dietary protein concentrations on finishing cattle. II. Nutrient retention and ammonia emissions. *Journal of Animal Science*. 85:1496-1503.

Cole, N.A., Defoor, P., Galyean, M., Duff, G., Gleghorn, J. 2006. Effects of phase-feeding of crude protein on performance, carcass characteristics, serum urea nitrogen concentrations, and manure nitrogen of finishing beef steers. *Journal of Animal Science*. 84:3421-3432.

### *Problem Area 2: Innovative Technology for Collection, Storage and Treatment*

### Feedlot runoff control system

- A cost-effective solution for managing feedlot runoff is needed for small beef cattle feeding operations. ARS scientists developed and evaluated a passive runoff control and treatment system designed to reduce the volume of long-term liquid storage, provide adequate solids separation, and evenly distribute basin discharge water and nutrients for grass hay production. The system consisted of a grass approach, a terrace with a debris basin, and a vegetative treatment area (VTA). The system effectively reduced the cumulative mass of total and volatile suspended solids and reduced chemical oxygen demand by 80%, 67%, and 59%, respectively. No measureable water exited the VTA for storms below the 25-year, 24-hour system design. Therefore the discharge water was effectively contained and used for hay crop production. Estimated total N load in the discharge water entering the vegetative filter strip was equivalent to or less than the total N removed by the crop for most years. **Impact:** About half of the nation's approximate 41,000 feedlots have a 6000 head capacity or less. Feedlots of this size that have acceptable topography can utilize this new system to realize savings of 50% or more in construction costs, and similar savings in operational costs compared to conventional systems using retention ponds. This "Alternative Control Technology" provides smaller beef cattle feeding operations with a robust, cost-effective alternative to meet requirements of EPA NPDES Permit Regulations and Effluent Guidelines for CAFOs. Larger feedlots may benefit by using VTA designs to protect manure storage areas or for feedlot expansion.

  Woodbury, B.L., Nienaber, J.A., Eigenberg, R.A. 2003. Performance of a passive feedlot runoff control and treatment system. *Trans. ASAE* 46:1525-1530.

  Woodbury, B.L., Nienaber, J.A., Eigenberg, R.A. 2005. Effectiveness of a passive feedlot runoff control system using a vegetative treatment area for nitrogen control. *Applied Eng. in Agri*. 21:581-588. 2005.

- Vegetative treatment areas (VTA) are an important part of the passive runoff control and treatment system. Documentation of VTA ability to handle nutrient loads is needed. ARS scientists have used soil conductivity maps generated by electromagnetic induction (EMI) to provide valuable insights into nutrient-laden runoff distribution across the VTA. The conductivity map was linked to nutrient concentrations by using EMI data to generate a response surface sampling design (RSSD) to identify optimal locations to collect soil samples

for nutrient analysis. Coupling the nutrient analysis data with the soil conductivity data allows a detailed nutrient distribution map to be generated. **Impact:** This approach can be used to effectively target locations for soil sampling in a field, saving researchers time and money. The RSSD approach is being used to generate nutrient distribution maps at 6 sites in eastern Nebraska, 3 sites in South Dakota, and 7 sites in western and central Iowa that are in a multi-state project to evaluate the effectiveness of VTAs for nutrient control. Visual depiction of VTA performance has been a valuable tool for illustrating system performance for operators, design engineers, researcher, and regulatory authorities.

Eigenberg, R.A., Lesch, S.M., Woodbury B.L., Nienaber, J.A. 2008. Geospatial methods for monitoring a vegetative treatment area receiving beef feedlot runoff. *J. Environ. Qual*. (in press).

**Algal turf scrubber (ATS) technology to recover nutrients from manure**

- An alternative to land spreading of manure effluents is to mass-culture algae on the N and P present in the manure and incorporate manure N and P into algal biomass. ARS scientists examined one algal technology, termed algal turf scrubbers (ATS), for its ability to remove N and P from dairy and swine manure effluents and to generate a beneficial biomass. Algal N and P accounted for roughly 70-90% of input N and P at loading rates below 1 g TN/ square meter-day (equivalent to 2700 kg N/ha-year). The daily dry matter yield from pilot-scale raceways was about 10 g/square meter-day and is equivalent to 27,000 kg/ha for a 270 day season in Maryland. The algal biomass can be used as an organic fertilizer. Projected yearly operational costs of a farm-scale system per cow, per kg N, per kg P, or per kg of dried biomass are $778, $10.70, $53.30, and $1.31, respectively. Within the context of reducing nutrient inputs in sensitive watersheds such as the Chesapeake Bay, these costs are well below the estimates of $19 per kg N cited for upgrading existing water treatment plants. Sale of the dried algal biomass as an organic fertilizer could also provide a significant source of revenue. **Impact:** Pilot- and full-scale ATS systems are being constructed or are under consideration for nutrient treatment of agricultural drainage water in Florida, Maryland, and Pennsylvania. Additional interest in these systems is driven by the potential use of the algal biomass as a bioenergy feedstock.

Pizarro, C.X., Mulbry, W., Blersch, D., Kangas, P. 2006. An economic assessment of algal turf scrubber technology for treatment of dairy wastewater. *Ecological Engineering*. 26:321-327.

Westhead, E., Pizarro, C.X., Mulbry,W. 2006. Treatment of swine manure effluent using freshwater algae: production, nutrient recovery, and elemental composition of algal biomass at four effluent loading rates. *Journal of Applied Phycology*. 18:41-46.

**Alum additions to poultry litter to reduce ammonia emissions and phosphorus solubility**

- ARS scientists have developed a method using aluminum sulfate (alum) to reduce ammonia emissions and losses of phosphorus to the environment (described previously). When alum is added to litter it lowers the pH, which both reduces ammonia loss and decreases the number of microbial pathogens (see Problem Area 3 in the Emissions Component for more details). As a result, poultry reared on alum-treated litter weigh more, utilize their feed better, and have lower mortality. Energy cost (propane use) is also significantly reduced due to less ventilation needed for ammonia removal in cooler months. Cost-benefit analysis of this best management practice indicate that producers make an additional two dollars for every dollar

spent on this technology. Alum treatment of litter also reduces P solubility. Long-term studies have shown that when treated litter is applied to land, P in runoff is reduced by 75% compared to untreated litter, while increasing forage production and improving soil quality. Alum treatment of poultry litter is one of the few cost-effective best management practices that protects air, soil and water quality. **Impact:** This technology was patented and licensed to General Chemical Corporation, the largest alum supplier in North America. Poultry grade alum is being sold to poultry producers under the trade name of $Al^{+}$Clear. During the past five years, 700-800 million broilers were produced annually with this technology, resulting in substantial reductions in air and water pollution, while producing healthier chickens at a lower cost. Producers can receive funding to use the technology under the Environmental Quality Incentives Program administered by the Natural Resources Conservation Service.

Smith, D.R., P.A. Moore, Jr., D.M. Miles, B.E. Haggard, and T.C. Daniel. 2004. Decreasing phosphorus runoff from land-applied poultry litter with dietary modifications and alum addition. *J. Environ. Qual*. 33:2210-2216.

Gilmour, J.T., M.A. Koehler, M.L. Cabrera, L. Szajdak, and P.A. Moore, Jr. 2004. Alum treatment of poultry litter: Decomposition and nitrogen dynamics. *J. Environ. Qual*. 33:402-405.

**Comprehensive swine wastewater treatment system**

- To be permitted, new swine waste management systems in North Carolina need to meet the strict performance standards of an "Environmentally Superior Technology" (EST). These technologies must be able to substantially remove nutrients, heavy metals, pathogens, and emissions of ammonia and odorants. ARS scientists and cooperators developed a system of treatment technologies that met these requirements in an independent evaluation under the North Carolina Attorney General – Smithfield Foods Consent Agreement. ARS scientists have subsequently designed and demonstrated a second generation treatment system for swine wastewater that can achieve the high treatment performance standards of an EST, yet it is four times more economical than earlier versions. The system combines solid-liquid separation, biological ammonia treatment, and P removal and produces a deodorized and disinfected liquid effluent. The second generation system was installed full-scale at a 5,150-head swine finishing facility and operated under steady-state conditions during cold and warm weather. The system removed 98% of the suspended solids, 100% of biological oxygen demand, 97% of the ammonia, 94% of the P, 99% of the copper and zinc, and produced a deodorized and sanitized effluent. Ammonia concentration in air of the barns was significantly reduced, and animal health and productivity were enhanced. Compared to the traditional lagoon management, the mortality decreased 57% with the new system, daily weight gain increased 11%, and feed conversion improved 5.4%. This cleaner alternative technology provides significant environmental benefits and increased income for the producer. **Impact:** The EST can be used to replace anaerobic lagoons resulting in significant environmental improvements. Swine producers can increase their income through reduced mortality, increased weight gain and improved feed conversion. The separated solids can be converted to value-added products through composting or used for energy production. In addition, the EST reduces emissions of green house gases such as methane resulting in carbon dioxide equivalent reduction credits that can be sold. In July 2007 the State of North Carolina enacted Senate Bill 1465 that made the environmental performance standards of an EST a requirement for construction of new swine farms or expansion of existing swine farms

in North Carolina. The state also established a Lagoon Conversion Program that provides financial incentives to assist producers in the conversion of anaerobic swine lagoons to EST. Two hog producers have just received grants through this program to install this swine wastewater treatment system on their farms.

Vanotti, M.B., Szogi, A.A., and Hunt, P.G. 2005. U.S. Patent No. 6,893,567. Wastewater treatment system.

Vanotti, M., and Szogi, A. 2007. Evaluation of environmental superior technology contingent determination – Second generation super soil technology. *Final Report for NC Department of Justice* – Office of the Attorney General Environmental Enhancement Fund Program. 48 pp. Available at: http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/supersoils2ndgeneration/pdfs/technical_report.pdf

Vanotti M.B., Szogi, A.A., Hunt, P.G., Millner, P.D., and Humenik, F.J. 2007. Development of environmentally superior treatment system to replace anaerobic swine lagoons in the USA. *Bioresource Technol.* 98(17):3184-3194.

Vanotti, M.B., Szogi, A.A., and Fetterman, L. 2008. U.S. Patent Application S.N. 11/820,396 filed 6/19/07. Wastewater treatment system with simultaneous separation of phosphorus sludge and manure solids.

- ARS scientists developed a method for separation of manure solids and liquids using polyacrylamide (PAM) polymers. More than 95% of suspended solids were removed using PAM as compared to about 10% solids removal using traditional screening methods. This method of solids separation is an important component of the treatment system described in the previous accomplishment. **Impact:** By capturing the suspended solids early, most oxygen-demanding compounds and organic nutrients are removed from the liquid stream. This lowers the cost of treating the remaining wastewater. The separated dry solids can be transported and used more effectively as crop fertilizer or processed into value-added products. Over the last five years, this enhanced separation technology has been used to treat the waste from several million swine in the U.S., Europe, and South America.

Vanotti, M.B., Rice, J.M., Ellison, A.Q., Hunt, P.G., Humenik, F.J., and Baird, C.L. 2005. Solid-liquid separation of swine manure with polymer treatment and sand filtration. *Trans. ASAE*. 48:1567-1574.

- ARS scientists have developed a method, using small quantities of liquid lime, to recover soluble P from liquid manure by precipitation of calcium phosphate. The technology can be used to retrofit animal lagoons or in new systems without lagoons. Due to its high content of plant available P, the recovered calcium phosphate can be recycled into a marketable fertilizer without further processing. A second generation of the technology is available that simultaneously separates solids and P from municipal and agricultural wastewater. **Impact:** The combined separation process is more efficient in terms of equipment needs and chemical use. Thus, it reduces installation and operational cost which should encourage adoption of the new technology by livestock producers.

Vanotti, M.B., Szogi, A.A., and Fetterman, L. 2008. U.S. Patent Application S.N. 11/820,396 filed 6/19/07. Wastewater treatment system with simultaneous separation of phosphorus sludge and manure solids.

- ARS scientists have developed a process called "quick wash" to recover P from livestock solid manure. The process includes a rapid reaction to extract the manure-bound P followed by quick concentration and recovery to prevent unnecessary C and N oxidation. Results from evaluation of laboratory and field prototype systems indicated that up to 80% of P can be selectively removed and recovered from poultry litter. **Impact:** This technology allows poultry producers to capture manure P in a form that can be applied to their own crops or transferred to areas with a greater P need.

Szogi, A.A., Vanotti, M.B., and Hunt, P.G. 2008. Process for removing and recovering phosphorus from animal waste. U.S. Patent Application S.N. 12/026346 filed 2/5/08.

**Predicting nitrous oxide releases from riparian buffers**

- Riparian buffers are used throughout the world for the protection of water bodies from nonpoint source pollution, particularly N. However, there is a concern that denitrification processes in the buffer will result in the release of the greenhouse gas, nitrous oxide, to the atmosphere. ARS scientists investigated nitrous oxide release from riparian buffers in the southeastern Coastal Plain. They found that the controlling factor for nitrous oxide production was the soil C/N ratio. When the ratio was below 25, there was essentially no nitrous oxide production. While a few riparian buffers were found that released nitrous oxide to the atmosphere, there was little evidence for broad deleterious greenhouse gas emissions from riparian buffers. **Impact:** These findings provide important data concerning the tradeoffs between water and air quality associated with the use of riparian buffers for nutrient management. Soil C/N ratio can be used by producers and their advisors (university Extension, NRCS) to determine sites where riparian buffers can be used to protect water quality from nutrients in manure without releasing nitrous oxide to the atmosphere.

Hunt, P.G., Matheny, T.A., and Ro, K.S. 2007. Nitrous oxide accumulation in soils from riparian buffers of a Coastal Plain watershed carbon/nitrogen ratio control. *J. Environ. Qual*. 36:1368-1376.

Hunt, P.G., Matheny, T.A., and Stone, K.C. 2004. Denitrification in a Coastal Plain riparian zone contiguous to a heavily loaded swine wastewater spray field. *J. Environ. Qual*. 33:2367-2374.

**Wetlands for treatment of wastewater**

- While surface flow wetlands are typically covered with continuous communities of wetland plants, some wetlands use the marsh-pond-marsh (M-P-M) design. The premise of this design is that the pond section will promote aerobic conditions which will synergistically interact with the more anaerobic condition of the subsequent marsh section. ARS scientists investigated constructed wetlands in the southeastern U.S. for their effectiveness in treating swine wastewater applied at varying rates. Significant amounts of N and P were removed, particularly during the warmer months. Yet, there was no improvement in the treatment of either N or P relative to the previously investigated continuous marsh constructed wetlands. Modifications of continuous marsh constructed wetlands to M-P-M wetlands design did not improve the performance relative to N or P removal. **Impact:** This study demonstrated that the varying ecological characteristics of both marshes and ponds have not yielded a simple synergistic advantage in M-P-M wetlands for swine lagoon wastewater. More novel

approaches such as adding constructed floating wetlands to the pond section will be needed to retrofit M-P-M wetlands.

Hunt, P.G., Poach, M.E., Matheny, T.A., Reddy, G.B., and Stone, K.C. 2006. Denitrification in marsh-pond-marsh constructed wetlands treating swine wastewater at different loading rates. *Soil Sci. Soc. Amer. J.* 70:487-493.

Poach, M.E., Hunt, P.G., Reddy, G. B., Stone, K.C., Johnson, M.H., and Grubbs, A. 2007. Effect of intermittent drainage on swine wastewater treatment by marsh-pond-marsh constructed wetlands. *Ecol. Engr*. 30:43-50.

- Quality of surface water in the Santa Ana watershed, a major source of drinking water, has been significantly affected by intensive dairy operations and the disposal of untreated wastewater into the Chino Basin. ARS scientists and cooperators evaluated constructed wetlands for their ability to remove contaminants from agricultural waste water prior to land application. They found that the most effective N removal occurred when the plant cover was 50-75% in surface flow constructed wetlands. Efficient reduction of nitrate in dairy wastewater was attributed to development and maintenance of healthy diverse microbial communities. In related studies, the effectiveness of subsurface constructed wetlands for contaminant removal also was demonstrated. **Impact:** This wetland project has served as a model for the dairy industry throughout the Chino basin. Producers are independently building and managing cost-effective, low-maintenance subsurface wetland systems on their own farms. Critical findings from this research are being used as a guide to restore the Prado wetland in the middle Santa Ana River watershed.

Ibekwe, A.M., Lyon, S.R., Leddy, M., Jacobson-Meyers, M. 2007. Impact of plant density and microbial composition on water quality from a free water surface constructed wetland. *Journal of Applied Microbiology*. 102:921-936

Ibekwe, A.M., Grieve, C.M., Lyon, S.R. 2003. Characterization of microbial communities and composition in constructed dairy wetland wastewater effluent. *Applied and Environmental Microbiology*. 69(9):5060-5069.

### *Problem Area 3: Management Tools for Indexing and Evaluating Nutrient Fate and Transport*

#### Methods for measuring nutrients in manure and soil

- Quick measurements and timely information about manure nutrient content minimize the risks of P over-application and losses of dissolved P in runoff from fields treated with manure. ARS scientists evaluated a handheld reflectometer and a turbidity meter for measuring P in slurry manure. The reflectometer was acceptable for measurements of soluble P; sample pre-treatment was not needed, thus reducing time and cost of the measurements. Coupling a pH measurement with the reflectometer reading improved soluble P prediction for 95% of the manure samples tested. In a related investigation, a rapid X-ray fluorescence method was developed to non-destructively obtain P content of feed samples, manures, and soils. This method also allowed other mineral constituents such as calcium, potassium, iron, aluminum, copper, or zinc to be determined to explain differences in the availability of P between manures of animals receiving feed rations of varied composition and mineral supplements. The multi-element analytical capabilities of x-ray fluorescence

allowed rapid analysis of trace elements that can pose an environmental threat such as arsenic (As) and copper in poultry feed and manure. In a large survey of broiler and layer litter, broiler litter contained an 18-fold higher As content. Twenty percent of the broiler litter samples analyzed in the investigation contained As concentrations which exceeded the threshold limit for land application of As in biosolids. **Impact:** The handheld reflectometer can give in-field measurement of soluble P to allow producers and their advisors to make improved manure application decisions. The x-ray fluorescence method provides a tool for rapid assessment of nutrients and trace elements in manure and soil. A database of total composition of manures and soils is being assembled for use in the development of a new P fate model and decision-support tools for comprehensive management of manure nutrients and trace elements.

Dao, T.H., and H. Zhang. 2007. Rapid composition and source screening of heterogeneous poultry litter by energy dispersive x-ray fluorescence spectrometry. *Annals of Environmental Science*, 1:69-79.

Lugo-Ospina, A., Dao, T. H., Van Kessel, J.A., and Reeves, J.B. III. 2005. Evaluation of quick tests for dissolved phosphorus determination in dairy manures. *J. Environ. Pollution*, 135:155-162.

- ARS scientists have been involved in developing and promoting use of infrared spectroscopy in manure and soil analysis. They helped organize and write a book "Near-Infrared Spectroscopy in Agriculture" which described the instrumentation and uses of the technique for analysis of manure, soil and crops. ARS scientists developed software to relate infrared reflectance spectroscopic data to manure and soil composition. **Impact:** The book provides a comprehensive information guide for agricultural scientists who can utilize NIR to improve nutrient management. The software programs are documented in a series of journal and popular articles that are freely available at: www.impublications.com/nir/page/software. This background information facilitated development of portable infrared spectrometers for in-field determination of N and C (see the following paragraphs).

Roberts, C., Workman, Jr. A., J., and Reeves, III J. B. (editors). 2004. Near-Infrared Spectroscopy in Agriculture, vol. 44 in series Agronomy Monograph series. Am. Soc. Agron., Crop Sci. Soc. Am., and Soil Sci. Soc. Am. Madison, WI.

- ARS scientists have developed and tested a portable near-infrared (NIR) spectrometer for determining moisture, total-N, organic-N and ammonium-N in poultry and dairy manures. The instrument is based on wavelength filters that selectively target the manure constituents listed above. The instrument is capable of employing up to 20 filters, which allows testing for several manure constituents from different species or different manure management systems. Field evaluation showed that the instrument was capable of providing accurate estimates of several N species in poultry manure and dairy manures, although high moisture dairy manures had to be mixed with silica agents to suspend the manures and produce accurate results. **Impact:** A commercial version of the instrument will soon be available. Such an instrument will be a valuable tool to producers and their advisors as they design nutrient management plans for livestock operations.

Reeves, III., J. B. 2007. The present status of "quick tests" for on-farm analysis with emphasis on manures and soil: What is available and what is lacking? *Livestock Science*: 112:224-231.

- ARS scientists have investigated the feasibility of using a portable infrared spectrometer to determine total C, organic C and inorganic C fractions in soil. Performance of the portable

instrument for soil C determination was found to be comparable to data obtained using laboratory-based near-infrared and mid-infrared spectrometers. Air-drying of soil samples and sieving to remove plant residues was necessary to achieve high accuracy with the portable instrument. These investigations demonstrated that infrared spectroscopic techniques can measure organic and inorganic C fractions as well as total C. **Impact:** This instrument is currently being used to measure C under various cropping systems and practices, and to determine the contribution of manure addition to C sequestration in soil.

Reeves, III, J. B., Follett, R. F., McCarthy, G. W. and Kimble, J. M. 2006. Can near- or mid-infrared diffuse reflectance spectroscopy be used to determine soil carbon pools?. *Comm. In Soil Science and Plant Analysis*. 37:2307-2325.

Sarkhot, D. V., Comberford, N. B., Jokela, E. J. and J. B. Reeves. 2007. Effects of forest management intensity on carbon and nitrogen content in different soil size fractions of a north Florida spodosol. *Plant and Soil.* 294:291-303.

- Electromagnetic induction (EMI) soil conductivity, measured in real time using a mobile system, was used to track available N levels from manure or compost application and use of a green winter cover crop during four growing seasons. A series of soil conductivity maps of a research cornfield were generated using a global positioning system (GPS) and EMI methods. Soil samples were collected and analyzed to verify predictions from the EMI method. The sequential measurements of soil conductivity effectively identified the dynamic changes in available soil N, as affected by animal manure and commercial anhydrous ammonia fertilizer treatments during the corn growing season. The sequential measurements also clearly identified the effectiveness of cover crops in minimizing levels of available soil N before and after the corn growing season, when soluble N is most subject to loss. Soil conductivity appears to be an indicator of soluble N gains and losses, and may serve as a measure of available N sufficiency for corn early in the growing season, as well as an indicator of nitrate surplus after harvest, when soluble N is prone to loss from leaching and/or runoff. **Impact:** The technique provides a rapid assessment of nutrient variability across a field. Maps generated by this technology are useful in precision farming applications. The maps can be used by producers to enhance N-use efficiency and to minimize N losses to the environment. The method is currently being used to help evaluate nutrient distribution in a multi-state study of the effectiveness of vegetative treatment areas associated with feedlot runoff control systems.

Eigenberg, R.A., Nienaber, J. A. Electromagnetic induction methods applied to an abandoned manure handling site to determine nutrient buildup. *J. Envir. Qual*. 32:1837-1843. 2003.

Eigenberg, R.A., Nienaber, J.A., Woodbury, B.L., Ferguson, R.B. 2006. A four year summary of the use of soil conductivity as a measure of soil and crop status. *Handbook of Agricultural Geophysic.*

**P forms, transformations, and bioavailability**

- Phosphorus in livestock and poultry manure has contributed to a buildup of excess P in terrestrial and aquatic environments. Appropriate management of manure P for crop production and environmental protection will require a greater understanding of P forms and transformations in manure, soil and wastewater in a variety of environmental conditions. ARS scientists developed a novel ligand-based enzymatic assay for bioavailable P fractions in manure, soil, and wastewaters. The assay was used on manure samples collected from

dairy farms across five states in the northeastern U.S.. The assay showed that water-soluble and insoluble inorganic phosphates accounted for between 15 to 30% of total P in dairy manure, whereas 40 to 80% of the total P occurred in organic forms that were hydrolysable by phosphohydrolase enzymes and released as soluble phosphate. A large fraction of the farms evaluated in this study had low water soluble P (the form of P generally associated with negative environmental impacts), suggesting that the producers are using good nutrient management practices. **Impact:** The assay is effective over a wide range of manure characteristics so it may be possible to use the method for routine evaluation of whole-farm accumulation of environmentally-sensitive P forms. The enzymatic method has been used by researchers to assemble a new P transformation database and to generate novel equations for a new P model under development. Current models of P fate in the environment date back to the early 1980's and must be updated to reflect new knowledge of the chemistry of environmental P.

Dao, T. H. 2004. Ligands and phytase hydrolysis of organic phosphorus in soils amended with dairy manure. *Agronomy Journal*, 96:1188-1195.

Green, V.S., Dao, T.H., and Cavigelli, M.A. 2006. Phosphorus fractions and dynamics among oil aggregate size classes of organic and conventional cropping systems. *Soil Science*, 171:874-885.

**Predicting the plant availability of manure N**

- Producers and their advisors need to be able to predict plant availability of manure N over time to use appropriate manure application rates for crop production and environmental protection. Nitrogen transformations are controlled by the interactive effects of soil, temperature, water, and manure composition, making it difficult to predict manure N availability. A team of ARS scientists from six labs around the country have conducted a coordinated research effort to develop, validate and employ predictive relationships that quantify the impacts of key soil, environmental, and soil x environmental factors on manure N mineralization (conversion of other forms of manure N to nitrate). Common experimental design and research protocols were developed and used at all locations to conduct a laboratory incubation study and a field study. Each lab used major soils from the lab's area of the country plus a common soil used as an internal reference by all labs. Laboratory data was used to generate generalized predictions of N mineralization which were then validated by N transformation data from the field studies.

  A wide range in manure derived nitrate was observed across different soil temperatures, however, these differences were accounted for using the concept of degree days after application (accumulating soil temperature over time). Fluctuating soil water regimes between 30 and 60% water-filled pore space did not impact manure-derived nitrate. A first order equation was used to describe the relationship between manure derived nitrate and degree days after application, but the relationship can vary across soils. For example ARS scientists found that N mineralization in broiler litter was much slower in clayey soils than sandy soils. Research is currently being done to look at the role of microbial communities in manure N mineralization. A decision support system is being developed that will predict manure N mineralization across a range of soils, climate and manure composition. **Impact:** The experimental design, research protocols, degree day concept and N mineralization data generated in this investigation are being used by other research groups around the country

including the CSREES North Central Regional Project (NC 218) working on manure N mineralization in crop systems to protect water resources. The current N mineralization data generated in 8 states and the decision support system under development will contribute to optimal N use-efficiency in manure amended soils, maximizing economic benefits and minimizing deleterious environmental consequences.

Honeycutt, C.W., T.S. Griffin, B.J. Wienhold, B. Eghball, S.L. Albrecht, J.M. Powell, B.L. Woodbury, K.R. Sistani, R.K. Hubbard, H.A. Torbert III, R.A. Eigenberg, R.J. Wright, M.D. Jawson, and Z. He. 2005. Protocols for nationally coordinated laboratory and field research on manure nitrogen mineralization. *Communications in Soil Science and Plant Analysis*. 36: 2807-2822.

Griffin, T.S., C.W. Honeycutt, S.L. Albrecht, K.R. Sistani, H.A. Torbert, B.J. Wienhold, B.L. Woodbury, R.K. Hubbard, and J.M. Powell. 2008. Nationally-coordinated evaluation of soil nitrogen mineralization rate using a standardized aerobic incubation protocol. *Communications in Soil Science and Plant Analysis*. 38:257-268.

- To accurately assess total plant availability of manure nutrients it is necessary to account for nutrients remaining in soil from previous manure applications. ARS scientists discovered that estimates of manure N uptake by corn during the second and third year after manure application were more precise using manure labeled with the stable isotope $^{15}N$. **Impact:** The $^{15}N$ labeling technique has been adopted as a research tool to improve predictions of manure N cycling in soils and availability to crops. Results from ARS field trials using $^{15}N$-labeled dairy manure provide better estimates of N availability from manure in nutrient management plans. Information from these investigations has been incorporated into Wisconsin's soil fertility recommendations.

Cusick, P.R., Kelling, K.A., Powell, J.M., and Muñoz. 2005. G.R. Estimates of Residual Dairy Manure Nitrogen Availability Using Various Techniques. *Journal of Environmental Quality*. 35: 2170-2177.

**Predicting P losses to surface water**

- ARS scientists, university cooperators and NRCS developed and refined a tool, the P Index, to identify areas on a farm or in a watershed that are susceptible to P losses to surface water. The scientific rationale for the P Index is based on ARS findings that most of the P exported (>80%) from agricultural watersheds comes from only a small area of land (<20%) during a limited number of storms. For P losses to occur there must be a source of P and a mechanism to transport P to surface water. The original P Index accounted for and ranked P source (soil, fertilizer and manure) and transport factors (erosion, surface runoff, leaching, and distance of the field from water bodies) controlling P loss in overland and subsurface flow, and identified sites where the risk of P movement was expected to be high. The P Index has been adopted by NRCS and used throughout the U.S. and in a large number of other countries to identify risk and to develop Nutrient Management Plans (NMP). The P Index has been modified by individual states to meet their particular needs, and improved methods to assess source strength and transport have been developed. Examples of these modifications and improvements are given in the following paragraphs. **Impact:** The P Index has been adopted by NRCS and is being used in 47 states to identify sensitive areas that need to be targeted for management alternatives and remedial measures to reduce the risk of P loss from farms. EPA has estimated that use of the P Index to develop NMPs has reduced P losses by 50 million pounds per year. Economic benefits of improved nutrient management are estimated to be

between $200M and $350M annually and are related to increased use of recreational waters, improved shellfish harvest, fewer fish kills, and lower drinking water treatment costs.

Sharpley, A.N., J.L. Weld, D.B. Beegle, P.J.A. Kleinman, W.J. Gburek, P.A. Moore and G. Mullins. 2003. Development of phosphorus indices for nutrient management planning strategies in the U.S. *J. Soil Water Conserv*. 58:137-152.

- Research has shown that the most important parameter effecting P runoff from land fertilized with manure is the amount of water soluble P in manure. ARS scientists were first to publish a method of measuring water soluble P, and recently led a large national study that validated the method and established 1:100 as the extraction ratio that gave the best correlation between water soluble P in manure and P in runoff. **Impact:** This new method has been accepted as the standard method for extraction of water soluble P from manure by the SERA-17 National P group. The method is being used to provide input data to P Indices. The P Index is used to develop an NMP that guides producer's decision about the amount of manure that can be safely applied to a given field.

Kleinman, P.J., D. Sullivan, A. Wolf, R. Brandt, Z. Dou, H. Elliott, J.L. Kovar, A.B. Leytem, R. Maguire, P.A. Moore, Jr., A.N. Sharpley, A. Shober, J.T. Sims, J. Toth, G. Toor, H. Zhang, T. Zhang, and L.S. Saporito. 2007. Selection of a Water-Extractable Phosphorus Test for Manures and Biosolids as an Indicator of Runoff Loss Potential. *J. Environ. Qual*. 36:1357-1367.

- Surface-applied, unincorporated manure and fertilizer can be significant sources of P loss in runoff. However, computer models commonly used to quantify agricultural P loss do not correctly simulate P loss from surface manure and fertilizer. ARS scientists developed two separate models, one to predict P loss in runoff from surface manure and a second to predict runoff P loss from surface fertilizer. These new model routines were developed by: 1) compiling experimental runoff data from dozens of sources in the literature and from new experiments conducted in Pennsylvania and Texas, 2) discovering consistent trends in experimental and literature data to elucidate major mechanisms controlling runoff P loss, and 3) translating these mechanisms into model routines that function reliably across a variety of soil, climate, and management conditions, and are easily incorporated into existing models. This process resulted in innovative, novel model routines that accurately predict P loss from surface manure and fertilizer. **Impact:** The P loss models have been transferred to ARS and university researchers where they have been incorporated into the following models: SWAT, APEX, IFSM and SNAP+ (official nutrient management and P Index software for Wisconsin).

Vadas, P.A., Harmel, R.D., and Kleinman, P.J.A. 2007. Transformations of soil and manure phosphorus after surface application of manure to field plots. *Nut. Cycl. Agroeco*. 77:83-89.

Vadas, P.A., Gburek, W.L., Sharpley, A.N., Kleinman, P.J., Moore, P.A. Jr., Cabrera, M.L., and Harmel, R.D. 2007. A model for phosphorus transformation and runoff loss for surface-applied manures. *J. Environ. Qual*. 36:324-332.

- ARS scientists developed a P Index for Arkansas based on data generated by several hundred rainfall simulation runs conducted on manure treated plots. These studies showed that P as measured by soil test was only a minor contributor to P runoff and soluble P in manure was the major factor. Validation studies using data from a long-term field study on paired watersheds fertilized with poultry litter showed that this P Index accurately predicted edge of

field P losses from pastures. After the research was completed, the P Index was transferred to all key agencies in Arkansas responsible for non-point source pollution. **Impact:** Arkansas has been using this P index for writing nutrient management plans in the state. This P Index not only assesses risk of P loss, it also predicts P loads in runoff. The Arkansas Natural Resources Commission has recently requested that ARS scientists revise this index to include sewage sludge and commercial fertilizers. This research was partially supported by funding from the EPA, the Arkansas Natural Resources Commission, the U.S. Poultry and Egg Association, and the City of Tulsa, OK.

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel. 2004. Development of a phosphorus index for pastures fertilized with poultry litter - factors affecting phosphorus runoff. *J. Environ. Qual*. 33:2183-2191.

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, A.N. Sharpley, B.E. Haggard, and T.C. Daniel. 2004. Evaluation of the phosphorus source component in the phosphorus index for pastures. *J. Environ. Qual*. 33:2192-2200.

- The State of Arkansas passed several new laws in 2003 that affected poultry producers. One of these laws stated that poultry litter and commercial N and P fertilizers must be applied at the "Protective Rate" in 8 watersheds deemed by the State to be nutrient enriched (these were in major poultry producing areas). The Arkansas Soil and Water Conservation Commission requested that ARS scientists develop these Protective Rates. A series of rainfall simulation studies were conducted that evaluated P and N runoff from different nutrient sources (poultry litter, fertilizers, and biosolids). Based on these results and predictions made using the Arkansas P Index, Protective Rates were determined which equally balanced environmental and agronomic concerns. **Impact:** Application of poultry litter, commercial fertilizers and biosolids in 8 watersheds is regulated based on ARS research on “Protective Rates”. The Protective Rate allowed growers to legally apply manure and commercial fertilizers until each farm had a proper NMP in place. These Arkansas laws are the first of their kind in the U.S. and will serve as a template for other states in the future.

Moore, P.A., Jr., and J. Barrentine. 2005. Determining the protective rates of poultry litter and commercial fertilizers for Arkansas. *Final Report to Arkansas Natural Resources Commission*. pp. 42. (Basis for Title 22 – AR State Law Regulating Nutrient Applications).
http://www.aswcc.arkansas.gov/Title%2022%20doc.pdf.

### *Problem Area 4: Farming Systems and Practices for Efficient and Balanced Manure Nutrient Management*

#### Management practices and guidelines for efficient use of manure

- Cotton uses relatively large amounts of N fertilizer and estimates for six southeastern states where the crop is grown suggest 3-4 million acres of cotton are within 150 miles of major poultry producing areas. Poultry litter is valued between $20-30 per ton based on the major and minor nutrients it supplies. Growers may realize a substantial savings from complete or partial replacement of commercial fertilizers with broiler litter. Multi-location research has shown that broiler litter is an effective cotton fertilizer, sometimes more effective than conventional inorganic fertilizers. The often-recommended litter rate of 2 ton/acre while adequate for upland soils that yield about 1 to 1.5 bale/acre, may not be sufficient for more

productive soils where much of the cotton in the southern and southeastern U.S. is grown. If the more productive soils have a high level of P, manure application will be restricted to meet the P requirement of cotton, therefore the N requirement of the crop will not be met and supplementation with inorganic N fertilizers will be required. Litter was generally a more effective cotton fertilizer than inorganic fertilizers under both no-till and conventional-till cropping systems in upland soils of Mississippi. Growers may apply litter in the fall, but winter rainfall increases the risk of nutrient loss. Over-seeding cereal rye on fall-applied broiler litter sites increased N availability to the following cotton crop by 33% and decreased residual soil N below 30 cm by 78%, as compared to cotton-fallow. Guidelines have been developed for N fertilization of cotton with broiler litter on several soils in Mississippi. **Impact:** The research results have been communicated to cotton farmers, NRCS nutrient management planners, and state extension agents. Results from these investigations are currently being used to provide agronomic recommendations for effective use of poultry litter for cotton production. When more formal guidelines are fully developed, the number of growers using poultry litter as a primary cotton fertilizer will increase dramatically. Increased use of poultry litter in cotton production will help alleviate the burden of litter overload on forage and pasture lands near poultry houses.

Adeli, A., Sistani, K.R., Rowe, D.E., and Tewolde, H. 2007. Effects of broiler litter applied to no-till and tillage cotton on selected soil properties. *Soil Science Society of America Journal* 71:974-983.

Tewolde, H., Sistani, K.R., Rowe, D.E., Adeli, A., and Johnson, J.R. 2007. Lint yield and fiber quality of cotton fertilized with broiler litter. *Agronomy Journal* 99:184-194.

Tewolde, H., K. R. Sistani, D. E. Rowe, A. Adeli, and J. R. Johnson. 2007. Lint yield and fiber quality of cotton fertilized with broiler litter. *Agron. J*. 99:184–194.

- A common practice in the southeastern U.S. is manure application to perennial bermudagrass cut for summer hay. Producing high biomass, high quality hay significantly impacts producer profitability. ARS scientists conducted research to develop management practices that result in the most efficient use of nutrients from poultry litter and swine effluent by forages while protecting environmental quality. Some general results of these investigations are summarized in the following text: (1) Swine effluent applications in April through July, corresponding to the most vigorous growth of bermudagrass, resulted in the greatest recovery of N (59%) and P (49%). (2) The N:P ratio in manure is lower than the requirement of bermudagrass so P can accumulate in soil with long-term manure application. A P-based application of manure plus a supplemental application of fertilizer N can produce forage yields comparable to N-based manure application, while significantly increasing recovery of manure P. (3) Summer annuals such as pearl millet and sorghum-sudan were shown to have P removal rates comparable to bermudagrass (up to 56 kg P/ha/yr). (4) Fall overseeding of grass and clover species increased P removal by 23% and did not adversely affect summer bermudagrass hay yield. (5) Annual forages such as ryegrass can be used to complement or replace existing bermudagrass hay systems for management of nutrients in manured fields. (6) The combination of winter annual forages such as rye grass and perennial warm season grasses such as bermudagrass offers a year-round green pasture system for grazing. **Impact:** These results have been transferred to producers, nutrient management planners, extension agents and NRCS through workshops and field demonstrations. The results have been used by NRCS to revise Code 590 (Nutrient Management) and Code 633 (Waste Utilization) guidelines that relate to use of poultry litter and swine effluent in the southeastern U.S. These

guidelines determine the management practices producers will use for environmental protection and improvement. Many forage-livestock producers in the south have already adopted the practices developed in these investigations.

Adeli, A., Rowe, D.E., and Read, J.J. 2006. Effects of soil type on bermudagrass response to broiler litter applications. *Agronomy Journal* 98:148-155.

Read, J.J., Sistani, K.R., Brink, G.E., and Oldham, J.L. 2007. Reduction of high soil test phosphorus by bermudagrass and ryegrass-bermudagrass following the cessation of broiler litter applications. *Agronomy Journal* 99:1492-1501.

Sistani, K.R., and McLaughlin, M.R. 2006. Soil nutrient dynamics from swine effluent application to common bermudagrass overseeded with cool-season annuals. *Journal of Sustainable Agriculture* 28:101-116.

McLaughlin, M.R., Sistani, K.R., Fairbrother, T.E., and Rowe, D.E. 2005. Overseeding common bermudagrass with cool-season annuals to increase yield and nitrogen and phosphorus uptake in a hay field fertilized with swine effluent. *Agron. J*. 97:487-493.

- Perennial forages are harvested several times during the growing season, and offer an alternative land base and time management strategy for manure application. ARS scientists and university cooperators evaluated the response of alfalfa and reed canarygrass to increasing rates of swine manure slurry applied in midsummer. Reed canarygrass yield increased with increasing rates of slurry up to 3.3 Mg/ha of organic solids applied. Alfalfa yields were unaffected by slurry application. At higher rates, yields of both species declined in the subsequent harvest. Producers who apply manure slurry to forage can use slurry solids content as a tool to simplify slurry application rate decisions. **Impact:** This research offers producers a simple method to avoid over-application of manure. This information has been transferred through producer meetings and popular press articles.

Lamb, J.F.S., M.P. Russelle, and M.A. Schmitt. 2005. Alfalfa and reed canarygrass response to midsummer manure applications. *Crop Sci.* 45:2293-2300.

- The common practice of broadcast application of poultry litter to the soil surface has a high potential for undesirable transport of litter nutrients off the field through runoff and volatilization. ARS scientists have addressed this problem by developing a four trench poultry litter applicator that applies the litter in shallow bands in the soil. Rainfall simulation studies have indicated that runoff losses of N and P are reduced by 80-95% from litter applied with the new applicator compared to surface broadcast application. **Impact:** This application system is currently being evaluated for use in row crop and pasture systems. Improvements are being made in the overall application system, a patent application has been filed and commercialization of the technology is likely.

Sistani, K. R., H.A. Torbert, T. Way, C.H. Bolster, and J.G. Warren. 2008. Broiler Litter Application Method and Runoff Timing Effect on Nutrient and *E. coli* Losses from Tall Fescue Pasture. *J. Environ. Qual* (in press)

- In another approach to litter management, ARS scientists have developed a knifing technique to incorporate poultry litter below the pasture surface. Applying litter in this manner decreased nutrient losses in runoff more than 90% and essentially eliminated ammonia losses compared to surface-applied litter. **Impact:** The initial success of the method encouraged the

scientists to move from a single shank incorporator to an eight-shank tractor drawn prototype that can apply five tons of poultry litter under a pasture surface before reloading. This research was partially supported by a grant from NRCS.

Pote, D.H., W.L. Kingery, G.E. Aiken, F.X. Han, P.A. Moore, Jr., and K.K. Buddington. 2003. Water-quality effects of incorporating poultry litter into perennial grassland soils. *J. Environ. Qual*. 32:2392-2398.

- Nitrogen management on Northeast dairy farms is a challenge because of the range of farm-grown feeds, the wide array of manure management systems, and the wide range of field crops and soils. ARS scientists and university cooperators developed a web site, www.DairyN.cornell.edu,that emphasizes a whole-farm perspective for N management. The web site contains components on: concerns about N losses, crop and soil N management practices, feed storage practices, managing dairy herd nutrition and precision feed management, manure storage practices, and integrating the above components into a whole-farm system. **Impact:** The web site has been written up in popular press articles and is an important resource for Extension agents, dairy consultants, NRCS agents, and nutrient managers as they develop site-specific whole-farm nutrient management plans for Northeastern dairies.

Ketterings, Q.M., Meisinger, J.J., Albrecht, G., Fox, D., Jokela, W., Czymmek, K.J. 2005. Nitrogen management on dairy farms. Department of Crop and Soil Extension Cornell University, Ithaca, New York. Website at: http://www.DairyN.cornell.edu.

- An important aspect of managing agricultural N from manure and fertilizer is the synthesis and integration of soil N cycle processes into coherent state of the art summaries. Two review and analysis chapters were completed from the large scientific literature on soil N budgets and on fertilizer N recommendations for the revised American Society of Agronomy Monograph "Nitrogen in Agricultural Systems". The chapter on Soil N Budgets presents a detailed review of labeled-N and total-N budgets covering a range of spatial scales from field plots to watersheds. It emphasizes that N interacts in complex physical-chemical-biological ways that must be carefully documented and interpreted to estimate the complete N budget. The chapter on Crop N Requirement and Fertilization provides a detailed review of the principles undergirding N recommendations; which are the N mass-balance, the economic optimum, and the concept of soil-plant N resiliency. It also summarizes opportunities arising from new tools such as real-time crop N sensors, spatial databases on soil properties and yields, and the integration of these approaches into small-scale, spatially-based N applications with variable rate equipment. **Impact:** These chapters are used as reference books by soil scientists and agronomists, and will provide textbook material for graduate and under-graduate courses. They will also provide material that will be used in reference and training books for nutrient managers in CSREES, NRCS, and private agricultural consultants.

Meisinger, J.J., Calderon F.J., and Jenkinson, D.S.. 2008. Soil Nitrogen Budgets. pp. 501-558 (Chpt.13). Schepers, J.S. and Raun W.R. (eds.) *Nitrogen in Agricultural Systems.* Am. Soc. Agron. and Soil Sci. Soc. Am. Monograph. Madison, WI.

Meisinger, J.J., J.S. Schepers, and W.R. Raun. 2008. Crop Nitrogen Requirement and Fertilization. pp. 559-608 (Chpt. 14). Schepers, J.S. and Raun W.R. (eds.) *Nitrogen in Agricultural Systems.* Am. Soc. Agron. and Soil Sci. Soc. Am. Monograph. Madison, WI.

**Management practices for water quality protection from manure application**

- Research was conducted to investigate the impact of pasture management and broiler litter application rate on nutrient runoff from bermudagrass pastures. Runoff was generally greater (29%) from grazed than hayed pastures regardless of the litter application rate. There was greater inorganic N in runoff from grazed paddocks when litter rate was based on N rather than P. The mean total P loss per runoff event for all treatments ranged from 7 to 45 g $ha^{-1}$ and the grazed treatment with litter applied on an N basis had the greatest total P loss. Total dissolved P was the dominant P fraction in the runoff, ranging from 85% to 93% of the total P. In general, poultry litter can be applied on an N basis if the pasture is hayed and soil P is not in excess. Poultry litter application based on P is the preferred approach if the pasture is grazed. **Impact:** This information has been transferred to producers, extension agents and NRCS personnel in the Mid-South region of the U.S. The information is being used for improved nutrient management in grazed and hayed bermudagrass pastures receiving poultry litter.

  Sistani, K.R. Brink, G.E., and Oldham, J.L. 2008. Managing Broiler Litter Application Rate and Grazing to Decrease Watershed Runoff Losses. *J. Environ. Qual*. 37: (in press)

- Five grazing-management strategies (1) hayed, (2) overgrazed, (3) rotationally grazed, (4) rotationally grazed with an application buffer, and (5) rotationally grazed with a fenced riparian buffer were evaluated to determine the influence of management on runoff and movement of nutrients and sediment from pastureland receiving broiler litter. Runoff volumes were highest from overgrazed watersheds and lowest from hayed watersheds. Nutrient (N, P, and C) and sediment loads were also highest from overgrazed watersheds and were lowest from hayed watersheds. Soil bulk density values were highly correlated with runoff volume and increased with grazing pressure. A follow-up study was conducted to determine if pasture renovators (aerators) could be used to increase infiltration and reduce runoff and nutrient loss from overgrazed pastures. Rainfall simulation studies demonstrated that water infiltration was increased by 45%, total P loads were reduced by 43%, and total N loads were reduced by 55% in renovated compared to non-renovated areas. Forage yield data from this study showed pasture renovation increased yields by 27%. These data indicate that pasture renovation is a management practice that can be used to reduce nutrient runoff from pastures, while improving productivity. **Impact:** As a direct result of this research, USDA/NRCS purchased pasture renovators, which were rented to farmers to aerate their land. This management practice was included in the Arkansas Phosphorus Index. Partial funding for these investigations was provided by NRCS, EPA, and the SARE grant program in USDA-CSREES.

  Moore, P.A., Jr, S.J. Formica, M.Van Epps, and P.B. Delaune. 2005. Effect of pasture renovation on nutrient runoff from pastures fertilized with manure. In: *Proceedings of the 7th International Symposium on Livestock Environment, American Society of Agricultural Engineers*, May 18-20, 2005, Beijing, China.

- Shallow ground water can be contaminated by nitrate under open livestock feeding lots, and nitrate losses often are intensified after animals are removed. Perennial forage crops may offer an effective, low cost method for remediating abandoned sites and, furthermore, non-N-fixing alfalfa may be beneficial for cleanup due to its high growth potential and its ability to undergo multiple cuttings. ARS scientists found that on an area basis, non-N-fixing alfalfa

removed the same or less N from the soil and manure than N-fixing alfalfa, due largely to stand decline where inorganic N supply was inadequate for persistence of the non-N-fixing type. Maximum recovery of soil and manure N was about 450 kg N/ha over 3 yr. Ground water nitrate concentrations increased within 1 year of feedlot abandonment by 50 to 80 kg nitrate-N ha-1 but ground water P concentration did not change. **Impact:** Based on these results, it appears that nitrate leaching losses after feedlot abandonment on coarse-textured soils can be minimized by seeding a recommended cultivar of N-fixing alfalfa with a fast-growing companion crop using no-till seeding to avoid soil mixing and aeration.

Russelle, M.P., J.F.S. Lamb, N.B. Turyk, B.H. Shaw, and B. Pearson. 2007. Managing nitrogen contaminated soils: Benefits of $N_2$-fixing alfalfa. *Agron. J.* 99:738-746.

**Impacts of long-term manure application**

- Research was conducted to determine the long-term impacts of alum-treated poultry litter on soil chemistry and P runoff in tall fescue pastures. Alum-treated litter was compared to untreated litter and ammonium nitrate fertilizer to determine which nutrient source provided the best tall fescue yields with the least environmental impact. Soil pH increased with both untreated and alum-treated litter, indicating they had a net liming effect. However, soil pH of plots receiving ammonium nitrate decreased rapidly leading to a substantial increase in soil exchangeable aluminum (aluminum in soluble forms can be toxic to plants and aquatic species). Exchangeable Al stayed very low in soils fertilized with either untreated or alum-treated litter. Fescue yields were higher in alum treated plots than those receiving untreated litter or ammonium nitrate. Phosphorus runoff losses from small watersheds fertilized with untreated poultry litter were 330% higher than those receiving alum-treated litter. These studies showed that long-term fertilization of pastures with alum treated litter was more sustainable than application of untreated litter or ammonium nitrate. **Impact:** This study demonstrated the safety and environmental benefits of long-term land application of alum treated broiler litter. Alum treatment of litter previously had been shown to provide environmental benefits in the poultry house and in the field after application of manure. Based on these investigations, NRCS has recognized alum treatment of litter as a Standard Practice. Producers can receive funding through the NRCS Environmental Quality Incentives Program to use alum as a poultry litter treatment.

Moore, P.A. Jr., and D.R. Edwards. 2005. Long-term effects of poultry litter, alum-treated litter and ammonium nitrate on aluminum availability in soils. *J. Environ. Qual*. 34:2104-2111.

Moore, P.A., Jr., and D.R. Edwards. 2007. Long-term effects of poultry litter, alum-treated litter and ammonium nitrate on phosphorus availability in soils. *J. Environ. Qual.* 36:163-174.

- Animal feed is typically fortified with copper (Cu) and zinc (Zn) as dietary supplements. Because animals have low assimilation rates (<2%) for these elements, the excreted manure usually contains high Cu and Zn levels. Repeated manure applications to soils could result in these elements reaching levels that could harm sensitive crops such as peanuts. Long-term swine manure effluent application to a Coastal Plain soil resulted in topsoil Cu and Zn accumulation, but the concentrations of both elements were far below phytotoxic levels for peanuts. In a related seven-year study, litter application resulted in a four fold increase in Cu and a five fold increase in Zn in the top 15 cm of soil. Positive aspects of the litter application were maintenance of soil pH and an increase of 2.7 metric tons of C per hectare in the top

soil. **Impact**: This information is being used by NRCS and county extension personnel in the Coastal Plain region of the southeast U.S. to advise producers about potential concerns associated with Cu and Zn in manure. These findings were featured in an international swine nutrition trade journal (http://www.pig.progress.net) where suggestions were made to reduce Cu and Zn fortification levels in feed.

Novak, J.M., Watts, D.W., and Stone, K.C. 2004. Copper and zinc accumulation, profile distribution, and crop removal in Coastal Plain soils receiving long-term, intensive applications of swine manure. *Trans. ASAE* 7:1513-1522.

Gascho, G.J. and R.K. Hubbard. 2006. Long-term impact of broiler litter on chemical properties of a Coastal Plain soil. *Journal of Soil and Water Conservation* 61:65-74.

# Pathogens and Pharmaceutically Active Compounds

## Summary

Research within the Pathogens and Pharmaceutically Active Compounds Component was conducted in four Problems Areas. Problem Area 2 included five Sub-areas. The Problem Areas and Sub-areas are as follows: (1) Method Assessment and Development; (2a) Inactivation Rates and Transport Characteristics of Pathogens from Animal Agriculture; (2b) Pathogen Indicators for Fate and Transport Research; (2c) Biological Source Tracking; (2d) Bioaerosols; (2e) Modeling Fate and Transport of Manure-borne Pathogens from Pedon to Watershed Scale; (3) Pharmaceutically Active Compounds (PACs); and (4) Holistic Treatment Technologies for Nutrients, Pathogens and PACs.

Methods for the detection and quantification of pathogens in complex environmental matrices are essential to describing their fate and transport and to assess the effectiveness of mitigation practices to avoid contamination of soils, water, and air. Molecular techniques were used to develop a quantitative, real-time PCR (polymerase chain reaction) method to measure *Escherichia coli* O157:H7 and other pathogens in environmental samples which led to reliable data collection relative to prevalence, survival, fate and transport of pathogens. A long-term study of surface water in an urban/suburban community watershed identified both pathogenic and nonpathogenic forms of *E. coli* and highlighted the difficulty of detecting pathogenic *E. coli* because of high diversity in *E. coli* strains. In agricultural ecosystems a most probable number method was developed for detecting dilute densities of *Salmonella* and a rapid, reliable molecular method was developed to detect *Mycobacterium paratuberculosis* responsible for Johne's disease in cattle. Another new and more sensitive method was developed to detect the ubiquitous intracellular microsporidia parasite. This manure-borne pathogen occurs in both soils and water and infects many mammals including humans.

A PCR method was used to determine that *E. coli* O157:H7 could survive at least 45 days in soils with moisture contents as low as 3% and for months on feedlot surfaces. The viability of this organism was shorter in soils having high microbial diversity than in fumigated soils. *Cryptosporidium* oocysts can remain active up to 12 months in soils depending on variables such as cultivation, soil type and temperature.

Methods to identify sources of fecal contamination would allow for adoption of measures to correct the problems. Ribotype profiling was tested for its utility in identifying host origin of *E. coli*. Due to the large variability in *E. coli* populations this fingerprinting technique, although feasible, would require an extensive library of more than 2000 ribotypes. Another novel procedure identified 16 DNA markers (PCR primers) that could distinguish among 78 strains of E. coli belonging to 15 common diarrheagenic strains. These and other studies point out the extensive genetic diversity of E. coli in the environment and indicate that although generic *E. coli* may be useful indicators of fecal contamination they cannot directly predict public health risk and may not be positively correlated with the *eae* gene, a critical virulence factor. ARS scientists contributed to the development of the EPA 'Microbial Source Tracking Guide', which provides an overview of current methods to track the source of fecal contamination and outlines the strengths and weaknesses of current methods. They also substantiated EPA findings that

animal operations and land application of manure do not result in off-site movement of bioaerosols.

Pathogen fate and transport models are needed for the development of decision support tools for producers, action agencies and regulators. To develop these models information is needed about the dominant processes that control pathogen fate and transport. ARS scientists have developed models that simulate processes such as: (1) pathogen growth and die-off, (2) pathogen release and retention by manure and soil, (3) transport of pathogens facilitated by manure or soil particles, (4) straining of colloids in porous media and (5) pathogen movement through vegetative filter strips. Mathematical descriptions of these and other processes have been incorporated into a microbial component for the widely-used Soil and Water Assessment Tool (SWAT) model previously developed by ARS to estimate nutrient and sediment movement at the watershed scale. The SWAT microbial component has been tested with data from the U.S. and Canada. The model is being used by the Natural Resources Conservation Service and the Farm Services Administration to perform risk analysis for major USDA Conservation Programs, and by EPA to estimate pathogen movement and loading into water resources.

A realistic assessment of the occurrence of agriculturally-derived, pharmaceutically-active compounds in the environment is necessary to develop mitigation strategies that reduce risk to humans, wildlife and aquatic species. Poultry litter application to fields was sometimes related to the occurrence of chlorotetracycline, a poultry growth promoter, and sulfonamide in nearby water and sediment; whereas cortisol, estradiol and testosterone were detected in ng/ml amounts in beef cattle feedyard waste retention ponds and diary lagoons. New classes of tetracycline and erythromycin resistance genes were detected in bacteria isolated from stored swine manure. Studies on best management practices showed that steroid hormones in dairy manure rapidly degraded with manure piling time and increased residence time of wastewater in sequencing diary lagoons. Composting was very effective in decreasing tetracyclines in manure from therapeutically-treated beef calves, but tetracycline residues persisted in untreated and anaerobically digested manure. Constructed wetlands were found to be very effective, not only in removing nutrients from swine waste water, but also in reducing estrogenic activity well below concentrations known to have a biological effect. More rigorous methods for antibiotic and hormone removal are being tested. Nanofiltration techniques removed from 50% to 80% of tetracyclines, but were less effective for hormone removal. A TAML activator catalyst was able to rapidly degrade natural and synthetic reproductive hormones such as estradiol when applied at a rate of one kg per 20,000 tons of wastewater.

Treatment systems that address all contaminants as well as systems that specifically address pathogens have been developed and evaluated. A swine wastewater treatment system that separates solids, removes nutrients and reduces emissions also kills 99.99% of pathogen indicator organisms and *Salmonella*. Compost generated from the separated solids meets Class A biosolids quality standards due to low pathogen levels. Specifically-designed vegetative treatment areas have been effective in containing and removing pathogens in runoff from beef cattle feed lots. Other emergent technologies include control of *Salmonella* with naturally occurring *Salmonella*-specific phages, and inactivation of waterborne adenoviruses and noroviruses by treating water with polychromatic UV light or chlorine dioxide and ozone.

## Accomplishments

***Problem Area 1: Method Assessment and Development***

**Method to quantify *E. coli* O157:H7**

- All pathogen research conducted in this program is dependent on the availability of methods to detect and quantify pathogens in a variety of environmental matrices including manure, soil, water and air. ARS scientists developed a quantitative real-time PCR methodology to measure *Eschericha coli* O157:H7 and other pathogens in environmental samples. Primers and fluorogenic probes were designed to amplify, detect, and quantify the attaching and effacing (eae) gene of E. coli O157:H7 and Shiga toxin (Stx)-encoding genes of *E. coli* O157:H7 (STEC). Experiments were conducted to demonstrate that these primers and probes specifically detected very low levels of *E. coli* O157:H7 and STEC in soil and other difficult matrices. These assays were optimized to quantify >100 bacterial cells per gram of soil without enrichment or 1 to 10 bacterial cells per gram of soil with enrichment. The rapidity and high quantitative levels of the TaqMan PCR assay has reduced the time for detection and quantification of *E. coli* O157:H7 in environmental samples from 3 to 5 days for culture-based methods to less than 24 h for this technique. **Impact:** This work represents a considerable advance in pathogen quantification in environmental samples. This high through-put technology has been used to generate reliable data relative to prevalence, survival, fate and transport of E coli O157:H7 in the environment. This method is currently being used in California to address environmental and public health problems including control of *E. coli* O157:H7 movement from animal production operations to fresh produce (lettuce, spinach).


Ibekwe, A. M and C. M. Grieve. 2003. Detection and quantification of Escherichia coli O157:H7 in environmental samples by real-time PCR. *Journal of Applied Microbiology*. 94:421-431.

Ibekwe, A. M., P. M. Watt, C. M. Grieve, V. K. Sharma, and S. R. Lyons. 2002. Multiplex fluorogenic real-time PCR for detection and quantification of Escherichia coli O157:H7 in dairy wastewater wetlands. *Applied and Environmental Microbiology*. 68:4853-4862.


**Characterization of *E. coli* strains from surface water samples**

- There is currently little information regarding the contamination of surface and ground waters with specific bacterial pathogens or the correlation of pathogenic strains with indicators of fecal contamination such as generic *E. coli.* A 30-month monitoring study was conducted, in collaboration with the U.S. Forest Service, in urban/suburban Baltimore County watersheds. Surface water samples were analyzed for the presence of presumptive enterohemorrhagic *E. coli,* including *E. coli* O157. A substantial percentage of water samples contained *E. coli* O157 and/or virulence genes associated with enterohemorrhagic *E. coli.* However, characterization of several *E. coli* O157 strains isolated from water samples revealed that they were nonpathogenic. **Impact:** These results indicate that there is substantial diversity in *E. coli* O157 strains in surface waters, including both pathogenic and nonpathogenic strains. Consequently, the detection of water-borne enterohemorrhagic E. coli may be difficult due to the background diversity.

**Method to enumerate small numbers of *Salmonella* in surface waters.**

- Watersheds with animal agriculture have the potential to adversely impact recreational waters and threaten public health through contamination of surface waters with fecal pathogens such as *Salmonella*. To better manage the fate and transport of *Salmonella* in agricultural watersheds a most probable number (MPN) method for enumerating dilute densities of *Salmonella* in environmental waters was developed. The method was capable of detecting 0.1 *Salmonella* cells/L of surface water, and is more sensitive that other published methods of enumerating *Salmonella* in environmental samples.
  **Impact:** The sensitivity of this method will enhance our understanding of the fate and transport of *Salmonella* in agricultural watersheds. The technique will facilitate development of culture collections of *Salmonella* that could be used to identify sources of *Salmonella* contamination.

Jenkins, M.B., D.M. Endale, and D.S. Fisher. 2008. Most probable number methodology for quantifying dilute concentrations and fluxes of Salmonella in surface waters. J. Appl. Microbiol. (in press)

**Molecular detection of *M. paratuberculosis***

- Detection of Johne's disease, an enteric infection of cattle caused by *Mycobacterium avium subsp. paratuberculosis* (*M. paratuberculosis*), has been impeded by the lack of rapid, reliable detection methods. In recent years, Johne's disease researchers have recognized the impact of environmental sources of *M. paratuberculosis* contamination on the continued transmission and re-introduction of the disease on afflicted farms. In this research, molecular biological methods were optimized to detect *M. paratuberculosis* in agricultural environments. Data from this study showed that the Johne's disease agent could remain in pasture soil for more than 200 days after removal of a clinically infected dairy cow. This research provides fundamental new information regarding the ability of *M. paratuberculosis* to persist and possibly even grow in agricultural settings. **Impact:** These new methods will aid in early detection of the disease on farm sites. The methods may serve as a viable alternative to individual animal testing, thereby reducing costs as well as disease prevalence. Studies are currently underway to evaluate survival of the organism in biofilms on materials in the dairy facility including concrete, plastic, stainless, or galvanized steel trough materials.

Cook, K.L., Britt, J. 2006. Optimization of methods for obtaining, extracting and detecting *Mycobacterium avium* subsp. *paratuberculosis* in environmental samples using quantitative, real-time PCR. *Journal of Microbiological Methods*. 29:154-160.

**Method for detection of human pathogenic microsporidia**

- Microsporidia are intracellular parasites that have been detected in livestock and some species can infect humans. The only method available for detection of microsporidia was developed for calf manure. That method was not developed or assessed for other environmental matrices such as manure-impacted water, adult cattle feces, or soil. ARS scientists and cooperators have developed a more sensitive method for the detection and identification of pathogenic microsporidia in manure-impacted samples. The new method

was validated using cattle and swine feces and wastewater samples. Subsequent analysis of samples from livestock operations resulted in the detection of the human pathogenic microsporidia, *Encephalitozoon cuniculi*. **Impact:** Microsporidia are on EPA's Drinking Water Contaminate list. This new method can be used to determine the occurrence and dissemination of microsporidia from animal production operations. This will allow the potential human health threat to be assessed to determine if pathogen reduction strategies are needed.

Kahler, A., Thurston Enriquez, J.A. 2007. Human pathogenic microsporidia detection: method development and assessment of agricultural samples. *Journal of Parasitology* 100:529-538.

### *Problem Area 2a: Inactivation Rates and Transport Characteristics of Pathogens from Animal Agriculture*

### Mechanisms, processes and factors affecting fate and transport of manure borne microorganisms

- ARS scientists investigated the mechanisms, processes and factors affecting fate and transport of manure borne pathogens. Pathogens are released to the environment along with manure particulates that can serve as carriers, abode, and food for the microbes. The presence of bovine manure particulates facilitated the transport of *E. coli*, *Cryptosporidium parvum* oocysts and *Giardia* oocysts through soil. Laser diffractometry revealed a remarkable temporal stability of manure particulate sizes when exposed to rain. In runoff experiments on manure treated plots, overland and subsurface transport of *E. coli* and various forms of phosphorus released from bovine manure were closely correlated. It may be possible to use movement of organic P to predict movement of pathogens. Substantial growth (up to 1.5 orders of magnitude) of *E. coli* populations was observed in cowpats during the first week after deposition. Inactivation of *E. coli* in bovine feces was found to occur more slowly in laboratory experiments than in the field at the same temperature and moisture content. **Impact:** This information is being used in the development of a predictive model for fate and transport of manure-borne microorganisms. The results from these investigations will strongly influence the selection of parameters to use in this and other pathogen fate and transport models. EPA is interested in testing the concept that movement of organic P in the environment may be used to estimate movement of pathogens. Many existing fate and transport parameter values obtained in the laboratory may be of limited value if they were measured in the absence of manure particulates. This research has generated considerable interest both in the U.S. and internationally. Partial support for continued research in this area has come from a NATO Science Program Grant and a grant from the Spanish Ministry of Education via the Technical University of Madrid.

Pachepsky, Y. A., Guber, A.K., Shelton, D.R., Yu, O.T. 2007. Effect of manure on fecal coliform attachment to soil and soil particles of different sizes. *Applied and Environmental Microbiology*. 73:3363-3370.

Pachepsky, Y.A., Sagedhi, A.M., Bradford, S.A., Shelton, D.R., Guber, A.K., Dao, T.H. 2006. Transport and fate of manure-borne pathogens: modeling perspective. *Agricultural Water Management*. Online – (doi:10.1016/j.agwat.2006.06.010.)

**Survival of *E. coli* O157:H7 in different environmental samples**

- Survival of *E. coli* O157:H7 in the environment is a major concern to growers of leafy green fresh produce. ARS scientists used the PCR method described in Problem Area 1 to determine survival of *E. coli* O157:H7 in different matrices. A detection limit for *E. coli* O157:H7 of 1.4 x $10^3$ CFU/ g soil was obtained from this study without enrichment. The concentrations of *E. coli* O157:H7 obtained by real-time PCR were comparable to the concentrations obtained by plate counts. Sandy and clay soils were fumigated with methyl bromide and methyl iodide to check the hypothesis that soil systems with reduced microbial diversity offer greater opportunities for survival of pathogenic bacteria such as *E. coli* O157:H7. The fumigant had a greater impact on the soil microbial community in the sandy soil and resulted in higher survival of *E. coli* O157:H7 compared to clay soil. In separate studies E. coli O157:H7 was shown to survive at least 45 days in soil with moisture content as low as 3%. In a related study, *E. coli* O157:H7 was found to be capable of survival for long periods (weeks to months) on feedlot pen surfaces. Application of water for dust control and urine from livestock contributed to this longevity by stimulating release of nutrients for microbial growth. These studies demonstrated that *E. coli* O157:H7 can survive for long periods of time in soil and other media, and can threaten food safety if transported to fields where leafy green fresh produce is grown. This research was partially supported by a grant from USDA-CSREES National Research Initiative. **Impact:** A sensitive method is available to measure the fate and transport of *E. coli* O157:H7. This real-time PCR assay has been used to monitor *E. coli* O157:H7 in manure, soil, irrigation water and fresh produce. This method has provided information about fate and transport of this pathogen to fields used for production of fresh produce and allowed assessment of management practices to reduce survivability of *E. coli* O157:H7.


Ibekwe, A.M., Watt, P.M., Shouse, P.J., Grieve, C.M. 2004. Fate of Escherichia coli O157:H7 in irrigation water on soils and plants as validated by culture method and real-time PCR. *Canadian Journal of Microbiology*. 50:1007-1014.

Ibekwe, A.M., Grieve, C.M., Yang, C. 2007. Survival of Escherichia Coli O157:H7 in soil and on lettuce after fumigation. *Canadian Journal of Microbiology*. Vol. 53:623-635


**Fate and transport of pathogens and indicator organisms in groundwater**

- *E. coli* is a commonly used indicator organism for detecting the presence of fecal pathogenic microorganisms. Research was conducted to compare the transport and survival characteristics of *E. coli* to the enteropathogen, *Camplobacter jejuni*, commonly found in animal waste. Transport characteristics were compared in porous media. *C. jejuni* was more negatively charged and more hydrophobic than *E. coli*. These characteristics along with differences in cell morphology resulted in more rapid transport of *C. jejuni* when conditions favored low attachment rates. In a related study, survival of *C. jejuni* and *E. coli* was compared in groundwater microcosms varying in nutrient composition. Die-off of *C. jejuni* was between 2.5 and 13 times faster than die-off of *E. coli*. *C. jejuni* had the highest survival rate when organic C was high, while *E. coli* survival was high when dissolved oxygen was high. Large differences between the two organisms in the duration of survival and response to water nutrient composition

suggested that *E. coli* may be present in waters much longer and respond to water composition much differently than *C. jejuni*. Finally, different strains of *E. coli* were found to have significant genetic diversity in transport characteristics and therefore significant differences in mobility in the environment. **Impact:** These results suggest that *E. coli* would not be an appropriate indicator organism for *C. jejuni*. The data generated in these investigations should be of significant benefit to groups developing fate and transport models and conducting pathogen risk assessments. Information from this research has been requested by government agencies in Canada, Australia, and India as well as scientists within the U.S. The research was also listed by the Food Standards Agency of the UK as an item of interest to members of the Advisory Committee on Microbiological Safety of Food.

Bolster, C.H., Walker, S.L. and Cook, K.L. 2006. Comparison of Escherichia coli and Campylobacter jejuni transport in saturated porous media. *J. Environ. Qual*. 35:1018-1025.

Cook, K.L. and Bolster, C.H. 2007. Survival of Campylobacter jejuni and Escherichia coli in groundwater during prolonged starvation at low temperatures. *J. Appl. Microbiol.* 103:573-583.

**Fate and transport of Crytosporidium parvum**

- *Cryptosporidium parvum* (*Crypto* for short) is a pathogenic microorganism that has been the cause of several large-scale outbreaks of gastrointestinal illness world-wide. ARS scientists and university cooperators conducted a field experiment where *Crypto* oocysts (infectious form of *Crypto*) were placed in surface soil at 70 sampling points on a grid that included pastures, corn fields, and uncultivated woodlands and tested for infectivity over time. After 120 days, on average, 10% of the *Crypto* remained infective, with an infectivity range of 0 to 30%. Additional studies on *Crypto* survival indicated that the time needed to reach 99.9% inactivation ranged from 9 days to greater than 12 months. Greatest survival was at 4 ºC and the greatest inactivation occurred at 30 ºC. The moisture content of the soil had no effect on oocyst survival. Survival was greatest in a silt loam soil compared to a loamy sand soil and a silty clay loam soil. Although most of the oocysts remained in the top 5cm of soil, a small fraction of the oocysts leached through the soil profile in channels and connected large pores, raising the possibility that they could be transported to groundwater. **Impact:** These results demonstrate that Crypto oocysts can survive for extended periods in soil and could be vulnerable to transport to surface waters or possibly to groundwater. The oocyst survival and transport data generated in these investigations encouraged use of manure management practices that would prevent movement of oocysts from manure to surface waters, especially surface waters that served as municipal drinking water sources.

Kato, S., M. Jenkins, E. Fogarty, and D. Bowman. 2004 *Cryptosporidium parvum* oocyst inactivation in field soil and its relation to soil characteristics: analysis using the geographic information system. *Science of the Total Environment* 321: 47-58.

Darnault, C.J.G., T.S. Steenhuis, P. Garier, Y.-J. Kim, M. Jenkins, W.C. Ghiorse, P.C. Baveye, and J.-Y. Parlange. 2004. Preferential flow and transport of *Cryptosporidium parvum* oocysts through the vadose zone: experiments and modeling. *Vadose Zone Journal* 3:262-270.

***Problem Area 2b: Pathogen Indicators for Fate and Transport Research***

**Suitability of generic *E. coli* as indicators of pathogenic *E. coli***

- Currently there is little information correlating pathogenic strains of *E. coli* with indicators of fecal contamination such as generic *E. coli*. A nine month monitoring study was conducted in a watershed where the predominant land use was grazing dairy cattle. Both generic *E. coli* and virulence markers decreased dramatically from summer/fall to winter due to fewer inputs from cattle in winter as well as heavy rainfall that "flushed" microbes from the watershed. Certain sites had very high *E. coli* levels in sediments, which likely contributed to downstream contamination. No correlation was observed between concentrations of generic *E. coli* and the *eae* gene which is the critical virulence factor for the enteropathogenic *E. coli* which are ubiquitous in water. This research indicated that various virulence factors, previously assumed to be unique to enterohemorrhagic *E. coli* (EHEC) are relatively widely dispersed among less pathogenic or non- pathogenic *E. coli*, as well as other common water-borne bacteria. The detection of water-borne enterohemorrhagic *E. coli* may be difficult due to the background diversity. **Impact:** These results suggest that virulence factors for enterohemorrhagic *E. coli* are not unique and a positive test doesn't mean a pathogen has been identified. In addition, the results suggest that, although generic *E. coli* may be useful as indicators of fecal contamination, they cannot be used to directly predict public health risks. A similar conclusion was reached in a California watershed study with the indicator organisms *Enterococcus* and generic *E. coli,* and in the research to compare transport and survival of *C. jejuni* and *E. coli* (described in the previous section).


Bolster, C.H., Walker, S.L. and Cook, K.L. 2006. Comparison of Escherichia coli and Campylobacter jejuni transport in saturated porous media. *J. Environ. Qual.* 35:1018-1025.

Ibekwe, A.M., Lyon, S.R. 2007. Microbial characteristics through drinking water aquifer sand material. *Engineering in Life Sciences*. 1:81-89


***Problem Area 2c: Biological Source Tracking***

**Methods for microbial source tracking**

- A significant percentage of U.S. surface waters do not meet Clean Water Act standards because of fecal pollution that can threaten public health. Identification of the source of fecal pollution, for example from human wastes, malfunctioning septic tanks, or animal production operations would allow for adoption of measures to correct the problem. Methods to identify sources of fecal pollution have been under development by the scientific community in the U.S. and abroad. These methods of microbial source tracking have focused on genetic fingerprints of fecal microorganisms, mainly bacteria and some viruses. A compilation and assessment of the effectiveness of these methods is needed. ARS scientists contributed to the development of the EPA publication, Microbial Source Tracking Guide. The document presents an overview of current methods to track the source of fecal contamination and discusses the strengths and weaknesses of the methods. **Impact:** The document provides a guide to available methods of source tracking that can be used to help improve impaired surface waters. The document is currently being used

by local, state, and federal regulatory agencies to find solutions that would lead to restoration of impaired waters to meet Clean Water Act standards.

Santo Domingo, J.S., Edge, T., Griffith, J., Hansel, J., Harwood, V.J., Jenkins, M., Layton, A., Marirosa, M., Nakatsu, C., Oshiro, R., Sadowsky, M., Shanks, O., Stelma, G., Stewart, J., Stoeckel, D., Wiggins, B., Wilbur, J. 2005. Microbial source tracking guide document. U.S. Environmental Protection Agency Special Publication. EPA/600R-05/064. p. 135.

- Ribotype profiling of *E. coli* is a genotypic method being developed to determine the host origin of fecal bacteria. This method requires a host origin database. A key assumption for using the database to identify sources of environmental isolates is that *E. coli* ribotypes display temporal stability. This assumption needs to be tested to determine the feasibility of this method for source tracking. ARS scientists and their cooperators genetically "fingerprinted" DNA from *E. coli* obtained from 24 yearling steers at four sampling times over a year to find out if common genetic fingerprints could be identified and subsequently used to track the source of manure contamination. They found a much larger variability in the fingerprints than expected. Results showed significant temporal variability of *E. coli* ribotypes. Although this fingerprinting technique is feasible, it would require development of an extensive library of fingerprints (more than 2000 ribotypes) to be effective at microbial source tracking. **Impact:** *E. coli* is likely problematic as the bacterium of choice for source tracking. Results of this study have encouraged scientists to identify other fecal bacteria or genetic markers for microbial source tracking methodologies.

  Jenkins, M.B., Hartel, P.G., Olexa, T.J., Stuedemann, J.A. 2003. Putative temporal variability of *Escherichia coli* ribotypes from yearling steers. *Journal of Environmental Quality* 32:305-309.

- The high genetic diversity of *E. coli* strains creates problems for evaluation of the fate and persistence of various strains of *E. coli* in animal feeding operations. A novel DNA mapping procedure was developed that identified DNA markers distributed along the genomic backbones of the pathogenic *E. coli* O157:H7 and the commensal *E. coli* K12. A collection of DNA markers (16 PCR primers) were identified that were able to resolve the genetic similarity of 78 strains of *E. coli* that belong to a group of 15 common diarrheagenic *E. coli* strains. **Impact:** This ALP-PCR mapping method will greatly facilitate the bacterial source tracking of *E. coli* strains within animal feeding agro-ecosystems, thus leading to improvements in management of feedyard manures and other byproducts.

  Rice, William C. 2008. Design and Evaluation of PCR Primers which detect and identify Escherichia coli O157:H7 and related serotypes. *Journal of Applied Microbiology* (in press)

- Field studies were undertaken by ARS scientists and their cooperators to quantify the main sources of fecal pollution to the Santa Ana River using specific gene markers. The spatial and temporal distributions of these markers showed that human-specific *Bacteroides* species were generally detected in all samples except the control sites while *Enterococcus* and *E. coli* showed unique genetic profiling based on land use. This study demonstrates the usefulness of source tracking approaches using non-culture-based gene markers for determining sources of fecal pollution. Results from this study showed that the Middle Santa Ana River watershed is affected by multiple sources of non-point

microbial pollution and that microbial contaminants may be reduced by implementing management strategies such as sub-surface constructed wetlands to improve water quality from agricultural sources and surface flow constructed wetlands to treat surface water from streams. **Impact:** These results suggest that *Enterococcus* and generic *E. coli* may be useful as indicators of fecal contamination, but they may not be suitable to predict public health risks. The use of gene markers, when fully developed, will contribute to the development of management practices for water quality improvement at the watershed scale. The overall long- term impact of this project is the general improvement of ground and surface water quality within the middle Santa Ana River watershed.

Ibekwe, A.M., Lyon, S.R. 2007. Microbial characteristics through drinking water aquifer sand material. *Engineering in Life Sciences*. 1:81-89

Ibekwe, A. M., Lyon S. R. 2008.Microbiological Evaluation of fecal bacterial composition from surface water through aquifer sand material. *Journal of Water and Health*: (in press)

### *Problem Area 2d: Bioaerosols*

### Bioaerosols from manure and biosolids

- Bioaerosols, airborne particulates ranging in size from 0.5 to 100 um in diameter, contain microorganisms and their byproducts (microbial toxins). ARS scientists collected and microbially characterized bioaerosols from a broiler house over a 6 month period. They found that relatively few bioaerosols escaped the house, despite year-round exhaust fan use. Research at a beef cattle feedlot indicated that endotoxins in the air may impact animal health, but enteric pathogens such as *E. coli* O157:H7 and *Salmonella* were not found in air that could be transferred to downwind neighbors. Research was conducted to determine if fecal bacteria concentrations in air were affected by manure or biosolid application to land. Surface application studies involved two different application methods: a low-solids (<12% solids) tank sprayer (application height 4m) and a high solids (>22% solids) hopper spreader (application height 0.6m). Results indicated that inhalable and respirable particulate matter and bacterial bioaerosols (<10 um aerodynamic diameter), were not significantly increased in the immediate vicinity of the sprayer and spreader, or at the field fence-line (15- 300m) during manure or biosolids application. In a separate study, land application of biosolids in the desert southwest did not increase the diversity of bioaerosols in the impacted area and the majority of bioaerosols originated from onsite soil. **Impact:** The results from these studies indicated that air transport of bioaerosols from animal production facilities and land application of manure or biosolids did not represent an off-site problem. These results substantiate EPA findings that land application of biosolids did not result in off-site movement of bioaerosols

Brooks, J.P., Gerba, C.P., and Pepper, I.L. 2007. Diversity of aerosolized bacteria during land application of biosolids. *Journal of Applied Microbiology* 103:1779-1790.

Brooks, J.P., Maxwell, S.L., Rensing, C., Gerba, C.P., Pepper, I.L. 2007. Occurrence of antibiotic-resistant bacteria and endotoxin associated with the land application of biosolids. *Canadian Journal of Microbiology* 53:616-622.

Purdy, C.W., D.C. Straus and D.B. Parker. 2004. Comparison of microorganisms and concentration of endotoxin in the air of Southern High Plains feedyard. Am. J. Vet. Res 65:45-52.

***Problem Area 2e: Modeling Fate and Transport of Manure-borne Pathogens from Pedon to Watershed Scale***

**Mechanistic models of manure pathogen transport in vegetated filter strips and at the watershed scale**

- Vegetated filter strips (VFS) are an important best management practice (BMP) to prevent contamination of surface water bodies from agricultural sources. The efficiency of VFS is currently evaluated exclusively from a nutrient and sediment retention standpoint. Methods to evaluate BMP efficiency with respect to manure-borne pathogen retention are currently absent. ARS scientists developed the STIR model to integrate knowledge on major processes of transport and retention of manure-borne microorganisms at the soil profile scale. Convective and dispersive transport, surface and subsurface retention and straining, and pathogen survival are simulated. The transport model is complemented with the novel model of *E. coli* release from manure in field conditions. STIR has been tested with data from a series of experiments conducted on the overland transport of manure-borne *E. coli* in grass buffer conditions. **Impact:** Use of the STIR model in uncertainty analysis has demonstrated its potential to predict VFS placement for manure-borne pathogen control.

- The watershed-wide dissemination of manure-borne pathogens is an issue of public concern and currently is addressed by the Total Maximum Daily Load process regulated by EPA and at the state level. ARS scientists developed a microbial component for the widely-used Soil and Water Assessment Tool (SWAT) model previously developed by ARS. SWAT is a watershed-scale model that is extensively used by EPA and others for estimating nutrient and sediment movement in watersheds at different geographical locations and under various climatic conditions. The SWAT microbial component describes processes such as bacterial die-off and re-growth rates, bacteria transport with runoff and sediment, stream transport, and filter strip efficiency. The SWAT microbial component has been tested with data from the U.S. and Canada and updated with a data base of new microbial fate and transport parameters that will allow more effective use of the model for risk assessment. **Impact:** The model is being used by the Natural Resources Conservation Service and the Farm Services Administration to perform risk analysis for major USDA Conservation Programs, and by EPA to estimate pathogen movement and loading into water resources. EPA has recommended use of the SWAT/microbial model for state-based TMDL assessments. The model is included in the EPA BASINS model (a platform system being used by state environmental offices in TMDL analysis). More than ten research groups from U.S. universities have proposed collaborative research using this model. A recent Google search for SWAT/microbial model showed that at least 23 research centers, state agencies, and foreign entities are using this model. ARS scientists working on this model have been sought as authorities by CSREES, state granting agencies (Michigan, Wisconsin, New Jersey, Canadian Ontario and Quebec provinces), and by the expert group of the European Union to review research proposals and participate in granting panels.

Pachepsky, Y.A., Sadeghi, A.M., Bradford, S.A., Shelton, D.R., Guber, A.K., and Dao, T.H. 2006. Transport and fate of manure-borne pathogens: modeling perspective. *Agricultural Water Management.* Online (doi:10.1016/j.agwat.2006.06.010)

Pachepsky, Y.A., Devin, B.A., Polyanskaya, L.M., Shelton, D.R., Shein, E.V., and Guber, A.K. 2006. The limited entrapment model to simulate the breakthrough of arthrobacter and aquaspirillum in soil columns. *International Agrophysics* 20:207-218.

Pachepsky, Y.A., Guber, A.K., Shelton, D.R., Yu, O.T. 2007. Effect of manure on fecal coliform attachment to soil and soil particles of different sizes. *Applied and Environmental Microbiology* 73:3363-3370.

Benham, B.L., Baffaut, C.,Zeckoski, R.W., Pachepsky, Y.A., Mankin,K.R.,Sadeghi, A.M., Brannan, K.M., Soupir, M.L., and Habersac, M.J. 2006. Modeling pathogen fate and transport in watersheds to support TMDLs. *American Society of Agricultural and Biological Engineers* 49: 987-1002.

**Submodels to describe important processes controlling pathogen transport**

- Pathogen release from manure to surface water serves as an important boundary condition for surface water and subsurface pathogen transport models. ARS scientists studied release rates of *Cryptosporidium* and *Giardia* oocysts under various physical (water application rate and duration, manure type, and temperature) and chemical (solution salinity) conditions. A conceptual model was developed to describe and predict manure and oocyst release rates. The pathogen release model provides a better description of *E. coli* bacteria loading than other available models. **Impact:** Knowledge of pathogen release rates is needed to accurately evaluate the influence of hydrologic conditions and animal management practices on water quality. Representatives from government, agriculture, public health, and academia have shown significant interest in this research.

  Schijven, J. F., S. A. Bradford, and S. Yang. 2004. Release of Cryptosporidium and Giardia from diary cattle manure: Physical factors. *Journal of Environmental Quality* 33:1499-1508.

- The transport and fate of colloids in subsurface environments is controlled to a large extent by their retention in soils. Laboratory and modeling studies were undertaken to explore the influence of colloid and soil particle size on colloid retention in saturated porous media. ARS scientists developed a novel conceptual and mathematical model that provided an improved description of colloid attachment, straining, and size exclusion compared to conventional models. Aspects of this model were subsequently incorporated into a comprehensive transport model to simulate colloid-facilitated transport of a wide variety of contaminants including pathogens. **Impact:** Previous literature largely neglected colloid straining, and this research has led to a growing recognition that straining can be an important mechanism of colloid retention. As a result, many researchers have redirected their research attention to this process, including national and international collaborators.

  Simunek, J., C. He, L. Pang, and S. A. Bradford. 2006. Colloid-facilitated transport in variably-saturated porous media: Numerical model and experimental verification. *Vadose Zone Journal* 5: 1035-1047.

- Experimental and theoretical studies were undertaken by ARS scientists to explore the coupling of physical and chemical mechanisms of colloid retention in saturated porous media under unfavorable attachment conditions. Results from micro-model studies, calculations of torques that act on colloids near grain surfaces, solution of the pore-scale fluid flow field, batch experiments, and column studies all indicated that straining of colloids is strongly dependent on the solution chemistry, the system hydrodynamics, the colloid concentration, and the size of the colloid and the porous media. **Impact:** Researchers are beginning to realize that straining of colloids in porous media is coupled to solution chemistry, hydrodynamics, and colloid concentration. These observations can potentially explain many of the reported limitations of filtration theory, and can lead to the development of a new paradigm for colloid retention.

  Bradford, S. A., J. Simunek, and S. L. Walker. 2006. Transport and deposition of E. coli O157:H7 in saturated porous media. *Water Resources Research*, 42, W12S12, doi:10.1029/2005WR4805.

  Torkzaban, S., S. S. Tazehkand, S. L. Walker, and S. A. Bradford. 2008. Transport and fate of bacteria in porous media: Coupled effects of chemical conditions and pore space geometry. *Water Resources Research* (in press).

- Experiments were conducted to elucidate the transport and fate of coliphage and *Giardia* cysts through aquifer sands in the presence and absence of manure suspensions. The transport potential of these microbes was observed to be enhanced in the presence of manure suspensions. Results indicate that transport studies conducted in the absence of manure suspension may not accurately characterize the enhanced transport potential of somatic coliphage and *Giardia* cysts in manure-contaminated environments. **Impact:** These findings are essential to develop improved management practices and treatments to minimize the movement of pathogens and pharmaceutically active compounds from farms to water resources and vegetable production sites.

  Bradford, S. A., Y. F. Tadassa, and Y. Pachepsky. 2006. Transport of *Giardia* and manure suspensions in saturated porous media. *Journal of Environmental Quality* 35: 749-757.

  Bradford, S. A., Y. F. Tadassa, and Y. Jin. 2006. Transport of coliphage in the presence and absence of manure suspension. *Journal of Environmental Quality* 35: 1692-1701.

- Experiments were conducted to study the transport and deposition behavior of bacteria and latex microspheres in unsaturated porous media under unfavorable attachment conditions. The roles of grain size, water content, bacteria hydrophobicity, metabolic state of bacteria, and solution chemistry were studied in these experiments. Colloid surface chemistry and aqueous phase solution chemistry had a big impact on the magnitude of attachment and straining deposition. Straining tended to increase with decreasing sand size and water content, and increasing cell hydrophobicity and solution ionic strength. The role of attachment increased for more hydrophilic bacteria, for coarser textured sand, and with increasing solution ionic strength. **Impact:** This research has helped to elucidate the roles of straining and attachment processes in unsaturated porous media and contributed to the development of colloid transport and retention models.

Gargiulo, G., S. A. Bradford, J. Simunek, P. Ustohal, H. Vereecken, and E. Klumpp. 2007. Bacteria transport and deposition under unsaturated conditions: the role of the matrix grain size and the bacteria surface protein. *Journal of Contaminant Hydrology*, 92, 255-273

### *Problem Area 3: Pharmaceutically Active Compounds (PACs)*

### Occurrence of hormones and antibiotics near AFOs

- Animal drugs and feed additives are routinely used in AFOs to improve animal health and production. Occurrence, persistence and transport of hormones (natural and synthetic), antibiotics, and antibiotic resistant bacteria in the environment near AFOs needs to be determined to assess risks to humans and wildlife. Studies were conducted to measure sulfonamide and tetracycline antibiotics and natural hormones in water and sediment sampled in a poultry production area on the Eastern Shore of Maryland. Chlortetracycline, which is very widely used to promote growth of poultry at low doses and to control various types of bacterial infections at higher doses, was the most frequently detected antibiotic in the water and sediment samples. This antibiotic was likely transported from poultry litter amended fields to water, since there were no other potential sources (e.g., wastewater treatment plants) within the sampled tributaries. In a related study, concentrations of cortisol, estradiol and testosterone were measured in 7 beef cattle feedyard retention ponds, 4 dairy lagoons and 3 non-feedyard playa lakes. Respective mean concentrations found in each of these sources were 6.6, 3.3, and 0.6 ng/ml cortisol; 0.2, 0.4 and 0,005 ng/ml estradiol; and 0.3, 0.4 and 0.003 ng/ml testosterone. Hormone concentrations were much greater in the feedyard retention ponds and dairy lagoons compared to the playa lakes. While hormone concentrations were in the ng/ml range, small doses may affect some species of wildlife and retention ponds and lagoons are used by wildlife such as waterfowl. Research was conducted to identify antibiotic resistant bacteria and genes in swine feces and stored swine manure. New classes of tetracycline and erythromycin resistance genes were identified in a new bacterial species from manure. Stored manure may be a source of novel antibiotic resistance genes. **Impact:** These results should be of interest to regulatory agencies since they demonstrate that hormones, antibiotics and antibiotic resistant bacteria exist, survive and have been transported into the environment around AFOs. The results also suggest that public health and environmental risks need to be addressed and control measures developed.

Arikan, O.A., Rice, C.P., Codling, E. 2008. Occurrence of antibiotics and hormones in a major agricultural watershed. *Desalination*, 226:121-133.

Purdy, C.W., Straus, D.C., Norman, R.L. 2006. RIA analysis for estradiol, testosterone and cortisol in feedyard playa lakes and non-feedyard playa lakes. Proceedings of 87th Annual Meeting of Conference of Research Workers in Animal Diseases, Dec 3 – 5, 2006, Chicago, IL. Abstract #118, p. 150.

Whittle, G., Whitehead, T.R., Hamburger, N., Shoemaker, N.B., Cotta, M.A., and Salyers, A.A. 2003. Identification of a new ribosomal protection type of tetracycline resistance gene, Tet(36), from swine manure pits. *Applied and Environmental Microbiology*. 69:4151-4158.

- The occurrence of steroid hormones in the aquatic environment is receiving considerable attention since most of the compounds are classified as highly potent endocrine-disrupting chemicals. Research was conducted to determine the potential risks of hormone contamination from land application of dairy wastes by determining steroid hormones in a typical dairy waste disposal system. Three endogenous hormones, 17 alpha-estradiol, 17 beta-estradiol and estrone were detected in dairy wastewater and lagoon water. The concentration of 17 alpha-estradiol in fresh milk parlor effluent rapidly decreased along the wastewater disposal route, while the concentration of estrone increased along the same pathway. This suggested that 17 alpha-estradiol was readily oxidized to the metabolite estrone. Levels of total steroid hormones in sequencing lagoon water were 1-3 orders of magnitude lower than those in fresh dairy wastewaters, indicating a significant removal of these hormones during transport of dairy wastewater through the system. Steroid hormones also decreased rapidly with storage time of solid dairy manure. **Impact:** These results suggest that steroid hormones were rapidly degraded in the dairy waste management system. Increasing the piling time of solid wastes and increasing the residence time of wastewater in sequencing lagoons would appear to be economical and efficient agricultural practices to extend the degradation time of hormone contaminants, thereby reducing hormone loads to the environment.

  Zheng, W., S.R. Yates, and S.A. Bradford. 2008. Analysis of steroid hormones in a typical dairy waste disposal system. *Environmental Science & Technology* 42:530-535

- Research was conducted to determine if applications of poultry litter at levels recommended to meet the N requirement of crops contributed to the hormone (estradiol and testosterone) load in soil and water. Runoff from poultry litter treated plots during rainfall events did not contain hormone levels greater than background. The results indicate that poultry litter application at prescribed agronomic rates to meet plant nutrient requirements should not contaminate surface waters with estradiol or testosterone. I**mpact:** These results should be of interest to regulatory agencies, extension agents, and NRCS personnel. These results were communicated in a National Web-cast by the Livestock and Poultry Environmental Learning Center, an extension service supported by USDA-CSREES.

  Jenkins, M.B., D.M. Endale, H.H. Schomberg, and R.R. Sharpe. 2006. Fecal bacteria and sex hormones in soil and runoff from cropped watersheds amended with poultry litter. *Sci. Tot. Environ.* 358:164-177.

**Control of hormones and antibiotics**

- Animal feeding operations and wastewater treatment plant discharges are thought to be major sources of pharmaceuticals to the aquatic environment; therefore technological solutions for treating these effluents are needed. Nanofiltration methods were investigated for their efficacy at removal of several antibiotics (sulfonamides and tetracyclines) and hormones. Tetracyclines were observed to have a high adsorptive affinity for the membrane. Almost 80% of chlorotetracycline was adsorbed on the membrane surface compared with 50% for doxycycline while the adsorption rates for hormones were lower than those obtained for the tetracyclines. Calcium, organic matter, salinity and cross-reactivity between compound classes affected the sorption efficiencies

of other compounds. **Impact:** The potential for effective removal of antibiotics and hormones by nanofiltration methods is very promising, but scale-up will be needed. However, economic considerations may make this approach more suitable for wastewater treatment plants than AFOs.

Koyuncu, I., Arikan, O.A., Wiesner, M.R., Rice, C.P. 2008. Removal of hormones and antibiotics by nanofiltration membranes. *J. Membrane Science.* 309:94-101

- ARS scientists conducted research to assess the impact of composting on oxytetracycline (OTC) and chlorotetracycline (CTC) in manure from therapeutically treated beef calves. OTC and CTC in the manure was rapidly decreased by composting. Results from incubation studies using sterilized manure samples showed that the decrease in extractable residues is not due to biological processes, but is due to enhanced binding of antibiotic residues to organic material at composting temperatures (> 55° C). A companion study showed that OTC and CTC residues in manure slurries were unaffected by anaerobic digestion. **Impact:** The persistence of tetracycline residues in untreated and anaerobically digested manure should be important information to producers and their advisors. Composting is the method of choice if tetracycline levels in the manure need to be greatly reduced.

  Arikan, O.A., Sikora, L.J., Mulbry III, W.W., Khan, S.U., Foster, G.D. 2007. Composting rapidly reduces levels of extractable oxytetracycline in manure from therapeutically treated beef calves. *Bioresource Technology*. 98:169-175.

  Arikan, O.A., Sikora, L.J., Mulbry III, W.W., Khan, S.U., Rice, C. 2006. The fate and effect of oxytetracycline during the anaerobic digestion of manure from therapeutically treated calves. *Process Biochemistry*. 41:1637-1643.

- ARS scientists and their cooperators documented that a recently developed "green catalyst" TAML activator (iron-tetraamidomacrocyclic ligand) in trace concentrations activates hydrogen peroxide to rapidly degrade natural and synthetic reproductive hormones in water. Based on liquid chromatography tandem mass spectrometry, apparent half-lives for 17 alpha- and 17 beta-estradiol, estriol, estrone and 17 alpha-ethinylestradiol in the presence of the TAML activator and hydrogen peroxide were approximately five minutes. A concomitant loss of estrogenic activity was established through the use of an E-Screen assay. One kg of TAML activator would be sufficient to treat more than 20,000 tons of typical municipal wastewater. **Impact:** Demonstration of the effectiveness of the TAML activator provides AFO and wastewater treatment plant operators a tool to degrade natural and synthetic hormones in wastewater.

  Shappell, N.W., Vrabel, M.A., Madsen, P.J., Harrington, G.E., Billey, L.O., Hakk, H., Larsen, G.L.,Beach, E.S., Horwitz, C.P., Ro, K.S., Hunt, P.G., Collins, T.J. 2008. Destruction of estrogens using Fe-TAML/peroxide catalysis. *Environ, Sci. Technol* 42:1296-1300.

- An anaerobic lagoon, constructed wetland system was evaluated for efficacy in removal of estrogenic activity from swine wastewater. Estrogenic activity was determined by an E-Screen assay, which uses cells that will grow only in the presence of an estrogenic compound. The lagoon reduced estrogenic activity to a low level during the warmer

periods of the year. When the lagoon wastewater had higher levels of estogenic activity, the wetlands reduced estrogenic activity 83-93%. Good agreement was found between the E-screen values and equivalent concentrations of hormones determined by chemical analyses. Constructed wetlands were effective in producing water with estrogenic activity well below the lowest equivalent 17-estradoil concentration (10 ng/L) known to have a biological effect. Thus, ARS scientists were the first to document the effectiveness of treatment wetlands in reducing the estrogenic activity of swine wastewater. **Impact:** This research demonstrates that constructed wetlands can be used to remove hormones as well as nutrients from wastewater. This information gives producers and their advisors an additional reason to use constructed wetlands. EPA and state regulatory agencies also should be interested in these results.

Shappell, N.W., Billey, L.O., Forbes, D., Poach, M.E., Matheny, T.A., Reddy, G.B., and Hunt, P.G. 2007. Estrogenic activity and steroid hormones in swine wastewater processed through a lagoon constructed-wetland system. *Environ. Sci. & Technol.* 41:444-450.

***Problem Area 4: Holistic Treatment Technologies for Nutrients, Pathogens and PACs***
*The focus will be on pathogens in this section although some of the technologies discussed have multiple benefits*

**Control of pathogens in vegetative treatment areas**

- Both *Escherichia coli* O157 and *Campylobacter* spp. are shed by cattle housed in pens, and have been recovered from soils, basin sludge, and basin water. Basin discharge can introduce *E. coli* O157, *Campylobacter* spp., and generic *E. coli* into vegetative treatment areas (VTA). Isolation frequencies of *E. coli* O157 and *Campylobacter* spp. from VTA soils decrease over time. Similarly, levels of generic *E. coli* in soil initially decrease rapidly, but lower residual populations appeared to persist for long periods. Generic *E. coli* were isolated from fresh-cut hay in three out of the 15 regions of the VTA that received runoff, while *E. coli* O157 was only isolated from one fresh-cut hay sample. However, neither pathogen was recovered from hay following baling. **Impact**: The sustainability of alternative runoff control systems depends, in part, on the system's ability to contain and remove pathogen from runoff. The current study detailed low survivability of *E. coli* O157 and *Campylobacter* in the VTA system. These results demonstrate to producers and their advisors that VTA can be used to control pathogens as well as nutrients in runoff from beef cattle feedlots.

Berry, E.D., Woodbury, B.L., Nienaber, J.A., Eigenberg, R.A., Thurston, J.A., Wells J.E. 2007. Incidence and persistence of zoonotic bacterial and protozoan pathogens in a beef cattle feedlot runoff control-vegetative treatment system. *J. Environ. Qual.* 36:1873-1882.

**UV and ozone inactivation of viruses in water**

- The EPA's Contaminant Candidate List includes the enteric adenoviruses and noroviruses. These viruses are included for several reasons, one of which is the lack of information on the effectiveness of drinking water disinfection. Adenoviruses are extremely resistant to UV inactivation at doses commonly applied for water treatment. Research was conducted to evaluate inactivation of adenoviruses by low and medium pressure UV and pulsed UV lamps. This work is the first to show enhanced inactivation

of waterborne viruses important to human health by polychromatic UV light sources. When medium pressure and pulsed UV systems are used, the required fluences (energy density) for obtaining virus inactivation may prove to be significantly lower. A companion study was conducted to determine the efficacy of chlorine dioxide and ozone on viral inactivation in water. The results of this study clearly showed that chlorine dioxide and ozone are capable of inactivating adenoviruses and novoviruses in water. **Impact:** These results provide municipal water treatment plants with a lower-cost approach to disinfection of enteric viruses and may have applications in animal waste treatment systems.

Linden, K.G., Thurston, J., Schaefer, R., and Malley, J.P. 2007. Enhanced UV inactivation of adenoviruses under polychromatic UV lamps. *Applied and Environmental Microbiology* 73: 7571-7574.

Enriquez, C. and J. Thurston-Enriquez. 2006. Adenoviruses. In: Waterborne Pathogens: Manual of water supply practices. 2nd ed. Pp. 253-258. American Water Works Association, Denver, CO.

**Disinfection of swine manure with multi-step aerobic treatment**

- Concern has increased about the potential for contamination of water, food, and air by pathogens present in manure. A new treatment system invented by ARS was evaluated for its capacity to eliminate pathogens. The aerobic system (described in greater detail elsewhere in this report) was pilot tested and then demonstrated full-scale in two swine operations in North Carolina. The system combines solid-liquid separation, nitrification and phosphorus extraction and generates water that can be reused and separated manure solids. The treated liquid was used for crop irrigation, and the separated solids were composted with other residues to give fertilizers and potting media. The system was evaluated for its effectiveness in reducing total and fecal coliforms, enterococci, and salmonellae counts on selective and differential nutrient media. Pathogen indicators were reduced 99.99% in the liquid, and Salmonella was eliminated. The compost products conserved 95-100% of the nitrogen and other nutrients and met EPA Class A biosolids quality standards due to low pathogen levels. **Impact:** The system provides a variety of environmental benefits including nutrient control, emissions reduction and pathogen kill. This treatment system is currently in use on swine and dairy farms in North Carolina. The state of North Carolina has recently provided funding for installation of this system on two additional farms.

Vanotti, M.B., Szogi, A.A., and Hunt, P.G. 2005. Wastewater treatment system. U.S. Patent No. 6,893,567, Issued May 17, 2005. U.S. Patent & Trademark Office, Washington, D.C., USA.

Vanotti M.B., Szogi, A.A., Hunt, P.G., Millner, P.D., and Humenik, F.J. 2007. Development of environmentally superior treatment system to replace anaerobic swine lagoons in the USA. Bioresource Technol. 98(17):3184-3194.

**Control of *Salmonella* using phages**

- *Salmonella* infect livestock and poultry and are estimated to cause approximately 1.4 million cases of human gastroenteritis annually in the U.S. ARS scientists are working on a control method for *Salmonella* using naturally occurring enemies of bacteria called phages. *Salmonella*-specific phages have been isolated from swine effluent lagoons for

use as typing agents, indicators and biocontrol agents. Bioassays for assessing control of *Salmonella* by phages have been developed and successfully applied to *Salmonella* in swine lagoon effluent. *Salmonella* inactivation by phages has been documented in a laboratory model system that simulated swine lagoon effluent. Although additional work is necessary, this biocontrol approach to *Salmonella* inactivation seems to hold promise. Impact: While the phage biocontrol method is still in the developmental stage, the assays and methods developed for determining *Salmonella* inactivation are being used by other scientists to assess *Salmonella* control by other approaches and in other media.

McLaughlin, M.R., and Brooks, J.P. 2008. EPA worst case water microcosms for testing phage biocontrol of *Salmonella*. *Journal of Environmental Quality* 37:266-271.

McLaughlin, M.R., El Balaa, M.F., Sims, J., King, R. 2006. Isolation of *Salmonella* bacteriophages from swine effluent lagoons. *Journal of Environmental Quality* 35:522-528.

McLaughlin, M.R., and King, R.A. 2008. Characterization of *Salmonella* bacteriophages isolated from swine lagoon effluent. *Current Microbiology* 56:208-213.

# Byproducts

## Summary

Research within the Byproducts Component was conducted in four Problem Areas including: (1) Phytoavailability and bioavailability of nutrients, trace elements and xenobiotics in byproducts; (2) Protocols and methodology for byproduct evaluation; (3) Byproduct utilization technologies; and (4) Energy from byproducts.

Many agricultural, municipal and industrial byproducts have characteristics that would make them useful in agricultural and horticultural applications. Before these beneficial uses can be undertaken risks posed by the trace elements and xenobiotics in these materials need to be assessed. In addition, changes in phytoavailability and bioavailability of toxic trace elements such as cadmium (Cd) with remediation treatment and time need to be determined. Research field trials showed that land application of high Fe content biosolids reduced the phytoavailability of Cd to crops up to 25 years after the biosolids were applied. These results demonstrate the effectiveness and persistence of using high Fe content biosolids to remediate metal contaminated soils. A phytoremediation technology was developed, using alpine pennycress to phytoextract Cd. This phytoremediation method is the most cost-effective Cd decontamination technology discovered to date.

ARS is cooperating with EPA to assess risk of trace elements and xenobiotics in spent foundry sands (SFS) from molds and cores used in iron, steel, brass and aluminum casting processes. Aluminum, steel, and iron SFS tested in this study did not pose a toxicity and metal transfer risk. Brass SFS should not be considered for beneficial uses since they contain elevated levels of copper (Cu), lead (Pb) and zinc (Zn). Xenobiotics such as polycyclic aromatic hydrocarbons and phenolics were released from binders used to hold foundry sand grains together in metal casting molds. However, none of the xenobiotics measured were present at levels that would pose excessive risk to humans or environmental receptors. The xenobiotics present were generally biodegradable; therefore mixing SFS with soil would promote natural biodegradation. Data from the trace element and xenobiotics investigations were used as input for a risk assessment that concluded SFS could be safely applied to land or used in manufactured soil or potting media. One reason for reaching this conclusion was trace element levels in SFS from iron, steel and aluminum foundries were lower than the same elements in natural soils. Comparing trace element levels in a byproduct to trace element levels in soil may be a useful first step in risk assessment of any byproduct that is essentially uncontaminated and has demonstrated beneficial characteristics.

Methods were developed to use a number of organic and inorganic byproducts to remediate contaminated sites, improve soil properties, protect water quality, provide crop nutrients and serve as potting media. Mixtures of organic materials (manure, composts, biosolids) and inorganic byproducts such as Fe oxides were used to (1) reclaim Superfund sites contaminated with Cd, Pb, Cu and Zn; (2) reduce bioavailability of Pb in urban soils to prevent Pb poisoning of children; and (3) remove Pb, Zn and Cu from urban runoff. Several studies were conducted to mix, blend or compost two or more byproducts to produce value-added materials including: (1) horticultural potting media from poultry litter and residue from pulp wood harvesting; (2) cellulose pulp from garbage processing used to reclaim degraded sites on military bases; and (3)

fertilizer, soil amendments, and potting media from composting of swine manure solids and cotton gin waste. Methods were developed using drinking water treatment residuals to immobilize P in manure and soils treated with manure to reduce runoff losses of P to surface waters. Flue gas desulfurization gypsum, a byproduct that results when sulfur dioxide is scrubbed from exhaust gases released from coal-fired power plants, has proved to be a valuable product for improving soil properties and protecting water quality. Recycled ground rubber was shown to be a slow release Zn source for crops.

New technologies and processes need to be developed to convert agricultural residues and other byproducts into energy. Most conversion strategies including fermentation, anaerobic digestion, gasification and direct burning are being investigated in the Bioenergy and Energy Alternatives National Program. However, a few investigations were undertaken in the Manure and Byproduct Utilization National Program. Research was conducted to demonstrate three beneficial uses of poultry litter at coal-fired power plants: energy production, production of a sorbent for mercury emission control, and production of activated C. Research and theoretical assessments indicated that thermochemical conversion technologies such as gasification and pyrolysis could be used as manure treatment options that produce renewable energy. Investigations showed that catalytic hydrothermal processing of swine manure could produce more energy than either combustion of brown coal or anaerobic digestion. As ethanol production grows a substantial amount of distillers' grains will be available for use as livestock feed. Distillers' grains contain more bioavailable P than traditional grain sources, nutritionists will need to reduce supplemental P in diets to avoid environmental problems associated with excess P in manure.

## Accomplishments

### *Problem Area 1: Phytoavailability and Bioavailability of Nutrients, Trace elements and Xenobiotics in Byproducts Considered for Beneficial Use*

**High iron in biosolids significantly reduces availability of metals to plants**

- High iron (Fe) content biosolids have been used to remediate trace metal contaminated sites. Research was conducted to test the persistence of this remediation practice since it has been suggested that biodegradation of organic matter in amendments such as biosolids may lead to an increase in phytoavailability of metals in soil. A series of experiments were conducted to evaluate soil cadmium (Cd) phytoavailability 18-25 years after the initial incorporation of high Fe content biosolids. Lettuce and durum wheat were grown on control and biosolid treated plots amended with soluble Cd salts. Crop Cd uptake was much less on the biosolid treated plots than the control plots. The greater the amount of biosolids previously applied the lower the amount of Cd taken up by the crops. These results demonstrate the persistence of trace metal retention in biosolid amended plots. The Fe oxide originally added with the biosolids provided long-term metal adsorption capacity even after most of the organic matter had been degraded. **Impact:** These findings support EPA regulations for beneficial use of biosolids on cropland and validate the practice of using high Fe biosolids to remediate metal contaminated soils.

Basta. N.T., Ryan, J.A., Chaney, R.L. 2005. Trace element chemistry in residual-treated soil: Key concepts and metal bioavailability. *J. Environ. Qual*. 34:49-63.

Sukkariyah, B.F., Evanylo, G., Zelazny, L., Chaney, R.L. 2005. Recovery and distribution of biosolids-derived trace metals in a Davidson clay loam soil. *J. Environ. Qual.* 34:1843-1850.

Sukkariyah, B.F., Evanylo, G., Zelazny, L., Chaney, R.L. 2005. Cadmium, Cu, Ni, and Zn availability in a biosolids-amended Piedmont soil years after application. *J. Environ. Qual.* 34:2255-2262.

**Phytoextraction of cadimum from biosolids contaminated soils**

- A few locations in the U.S. have high levels of soil Cd which can pose a risk to wildlife or humans thru crop uptake of Cd. Some of these sites received excessive metal loading from application of highly metal contaminated biosolids before present biosolid regulations were established. ARS scientists have developed and patented a phytoextraction technology using selected genotypes of *Thlaspi caerulescens* (alpine pennycress) collected in southern France. These genotypes can concentrate significant amounts of Cd in plant tissue. Biomass can be harvested and Cd removed from the site. Field trials were conducted on a site that previously received contaminated biosolids to test the effectiveness of *T. caerulescens* for Cd removal. The most effective genotypes of *T. caerulescens* removed over 2000 mg Cd/ kg dry matter. Since *T. caerulescens* is a perennial, multiple harvests could bring about a significant reduction in the concentration of Cd in the contaminated soil. **Impact:** These results demonstrated that *T. caerulescens* can be an effective phytoremediation crop for Cd contaminated soil. This phytoremediation method is the most cost-effective Cd decontamination technology discovered to date.

Chaney, R.L., Angle, J.S., McIntosh, M.S., Reeves, R.D., Li, Y.-M., Brewer, E.P., Chen, K.-Y., Roseberg, R.J., Perner, H., Synkowski, E.C., Broadhurst, C.L., Wang, S., Baker, A.J.M. 2005. Using hyperaccumulator plants to phytoextract soil Ni and Cd. *Z. Naturforsch*. 60C:190-198.

Li, Y.-M., Chaney, R.L., Reeves, R.D., Angle, J.S., Baker, A.J.M. 2006. U.S. Patent 7,049,492; 8 pp *Thlaspi caerulescens* sub-species for Cd and Zn recovery.

Wang, A., Angle, J.S., Chaney, R.L., McIntosh, M.S. 2006. Soil pH effects on uptake of Cd and Zn by *Thlaspi caerulescens*. *Plant Soi*l 281:325-337.

**Assessing trace metals and organics in spent foundry sands**

- Approximately 2000 foundries in the United States use sand to create metalcasting molds and cores. The sand is reused a number of times by the foundry, but a point is reached where the sand is unsuitable for further use. Interest in beneficial use, rather than disposal of spent foundry sands (SFS) has grown in recent years as the cost of landfilling increased and the potential benefits of using SFS in agriculture and horticulture have become increasingly apparent. ARS and EPA Office of Solid Waste are cooperating to conduct a risk assessment for beneficial use of SFS and to develop guidelines for specific uses of SFS in agriculture and horticulture.

  Variations in SFS composition occur due to differences in sand source, metal casting processes, metals being poured, and binders used in the mold and core. The regulatory community is concerned that SFS contain elevated levels of potentially toxic organics and trace metals. A national study was initiated to determine the phytoavailability and bioavailability of metals in cast iron, steel, brass and aluminum SFS. Soil microbial activity

is a sensitive indicator of environmental stress caused by potentially toxic constituents and may be useful to assess which SFS are suitable for beneficial use in the environment. A brass SFS which contained high concentrations of the heavy metals copper (Cu), lead (Pb) and zinc (Zn), severely impacted soil microbial activity. In contrast, the microbial activity in soil amended with aluminum SFS was unaffected. Bioavailability of metals from SFS was also determined using earthworms. High earthworm mortality was observed for brass SFS, but not iron and steel SFS. The toxicity was highly correlated with total and extractable concentrations of Cu, Pb and Zn in the SFS. Heavy metal concentrations in the tissues of earthworms from iron, aluminum and steel SFS blends did not exceed those in the control. **Impact:** Aluminum, steel, and iron SFS tested in this study did not pose a toxicity and metal transfer risk. Brass SFS evaluated in this study exhibited high levels of Cu, Pb and Zn and had a negative impact on microbial activity and earthworms. Brass SFS should not be considered for beneficial use. Data from these investigations will be used by ARS and EPA to conduct a risk assessment for beneficial use of SFS in agriculture and horticulture. (Described in Problem Area 2)

Dungan, R.S., U. Kukier, and B.D. Lee. 2006. Blending foundry sands with soil: Effect on dehydrogenase activity. *Science of the Total Environment*. 357:221-230.

Dungan, R.S. and N.H. Dees. 2006. Metals in waste foundry sands: Assessment with earthworms. *Journal of Residuals Science & Technology*. 3:177-184.

Dungan, R.S. and N. Dees. 2007. Use of spinach, radish, and perennial ryegrass to assess the availability of metals in waste foundry sands. *Water, Air, and Soil Pollution*. 183:213-223.

- Foundry sand grains used in the molding process are held together by clay or other inorganic binders and a variety of organic resins including phenolic urethane, furan, phenolic novolac and phenolic resole. Organic thermal decomposition products are generated when molten metal contacts carbonaceous additives in sands and resin binders. ARS scientists measured release of xenobiotics including polycyclic aromatic hydrocarbons (PAH) and phenolics from SFS heated at temperatures up to 1000 degrees C. PAH generated during foundry operations were not highly carcinogenic compounds such as benzo[a]pyrene, but simpler and less toxic compounds such as naphthalene and phenanthrene. A large number of phenolic compounds were generated through thermal decomposition of phenol-based binders. None of the measured xenobiotics were present at levels which would comprise excessive risk to humans or environmental receptors. The compounds present were largely biodegradable; therefore mixing SFS with soil would promote natural biodegradation of these compounds. **Impact:** These studies showed that SFS from iron, aluminum and steel foundries had low levels of organics. These data will be used in the ARS –EPA risk assessment for beneficial uses of SFS in agriculture and horticulture.

Dungan, R.S. and J.B. Reeves, III. 2005. Pyrolysis of foundry sand resins: A determination of organic products by mass spectrometry. *Journal of Environmental Science and Health*, Part A. 40:1557-1567.

Dungan, R.S. 2005. Headspace solid-phase micro extraction (HS-SPME) for the determination of benzene, toluene, ethylbenzene, and xylenes (BTEX) in foundry molding sand. *Analytical Letters*. 38:2393-2405.

Dungan, R.S. and J.B. Reeves, III. 2006. Mid-Infrared spectroscopic analysis of foundry green sands and chemically bonded cores. *Journal of Residuals Science & Technology*. 3:61-66.

Dungan, R.S. 2006. Polycyclic aromatic hydrocarbons and phenolics in ferrous and non-ferrous waste foundry sands. *Journal of Residuals Science & Technology*. 3:203-209.

### *Problem Area 2: Protocols and Methodology Standards for Examination and Approval of Byproducts for Beneficial Uses in Agriculture and Horticulture*

**Risk assessment for beneficial use of spent foundry sand**

- Careful risk assessment allows development of regulations for beneficial use of a byproduct. ARS cooperated with EPA to conduct a risk assessment for beneficial uses of SFS. The SFS uses considered in the risk assessment were application to land (up to 50% by volume) or use in manufactured topsoil or potting media. The Pathway approach used in the risk assessment for biosolids was applied to SFS. An extensive data set of trace element and organic concentrations in SFS was obtained from this investigation and from experiments reported in the literature. These data were compared against EPA guidelines and trace element levels in natural soils in the U.S. Arsenic (As) was the only element that exceeded the EPA safety limit in some SFS samples. However, when compared to natural U.S. soils, As in SFS was less than As in soil. In fact, SFS were lower than most U.S. soils in nearly all trace elements. With few exceptions, there are no known adverse effects of trace elements in natural soils. Thus the risk assessment determined that SFS may be safely applied to land or used in manufactured topsoil or potting media. An official risk assessment and guidance document for beneficial use of SFS is expected to be released in 2008. The document will help states to develop or review regulatory structures that will ensure environmental protection and encourage beneficial use nationally. **Impact:** The risk assessment showed that trace elements and organics in SFS from iron, steel and aluminum foundries did not comprise a risk to human health or the environment. Arsenic in SFS does not appear to be a risk since land application of SFS would dilute As in natural soils. A risk assessment approach based on comparison of trace element concentrations in byproducts to trace element concentrations in natural soils would seem to be applicable to many byproducts that are essentially uncontaminated and have demonstrated beneficial characteristics. If a byproduct contains trace element concentrations that exceed levels in natural soils, a more complete risk assessment would be required. Lessons learned in risk assessment of beneficial uses of SFS will guide risk assessment of other byproducts. The Electric Power Research Institute plans to use this approach to conduct a risk assessment of beneficial uses of coal combustion products. Use of byproducts in place of virgin materials is increasingly seen as good public policy.

Dungan, R.S. and N.H. Dees. 2006. Metals in waste foundry sands: Assessment with earthworms. *Journal of Residuals Science & Technology*. 3:177-184.

Dungan, R.S. and N. Dees. 2007. Use of spinach, radish, and perennial ryegrass to assess the availability of metals in waste foundry sands. *Water, Air, and Soil Pollution*. 183:213-223.

Dungan, R.S. 2006. Polycyclic aromatic hydrocarbons and phenolics in ferrous and non-ferrous waste foundry sands. *Journal of Residuals Science & Technology*. 3:203-209.

*Problem Area 3: Byproduct Utilization Technologies*

**Remediation of metal toxic soils and urban runoff using mixtures of biosolids and byproducts**

- ARS scientists have used a variety of byproducts, alone or in combination, to remediate contaminated sites to improve soil chemical, physical and biological properties to protect environmental quality and human health and to improve soils for crop production. Metal contaminated soils at Superfund Sites are often acidic, contain high levels of metals (Zn, Cd, Pb and Cu) and are barren of vegetation. These sites pose a risk to human health and adjacent ecosystems. ARS researchers have developed mixtures of organic material (manure, composts, biosolids) and inorganic byproducts that fully remediated metal toxic mine wastes and smelter contaminated soils. These amendment mixtures supplied a number of components essential for remediation of metal toxic soils including organic matter, organic N, soil microbial innocula, alkalinity and phosphate. These methods provided cost-effective revegetation of contaminated soils and re-establishment of viable and safe ecosystems. In related studies phosphate and phosphate plus iron treatments were used to inactivate Pb at a Superfund smelter site and in urban soils. The effectiveness of the technique was documented by rat, pig and human feeding trials that demonstrated a dramatic reduction in the bioavailability of Pb in the treated soils. This method was demonstrated in cooperation with the In Situ Inactivation and Natural Ecosystem Restoration Action Team composed of Federal, state, university and industrial scientists. **Impact:** These remediation methods are very inexpensive compared to removal and replacement of contaminated soils or capping contaminated soils with topsoil to allow revegetation. These methods have been transferred to others. Private sector firms are beginning to apply this technology at several locations. Other scientists are testing the technology at sites with different characteristics to help define the range of problem soils which can be effectively remediated. The method is being applied to Brownfield locations at a considerable cost savings compared to standard remediation methods. EPA has developed a guidance manual for using this approach for ecosystem restoration.

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

  Brown, S.L., Chaney, R.L., Hallfrisch, J.G., Xue, Q., Ryan, J.A., Berti, W.R. 2004. Use of soil amendments to reduce the bioavailability of lead, zinc and cadmium *in situ*. *J. Environ. Qual*. 33:522-531.

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

- Industrial, urban and military facilities often generate storm runoff which contains metals in excess of discharge limits. Inexpensive methods to remove these metals are needed to protect surface water and comply with regulatory limits. Composted organic matter amended with byproducts supplying iron and alkalinity has been shown to be highly effective in binding dissolved or suspended metals, so tests were conducted to determine if this method can be used to remove metals from contaminated runoff. Simulated, very contaminated runoff containing Pb, Zn and Cu was applied to columns of several compost mixtures and the drainage water analyzed daily for 3.5 months. During this period the effluent did not exceed

5 μg Pb/L and the Zn and Cu levels were less than surface water discharge limitations. **Impact:** The compost treatment mixture can be put in a porous plastic net and placed on the soil to serve as a linear treatment system to inexpensively achieve metal reduction to discharge requirements at urban, industrial or military sites. This is a recent discovery, thus there are no publications to date.

**Organic byproducts to serve as horticultural potting media**

- Nursery and greenhouse industries are dependent on pine bark and peat moss as a potting media for container grown plants. However, in recent years the rising cost and deceasing availability of these substrates have begun to negatively impact these industries. New substrates that combine poultry little with Clean Chip Residues have been developed collaboratively with university partners. Clean Chip Residue is the forest residue material (limbs, needles, bark, pinecone, etc.) generated when pine plantations are harvested for "clean chips" for paper pulp mills. Greenhouse plants and nursery plants were successfully grown in experiments utilizing these new substrates. **Impact:** The development of these substrates will provide long-term availability and stability of potting media needed to maintain the economic viability of the horticulture industry.

Boyer, C.R., Fain, G.B., Gilliam, C.H., Torbert III, H.A., Gallagher, T.V., Sibley, J.L. 2006. Evaluation of freshly chipped pine tree substrate for container-grown lantana camera. *Hort. Science*. 41:1027.

Boyer, C.R., G.B. Fain, C.H. Gilliam, T.V. Gallagher, H.A. Torbert, and J.L. Sibley. 2008. Clean Chip Residual: A New Substrate for Greenhouse-Grown Annuals. *Hort. Technology* (in press).

**Non-composted municipal solid waste processing byproduct improves U.S. Army training land reclamation**

- The costs to the U.S. Army for handling, management, and disposal of non-hazardous solid waste are significant and are expected to increase. A new garbage processing technology has been developed that sterilizes and separates garbage and produces a light cellulose pulp called Fluff®. Studies were conducted at Fort Campbell, KY, and Fort Benning, GA, to evaluate the non-composted cellulose pulp as a soil amendment for improving soil quality, plant growth, and revegetation success on lands damaged due to extensive military training activities. The addition of cellulose pulp improved plant available nutrients and soil pH levels, reduced soil compaction, and increased soil C and N. No adverse environmental effects were detected. **Impact:** These results demonstrated that cellulose pulp from garbage processing could be effectively used to improve soil chemical and physical properties and to enhance revegetation efforts at degraded military sites. Reuse of this material at bases around the country is projected to save the military $100 million per year in solid waste disposal costs. Remediation of degraded sites also provides environmental benefits to adjacent ecosystems.

Busby, R.R., Torbert III, H.A., Gebhart, D.L. 2006. Carbon and nitrogen mineralization of composted and un-composted municipal solid waste in sandy soils. *Soil Biology and Biochemistry*. 39:1277-1283.

Busby, R.R., Gebhart, L., Torbert III, H.A. 2006. Effects of an uncomposted municipal waste processing by-product on prairie grass establishment. *Agronomy Journal*. 98:1073-1080.

Torbert III, H.A., Busby, R.R., Gebhart, D.L., Potter, K.N., Curtain, D.R. 2007. Non-composted municipal solid waste processing byproduct effect on soil reclamation. *Journal of Plant Nutrition*. 30:755-772.

**Use and handling of manures to produce quality compost**

- Improved liquid-solid separation treatment can solve many environmental problems associated with confined livestock production. However, the separated manure solids need to be converted into value-added products. ARS scientists conducted a full-scale demonstration of a process to separate swine manure solids followed by aerobic composting in a centralized facility serving several swine production farms. Solids were combined with cotton gin waste to optimize the composting process using a mechanically agitated bed system with further stabilization in static windrows. During the demonstration, 273 tons of raw manure solids were converted into 237 tons of quality compost. The compost conserved 95-100% of the N and other nutrients and met EPA Class A biosolids quality standards due to low pathogen levels. **Impact:** The composts were sold commercially as soil amendments, organic fertilizers, container substrate and soil-less media. This process allowed two waste streams to be recycled and generated additional income for the producer.

Vanotti, M.B., Millner, P.D., Szogi, A.A., Campbell, C.R., and Fetterman, L.M. 2006. Aerobic composting of swine manure solids mixed with cotton gin trash. ASABE Paper #064061. *Am. Soc. Agr. & Biol. Eng*.:St. Joseph, Michigan.

**Use of drinking water treatment residuals to reduce P in runoff**

- Drinking water treatment residuals (WTR) , a product of water purification, are often rich in amorphous Fe and Al oxides because Fe and Al salts are used to flocculate and coagulate suspended sediments in surface water used as a drinking water source. The high Fe and Al oxide content of many WTR gives them a significant P sorption capacity. ARS scientists and others have demonstrated the effectiveness of WTR to reduce P solubility in manure and soils treated with manure, thus reducing P losses to surface water through runoff. Water quality protection can be achieved by direct application of WTR to manure or to fields with high levels of P from long-term application of manure or biosolids. Research showed that P in runoff from biosolids treated with Al-based WTR was 95% lower than P in runoff from untreated biosolids. One concern with using WTR to immobilize P has been that manure or biosolids treated in this manner will not be able to supply P to crops. Field trials showed that unless Fe oxide and Al oxide levels in WTR greatly exceeded the amount of P to be immobilized crops could convert enough of the immobilized P to plant available forms so crop yields were not reduced. **Impact:** These results demonstrated WTR can be used to immobilize P in manure and soils treated with manure to greatly reduce runoff losses of P to surface waters. WTRs are available around the country and their beneficial use could reduce disposal costs to municipal drinking water facilities. A risk assessment would need to be performed to identify any problems associated with these materials.

Codling, E.E., Mulchi, C.L., Chaney, R.L. 2007. Grain yield and mineral element composition of maize grown on high phosphorus soils amended with water treatment residual. *J. Plant Nutr*. 30:225-240.

Novak, J.M., and Watts, D.W. 2005. An alum-based water treatment residual can reduce extractable phosphorus concentrations in three phosphorus-enriched Coastal Plain soils. *J. Environ. Qual.* 34:1820-1827

Moore, P.A., Jr., A.N. Sharpley, D. Parker, H.L. Goodwin, P. Kleinman, R. Young, and R. Williams. 2007. Mitigation options for reducing phosphorus runoff from biosolids. Pp. 275-278 in (G. Heckrath, G.H. Rubaek, and B. Kronvang, eds) *Diffuse Phosphorus Loss: Risk Assessment, Mitigation Options and Ecological Effects in River Basins*. Aarhus University Press. Silkkeborg, Denmark.

Dao, T.H., Codling, E.E., Schwartz, R.C. 2005. Time dependent phosphorus xtractability in calcium- and iron-treated high-phosphorus soils. *Soil Science*, 170:810-821.

**Beneficial agricultural uses of FGD gypsum**

- ARS is a member of the Coal Combustion Products Partnership (C2P2) along with EPA, the Department of Energy, the Department of Transportation and the electric power industry. The purpose of C2P2 is to promote beneficial uses of industrial byproducts. One of the most promising byproducts for agricultural uses is flue gas desulfurization (FGD) gypsum produced when sulfur dioxide is scrubbed from exhaust gases released from coal-fired power plants. Supplies of FGD gypsum will increase dramatically over the next few years as coal-fired power plants add scrubbers to meet Clean Air Act requirements. This material has the same chemical composition ($CaSO_4$-$2H_2O$) as mined gypsum that has been used for centuries as a soil amendment. ARS scientists have conducted research to document environmental benefits of FGD gypsum and to develop guidelines for safe and effective agricultural use of the material. FGD gypsum can be used as a fertilizer source to supply calcium and sulfur to crops. Application of FGD gypsum to soil improves soil chemical and physical properties resulting in greater infiltration and storage of rainwater. Since water moves into soil, more water is available for subsequent use by crops and less water runs over the soil surface reducing erosion and movement of sediment, nutrients, trace elements and pesticides to surface water. Improved soil water storage from rainfall events is especially important in areas of the country that have experienced severe drought. ARS scientists are looking at other beneficial uses of coal combustion products including removal of contaminants such as nutrients, trace elements, pesticides and hormones from surface and subsurface artificial drainage systems. These drainage systems can serve as conduits for movement of contaminants from agricultural fields to sensitive bodies of water (e.g., Chesapeake Bay, Gulf of Mexico). ARS scientists have developed methods to route drainage water through reactors loaded with materials like coal combustion products to remove contaminants. Reactors installed in surface drainage ditches on the Eastern Shore of Maryland have removed in excess of 70% of the P flowing through the reactor. **Impact:** These results demonstrate that FGD gypsum can be effectively used to improve soil properties and protect water quality. Many areas of the country have soils that could be significantly improved through use of FGD gypsum, for example the southeastern U.S. has over 10 million acres of highly erodible soils. Control of erosion in these soils would lead to improved water quality in an area of the country with the highest percentage of contaminated water bodies. Improved soil properties lead to greater infiltration and storage of rainwater. In a state such as Georgia, a 15% improvement in water infiltration and storage would provide more additional water for crop use than the annual amount of irrigation water used in the state. Farmers, power companies and the environment would benefit from agricultural uses of FGD gypsum. Farmers are already starting to use FGD gypsum in some areas of the country.

Torbert III, H.A., King, K.W., Harmel, R.D. 2005. Impact of soil amendments on reducing P losses rom runoff in sod. *J. Env. Qual*. 34:1415-1421

Penn, C.J., Bryant, R.B., Kleinman, P.J., Allen, A.L. 2007. Removing P from drainage ditch water. *J. Soil and Water Conservation*. 62:269-276

Norton, D.L. 2008. Gypsum soil amendment as a management practice in conservation tillage to improve water quality. *J. Soil and Water Conservation* 63: 46-48

**Using recycled ground rubber as a zinc source for crops**

- Cadmium (Cd) uptake by crops poses a risk to human health, but Cd uptake can be inhibited by zinc (Zn) in soil. Some soils in the Salinas Valley in California contain high natural levels of Cd which accumulates to undesired levels in Romaine lettuce and spinach due to low levels of Zn in the soil. ARS scientists conducted research to determine if recycled ground rubber (containing 1.2% Zn) could reduce Cd uptake by spinach. In a pot experiment, addition of Zn sulfate at high rates reduced spinach Cd uptake by 40%, but added ground rubber was less effective in reducing Cd uptake because Zn was slowly released from the rubber to the soil. **Impact:** These results demonstrated that Zn from recycled ground rubber could serve as a slow-release Zn source for crops and could have the potential to replace more costly Zn fertilizer sources. This is a recent discovery, thus there are no publications to date.

***Problem Area 4: Energy from Byproducts***
*Most bioenergy research is conducted in the Bioenergy and Energy Alternatives National Program. However, a few investigations were undertaken to convert manure and other byproducts to energy or to use byproducts from energy production in agriculture.*

- The total amount of energy contained in manure and other byproducts could make a significant contribution to the nation's overall energy needs. Research is being conducted to convert byproducts to energy and useful materials such as activated C (char). Fuel analysis indicated that poultry litter has higher ash, moisture, N and S contents, and a lower BTU value than coal. The combustion profiles of coal and poultry litter are quite different, but blends of these fuels, when co-fired under correct conditions, can perform satisfactorily as boiler fuels. Research also has shown that poultry litter can play a role in control of mercury emissions from coal-fired power plants. A mercury sorbent has been prepared by mixing poultry litter with different coals and using high temperature activation to generate a so-called wood-ceramic sorbent. This sorbent can be injected into the flue gas at power plants to reduce mercury emissions. Finally, the impact of poultry litter moisture content, ratio of litter to coal, gasification temperature and residence time on char production and char characteristics has been determined to identify appropriate conditions for generating this valuable product. **Impact:** This research demonstrated several beneficial uses of poultry litter: energy production, mercury control at power plants, and production of activated C. The conditions and processes required for these three outcomes were defined and their effectiveness documented. Alternative uses for poultry litter should benefit poultry producers and the electric power industry.

Li, S., Wu, A., Deng, S., and Pan, W-P. 2008. Effect of co-combustion for chicken litter and coal on emissions in a laboratory-scale fluidized bed combustor. *Fuel Processing Technology*. 89:7-12.

Zhang, Y., Cui, H., Ozao, R., Cao, Y., Chen, B., Wang, C-P, Wei, P. and Pan, W-P. 2007. Characterization of activated carbon prepared from chicken waste and coal. *Energy & Fuels.* 21: 3735-3739.

Cui, H., Cao, Y. and Pan, W-P. 2007. Preparation of activated carbon for mercury capture from chicken waste and coal. 2007. *J. Anal. Appl. Pyrolysis*. 80:319-324.

Whitely, N., Riko Ozao, Ramon Artiaga, Yan Cao and Wei-Ping Pan. 2006. Multi-utilization of chicken litter as biomass source – Part I. Combustion. *Energy & Fuels*. 20: 2660-2665.

**Identification of emerging thermochemical conversion technologies: Analysis and assessment.**

- Animal manure is a carbon-rich substance that represents a significant renewable resource that can be used as a bioenergy feedstock in various thermochemical conversion (TCC) technologies. For both wet and dry animal manures, TCC technologies like gasification and pyrolysis can be utilized as a waste treatment option that produces renewable energy. Based on theoretical considerations and limited experimental data, a direct evaluation of TCC processing of raw wet wastes such as swine manure determined that catalytic hydrothermal processing could produce more energy than either combustion of brown coal or anaerobic digestion. The estimated cost of a conceptual first generation wet gasification manure management system for a model swine farm would be significantly higher than that of a traditional anaerobic lagoon system. However, there are many significant environmental advantages of wet gasification including: (1) removal of oxygen demanding solids, hormones and odorous compounds; (2) total pathogen kill; (3) recovery of most nitrogen as ammonia, which could be used as a fertilizer; (4) recovery of water which could be reused in the livestock operation. **Impact:** This work is the first step for presenting information to livestock operators regarding the various scenarios for integrating current manure management processes with TCC technologies. Successful implementation of TCC technologies as a waste treatment option would not only reduce associated disposal costs, but it would also produce both energy and relatively clean water. The results of the study have been presented at various professional meetings and workshops.

Cantrell, K.B., Ducey, T., Ro, K.S., and Hunt, P.G. 2008. Livestock waste-to-bioenergy generation opportunities. *Bioresource Technology* (in press).

Cantrell, K.B., Ro, K.S., Mahajan, D., Anjom, M., and Hunt, P.G. 2007. Role of thermochemical conversion in livestock waste-to-energy treatments: Obstacles and opportunities. *Ind. Eng. Chem. Res*. 46: 8918-8927.

Ro, K.S., Cantrell, K.B., Elliott, D., and Hunt, P.G. 2007. Catalytic wet gasification of municipal and animal wastes. *Ind. Eng. Chem. Res*. 46:8839-8845.

**Evaluating the effects of feeding distillers' grains from ethanol production to beef cattle and swine**

- Distillers' grains, a by-product of the production of ethanol from feed grains, can serve as feeds for livestock; however, few studies have examined their use in beef cattle and swine diets. Cooperative studies involving ARS and four universities indicated that the

feeding value of sorghum-based distillers' grains is approximately 92 to 95% of corn-based distillers' grains, that optimal concentrations of wet distillers' grain in steam-flaked corn-based diets is considerable less than with dry-rolled corn-based diets (15 to 20% vs. 30 to 40%), that supplemental fat concentration can affect the utilization of wet distillers' grains, and that feeding of distillers' grains (20% of diet dry matter) increases total manure production and total manure P, but does not appear to affect ammonia emissions. The measured digestible energy value for swine of corn-based distillers' grains was approximately 7% greater than sorghum-based distillers' grains and P bioavailability was approximately 12% greater in corn-based than sorghum-based distillers' grains. The P availability of dried distillers' grains fed to swine was considerably greater than the P availability in the original grain source. **Impact:** As ethanol production grows a substantial amount of distillers' grains will be available for use as livestock feed. These results are needed by nutritionists to formulate optimal diets for finishing cattle and will potentially affect the feeding programs of as many as 50% of all U.S. fed cattle (> 15 million head annually). Since distillers' grains contain more bioavailable P than traditional grain sources, swine nutritionists will need to reduce supplemental P in diets to avoid environmental problems associated with excess P in manure.

Cole, N. A., Brown, M. S., and MacDonald, J. C. 2008. Environmental issues related to feeding of distiller's grains in beef cattle finishing diets. *Journal of Animal Science* 86 (In press, Abstract).

Vasconcelos, J. T., Shaw, L. M., Lemon, K. A., Cole, N. A. and Galyean, M. L. 2007. Effects of graded levels of sorghum wet distiller's grains and degraded intake protein supply on performance and carcass characteristics of feedlot cattle fed steam-flaked corn-based diets. *The Professional Animal Scientist* 23:467-475.

Feoli, C., J. D. Hancock, C. Monge, T. L. Gugle, S. D. Carter, and N. A. Cole. 2007. Effects of corn- and sorghum-based distiller's dried grains with solubles on growth performance and carcass characteristics in finishing swine. *Journal of Animal Science* 85 (Supplement 2):95. (Abstract).