National Program 206: Manure and Byproduct Utilization

Research Accomplishments

The Assessment Report describes research accomplishments over the last 4 years in the Manure and Byproduct Utilization National Program. T he Report is organized into three Components (Nutrients, Emissions, and Pathogens) containing 20 research focus areas (Problem Areas). Accomplishments, their impact and selected publications documenting the accomplishments are organized under each Problem Area. The reader can use the Table of Contents to focus on areas of interest.

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Manure and Byproduct Utilization National Program

Overview: Manure and Byproduct Utilization is one of 22 National Programs within USDA-Agricultural Research Service (ARS). These National Programs are organized within three broad areas: Animal Production, Product Value and Safety (APPVS); Natural Resources and Sustainable Agricultural Systems (NRSAS); and Crop Production, Product Value and Safety (CPPVS). The Manure and Byproduct Utilization National Program is part of NRSAS, but interaction also occurs with researchers in APPVS and CPPVS. The National Program structure allows ARS to link scientists in laboratories around the country to address research problems of regional and national interest. Research in this National Program is conducted through 30 projects at 20 laboratories. The annual budget is $17m and 75 scientists are involved in the research.

Each National Program conducts a planning workshop to focus the research program by learning the problems and needs of customers, stakeholders, and partners. These workshops help ensure that our research programs are relevant to the concerns of our constituents. Approximately 120 participants attended the planning workshop for this National Program including producers, commodity group representatives, public interest group representatives, scientists from universities, and scientists and administrators from ARS and other Federal and State agencies. The participants identified three major problems associated with manure management: (1) excess nutrient enrichment of soil and water, (2) release of particulate matter and gases to the atmosphere, and (3) control of pathogenic microorganisms.

Based on input received at the planning workshop, research in the Manure and Byproduct Utilization National Program was organized into three component areas: nutrients, emissions and pathogens. Teams of ARS scientists worked with members of the National Program Staff to develop an Action Plan that provided the framework for ARS research over a five-year period. Each of the three components contained from five to nine problem areas that required research. Groups of ARS scientists at each of the 20 laboratories wrote Project Plans that described the research they would conduct, the anticipated products or information to be generated by the research, roles and responsibilities of ARS scientists and their cooperators, and timelines and milestones to measure progress toward achieving the goals of the research. All the Project Plans were reviewed for scientific quality in February 2000 by a panel of experts in the field. ARS scientists used input from the panel to revise and improve their planned research.

The final stage in the cycle of an ARS National program involves assessment of research that has been conducted. An expert panel is assembled to evaluate the impact of ARS research accomplishments and to offer suggestions for future ARS research direction and emphasis. Input from the expert panel and from interested parties at a planning workshop to be held April 13-14, 2004 in Atlanta will be used to develop the framework for ARS research over the next five years.

Nutrients Component

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. A systems research approach involving all phases of animal feeding; manure handling, storage and treatment; land application; and crop production is being employed to solve problems in this area.

Research within the Nutrients Component of the Manure and Byproduct Utilization National Program is conducted in nine Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a workshop prior to the start of the current five-year National Program cycle. Research accomplishments described in this report may address more than one Problem Area and therefore may be repeated at multiple points in the report. The nine Problem Areas are: (Problem Area 1) Livestock and poultry diets need to be matched to animal nutrient requirements, and the digestibility and bioavailability of nutrients in feeds need to be increased to prevent excess nutrients in manure. (Problem Area 2) Efficient and cost-effective methods are required for manure handling, treatment and storage. (Problem Area 3) Methods need to be developed to determine nutrient concentrations and nutrient availability in manure, byproducts, and soil treated with manure or byproducts. (Problem Area 4) Management practices and decision tools are needed to integrate effective manure use into soil-crop-climate-livestock systems. (Problem Area 5) Methods to predict areas vulnerable to P losses and practices to reduce or eliminate these losses are required. (Problem Area 6) Conservation practices at the farm and watershed scale are needed to protect surface and ground water from manure nutrients. (Problem Area 7) The effects of long-term land application of manure and byproducts need to be determined. (Problem Area 8) Remediation strategies that minimize off-site impacts of excess nutrients and trace elements in soils are needed. (Problem Area 9) Alternative uses for manure and other byproducts need to be developed.

Nutrients research is currently conducted by the following ARS locations: Ames, Iowa; Auburn, Alabama; Beltsville, Maryland; Bushland, Texas; Clay Center, Nebraska; Fayetteville, Arkansas; Florence, South Carolina; Kimberly, Idaho; Lincoln, Nebraska; Madison, Wisconsin; Mississippi State, Mississippi; Orono, Maine; Temple, Texas; Tifton, Georgia; University Park, Pennsylvania and Watkinsville, Georgia.

Nutrients Component

Problem Area 1: Livestock and poultry diets need to be matched to animal nutrient requirements, and the digestibility and bioavailability of nutrients in feeds need to be increased to prevent excess nutrients in manure.

Background: Animal feed and animal nutrition are important components of manure management. Livestock and poultry diets directly influence the amount of manure produced; nutrient, trace element and pathogen concentrations in manure; and formation of volatile components. Research to increase feed use-efficiency emphasizes defining animal nutritional requirements, diet formulation, genetically altered crops, use of enzymes and alteration of intestinal microflora.

Accomplishments:

Controlling phosphorus in diets fed to dairy cattle: The sustainability of dairy production increasingly relies on both profitable milk production and the farmers' ability to comply with nutrient, especially phosphorus (P), management regulations. Dairy producers in the United States generally feed their cows diets containing excess P. ARS scientists and their cooperators studied P in diets on 93 representative dairy farms in Wisconsin. They found that 85% of the farms were supplying dietary P in excess of recommended levels. They also conducted feeding trials with cows placed on diets that contained 0.31, 0.39, or 0.47% P. Feeding 0.39% P provided a sufficient margin of safety above the critical required amount and had no effect on animal performance.

Impact: The research provided a sound basis for dairy producers and their advisors to reduce dietary P levels. Results have been incorporated into University of Wisconsin Cooperative Extension publications and nutrient management curriculum. The technique to collect information on P feeding practices on dairy farms has been widely requested and has been adapted for use in Iowa, Ohio, Pennsylvania and Wisconsin. National estimates indicate that by reducing P in feed to recommended levels the U.S. dairy industry could save $100 million annually, while reducing the risk of P pollution of surface waters.

Selected Publications:

Powell, J.M., Z. Wu and L.D. Satter. 2001. Dairy diet effects on phosphorus cycles of cropland. J. Soil and Water Conserv. 56: 22-26.

Ebeling, A.M., L.G. Bundy, J.M. Powell and T.W. Andraski. 2002. Dairy diet phosphorus effects on phosphorus losses in runoff from land-applied manure Soil Sci. Soc. Am. J. 66:284-291.

Powell, J.M., D. Jackson-Smith and L.D. Satter. 2002. Phosphorus feeding and manure recycling on Wisconsin dairy farms. Nutr. Cycl. in Agroecosyst. 62: 277-286.

Oscillating dietary crude protein in beef cattle diets: Beef cattle in feedlots are typically fed diets that contain a constant concentration of protein. ARS scientists oscillated dietary crude protein concentrations between moderately deficient (10% of dry matter) and adequate (14% of dry matter) levels by changing diets at 48-hour intervals. Nitrogen retention by sheep was increased approximately 20% and average daily gain of finishing cattle was improved approximately 5%. This feeding system has the potential to decrease the quantity of nitrogen fed by 5 to 15%, resulting in decreased feedlot nitrogen losses through runoff and volatilization.

Impact: This discovery could potentially benefit cattle feeders by decreasing ration costs and the general public by decreasing nitrogen losses to air and water.

Selected Publications:

Cole, N.A. 1999. Nitrogen retention of lambs fed oscillating dietary protein concentrations. J. Anim. Sci. 77:215-222.

Cole, N.A., L.W. Greene, F.T. McCollum, T. Montgomery and K. McBride. 2003. Influence of oscillating dietary crude protein concentration on performance, acid-base balance, and nitrogen excretion of steers. J. Anim. Sci. 81:2660-2668

Evaluating dietary phytase for poultry and swine: Broilers can utilize only a small percentage of phytate-P, which is the main form of phosphorus (P) in feed grains. Broiler rations are therefore formulated with substantial quantities of supplemental inorganic-P, which causes high P contents in manures, P build-up in manured soils, and accelerated P losses in surface runoff. ARS scientists conducted research to evaluate the effects of feeding broilers diets with phytase and three levels of reduced supplemental P: conventional 0.4% P with or without phytase, phytase with 0.3% P and phytase with 0.2% P. The diets tested had no significant effect on market weight, feed efficiency, or bone density. Adding phytase and decreasing supplemental P in diets reduced manure total-P, but increased the concentration of water extractable P in manure, compared to the non-phytase normal-P diet.

ARS scientists investigated the influence of dietary phytase in swine diets on soluble P in runoff. Water-soluble P levels were higher in manure from diets containing phytase. Phosphorus runoff from pastures treated with swine manure was 25 % higher when phytase was included in the diet. However, treatment of the swine manure with aluminum chloride prior to field application lowered P in runoff by 60%. The combination of phytase in the diet and treatment of the manure with aluminum chloride lowered total P, soluble P and P lost in runoff.

Impact: This research shows that phytase in poultry diet will allow reduction in supplemental P while maintaining production. However, phytase has the short-term disadvantage of increasing soluble P and thus increasing the risk of P losses to surface waters. Treatments to reduce soluble P after use of phytase were identified. This research benefits the poultry and swine industries, NRCS and consultants writing nutrient management plans by documenting the advantages and disadvantages of using phytase in broiler and swine rations.

Selected Publications:

Vadas, P.A., J.J. Meisinger, L.J. Sikora, J.P. McMurtry, and A.E. Sefton. 2004. Effect of poultry diet on phosphorus in runoff from soils amended with poultry manure and compost. J. Environ. Qual. (in press).

Smith, D.R., P.A. Moore, Jr., B.E. Haggard, C.V. Maxwell, T.C. Daniel, K. Vandevander and M.E. Davis. 2004. Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure. J. Anim. Sci. 82:605-611.

Low phytate corn effects on swine manure P components, crop growth, and soil properties: Manure from swine fed low phytate corn (LPC) diets had lower total P concentrations (20 vs. 34 g kg^{-1}) than manure from swine fed traditional corn (TC) diets in a commercial swine operation in Nebraska. Sequential extraction of LPC manure revealed that water-soluble P concentration was lower than in TC manure. LPC manure had a lower total P concentration (20 g kg^{-1}) than did TC manure (34 g kg^{-1}). Water-soluble P has been correlated with runoff losses of P in manured soils. When expressed as a percentage of total P, the distribution of P in various extracts was similar between LPC and TC manures suggesting that the solubility and crop availability should be similar for the two manures. The lability (physical and chemical behavior) of LP manure should be similar to that of TC manure. When applied to land for three years, accumulation of P in the soil was lower for LPC manure than for TC manure. Use of LPC in swine diets resulted in manure having a N:P ratio (4.5:1) more similar to that needed by a corn crop (6:1) than did manure produced from TC diets (3.3:1).

Impacts: Use of LPC produces a manure with a more favorable N:P ratio for crop production. When used as a nutrient source and applied at rates to meet the N nutritional requirements of a crop, LPC manure will result in a slower accumulation of P in surface soils. Conversely, when poultry litter is applied at rates to meet the P nutritional needs of a crop, LPC manure provides a greater percentage of the N and less synthetic N fertilizer supplementation is required. This information will be of value to swine producers and agricultural consultants and extension personnel providing nutrient management information.

Selected Publications:

Paschold, J.S., B.J.Wienhold, J.E. Gilley, P. Miller and R. Ferguson. 2000. Nutrient Management for manure produced by swine fed low phytate corn. pp 91-98. *In* M. Vigil and L. Pieper (ed.). Proc. Innovative Technologies for Planning Animal Feeding Operations.

Wienhold, B.J. and P.S. Miller. 2004. Phosphorus fractionation in manure from swine fed traditional and low phytate corn diets. J. Environ. Qual. 33:389-393. 2004.

Nutrients Component

Problem Area 2: Efficient and cost-effective methods are needed for manure handling, treatment and storage.

Background: Significant losses of nutrients can occur during manure handling and storage. Nitrogen is especially susceptible to losses through ammonia volatilization, denitrification, leaching, anaerobic decomposition in lagoons and during aerobic composting. Treatment technologies are being developed to control ammonia volatilization and to immobilize N and P. Research is needed to develop more efficient separation of manure liquids and solids, and to find improved ways to immobilize and capture manure nutrients. A combination of practices will be required to effectively manage nutrients during manure handling and storage.

Accomplishments:

Use of zeolites, coal combustion byproducts, and polymers to reduce phosphorus in dairy manure: Polymers used for pretreatment of drinking water along with aluminum sulfate or iron chloride were tested for their capacity to bind P in manure suspensions. Surfactant-modified and synthetic zeolites and fly ash also were tested and exhibit significant capacities to bind PO_4-P. Zeolite-based sorbents also decreased P in the liquid phase. The success of these post-excretion manure treatments to chemically bind or remove dissolved P in dairy manure before it is land-applied depended on the manure's chemistry and physical characteristics. Co-application of treatment chemicals caused more solid aggregation from dairy slurries than did single amendments. Synergism of flocculant types in concentrated liquid manures allowed input reductions and enhanced particulate and dissolved P separation and immobilization. Although differences in affinity exist, these sorbents are effective temporary sinks for the treatment of P-laden wastewater and in the development of reversible P recovery approaches. The integration of hydrolytic phytases with zeolite-based technologies showed promise for further development as an environmentally compatible and resource-conserving approach.

Impact: The results have applications in treating animal wastewaters and municipal waters to meet new P and other oxyanion drinking water standards. Research information on anaerobic digestion and P management in effluent was transferred to the Zero Waste Alliance. As a result of this research, modified zeolites are being recommended as a manure P recovery strategy for western Oregon dairies.

Selected Publications:

Dao, T.H. and T.C Daniel, 2002. Particulate and dissolved phosphorus chemical separation and phosphorus release from treated dairy manure. J. Environ. Qual. 31:1388-1398.

Dao, T.H. 2004. Competitive anion sorption effects on dairy wastewater dissolved phosphorus extraction with zeolite-based sorbents. J. Food. Agric. Environ.1: 263-269.

Addition of polyacrylamide (PAM) to wastewater to improve solid separation: High-rate separation of solids and liquids from animal wastewater is a critical step for development of alternative systems of manure management. Addition of polyacrylamide, a water-soluble polymer, to swine and dairy wastewater reduced suspended solids by more than 95% by improving solids flocculation in contrast to about 10% solids removal using traditional screening methods. Cationic polymers with low charge density were most useful for manure applications and treatment at higher strengths was always more effective and economical. Flocculation treatment also improved performance of gravity solid-liquid separation for flushed dairy manure. In a pilot study flocculation treatment of flushed waste improved drainage of a sand filter and removed 98% of suspended solids, 87% of BOD, 62% of total nitrogen and 76% of total phosphorus.

Impacts: By capturing the suspended solids, most oxygen-demanding compounds and organic nutrients are removed from the liquid stream. This treatment greatly lowers the cost of treating the remaining wastewater. In addition, separated dry solids and nutrients can be transported more economically or processed into value-added products. Over the last three years this method of liquid-solid separation has been adopted by swine farms in the US and Europe.

Selected Publications:

Vanotti, M.B. and P.G. Hunt. 1999. Solids and nutrient removal from flushed swine manure using polyacrylamides. Trans. ASAE 42:1833-1840.

Vanotti, M.B., D.M.C. Rashash and P.G. Hunt. 2002. Liquid-solids separation of flushed swine manure with PAM: Effect of wastewater strength. Trans. ASAE 45:1959-1969.

Innovative methods using bacterial immobilization technology to enhance biological removal of N in swine production wastewater: High ammonia concentrations exist in manure and wastewaters. Treatment systems to manage nitrogen in wastewater depend on microbial transformations of nitrogen from ammonium to nitrate forms (nitrification) and from nitrate to nitrogen gas (denitrification). To overcome the difficulty of maintaining a high population of nitrifying bacteria in animal wastewater with high ammonia and high biochemical oxygen demand, ARS scientists adapted a Japanese municipal wastewater treatment technology. Researchers showed that with proper acclimation, cultures of nitrifying bacteria could be adapted to high-ammonia strength wastewater and immobilized and used effectively to treat very concentrated (2600 ppm ammonia-N) animal wastewater. Nitrification rates of 650 grams of N per cubic meter of reactor per day with virtually no ammonia losses were obtained in a pilot study using swine lagoon effluent. Another pilot study demonstrated the utility of immobilization technology to efficiently treat N after solid-liquid separation of flushed swine manure as a treatment alternative to anaerobic lagoons.

Phosphorus removal methodology that produces a solid, marketable fertilizer: During processing of swine feeding operation wastewater, hydrated lime is used to precipitate most of the phosphorus in the wastewater. The phosphorus is thus converted into marketable calcium phosphate fertilizer. The high pH achieved by the process also destroys disease-causing

pathogens present in the residual effluent. This effluent contains an N to P ratio greater than 12 to 1, which is more favorable for crop production than untreated lagoon effluent, which has a much lower N to P ratio.

Impact: The biological N treatment technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The P removal provides a P fertilizer source. Recycling of P in this manner is important because world P reserves are finite. Both of these technologies are being used as part of a system to treat wastewater at a swine finishing operation.

Selected Publications:

Vanotti, M.B. and P.G. Hunt. 2000. Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets. Trans. ASAE 43: 405-413.

Vanotti, M. B., A.A. Szogi and P.G. Hunt. 2003. Extraction of soluble phosphorus from swine wastewater. Transactions of ASAE 46:1665-1674.

Comprehensive manure treatment system: Treatment technologies are needed that capture nutrients, reduce emissions of ammonia and nuisance odors, and kill harmful pathogens. These individual technologies must then be linked together into a practical system if they are going to be adopted. Such a system has been developed by ARS scientists based on the processes described above. This system greatly increases the efficiency of liquid-solid separation by injection of a polymer to increase solids flocculation. Nitrogen management to reduce ammonia emissions is accomplished by passing the liquid through a module where immobilized bacteria transform nitrogen. Subsequent alkaline treatment of the wastewater in a phosphorus module precipitates recoverable phosphorus and kills pathogens. A marketable calcium phosphate fertilizer is produced. Treated wastewater can be recycled to clean hog houses or for crop irrigation. The system has been pilot tested and demonstrated in full-scale as part of the Smithfield Foods-Premium Standard Farms/North Carolina Attorney General agreement to replace current lagoons with Environmentally Superior Technology. The full-scale demonstration facility was installed in Goshen Ridge, a 4,400-head finishing farm in Duplin County, NC. Treatment performance exceeded design expectations; it separated 97% of suspended solids, 99.9% of BOD, 98.9% of TKN and 94.8% of total P. Odorous compounds in the waste were reduced more than 99% by treatment and pathogens were not detected in the final compost product. In one year, the anaerobic lagoon that was replaced with the treatment system was converted into an oxic pond with ammonia concentration lower than 20 ppm.

Impact: The system has the potential for major positive impact as a functional advance in the treatment of animal waste. Beneficiaries of this work are pork and dairy producers, industrialists, entrepreneurs, policy makers, environmental and health regulators, NRCS, and the general public.

Selected Publications:

Vanotti, M. B., P.D. Millner, P.G. Hunt, and A.Q. Ellison. 2004. Removal of pathogen and indicator microorganisms from liquid swine manure in multi-step biological and chemical treatment. Bioresource Technology. (in press).

Vanotti, M.B. 2003. Evaluation of Environmental Superior Technology: Swine Waste Treatment System for Elimination of Lagoons, Reduced Environmental Impact, and Improved Water Quality. Year 3 Report For the NC Attorney General – Smithfield Foods / Premium Standard Farms / Frontline Farmers Agreements. http://www.cals.ncsu.edu/waste_mgt/3-year%20Smithfield%20Report/pi%20report%20pdfs/super%20soil%20original.pdf

Alum (aluminum sulfate) additions to poultry litter to lower ammonia levels: Birds grown on alum-treated litter weigh more, utilize their feed better, have lower death rates, and heating costs during winter months are significantly lower (due to less ventilation required to remove ammonia vapors). The use of alum in poultry houses is very cost-effective; producers make an additional two dollars for every dollar spent. Detailed studies over several years have shown that alum-treated poultry litter applied to pastures reduced phosphorus runoff by 75% compared to untreated litter. Field trials conducted in 15 states and on more than 30 million chickens proved this technology to be cost-effective and that its widespread utilization by the poultry industry will have great effects in reducing phosphorus pollution of the environment**.** Other benefits of treating litter with alum include a reduction in the number of pathogens, such as campylobacter, lower heavy metal and estrogen runoff from fields fertilized with litter, and higher yields from crops fertilized with alum (due to higher N contents in the litter).

Impact: This technology was patented and poultry grade alum is being sold under the tradename Al^{+}Clear. In the past year, it is estimated that more than 600 million broilers were produced on alum-treated litter that will undoubtedly result in less pollution of our nation's soils and waters, in addition to facilitating the production of healthier chickens at lower cost. During the past year the USDA Natural Resources Conservation Service has developed a Conservation Practice Standard of treating poultry litter with alum.

Selected Publications:

Moore, P.A., Jr., T.C. Daniel and D.R. Edwards.1999. Reducing phosphorus runoff and improving poultry production with alum. Poultry Sci. 78:692-698.

Moore, P.A., Jr., T.C. Daniel and D.R. Edwards. 2000. Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminum sulfate. J. Environ. Qual. 29:37-49.

A liquid alum delivery system for high-rise laying hen houses: High-rise laying hen houses have the highest level of ammonia of all animal-rearing facilities. Due to logistical constraints, it is not possible to use dry alum in the facilities as is done in broiler houses. A system was constructed at a commercial hen house utilizing liquid alum pumped through PVC lines to 130 nozzles attached to the floor of the second story of the high-rise house (under the hens). Alum applications can be made manually, on a timed basis, or applied automatically when ammonia levels are too high. The system has four main components; a tank which holds the liquid alum, a

spraying system consisting of PVC pipes and nozzles, an ammonia sensor and a microprocessor to control the system. Data on ammonia levels, egg production, egg quality and manure chemistry were collected after the system was made operational. The system was turned on for a month and off for a month over an 8-month period. When the system was on, egg production was 3.3% higher (35,722 vs 34,574 doz/wk). Feed conversion was also much better when the system was on (2.94 vs 3.02). The system used about $110 worth of alum per week, however, increased hen performance was valued at $536/week; resulting in a net return of $426/week. Manure also was collected from the houses in areas which had been treated with alum and in untreated areas. This manure was used for a small-plot study to evaluate the effects on phosphorus runoff using rainfall simulators to generate runoff. Phosphorus runoff was 40% lower with the alum-treated manure than normal manure. Therefore, this system appears to be a cost-effective method of controlling ammonia emissions from hen houses and phosphorus runoff from pastures fertilized with hen manure.

Impact: This patented system reduced ammonia levels from over 90 ppm to less than 10 ppm for just a few dollars a day. The alum scrubs the ammonia out of the air rather than preventing it from volatilizing. This is the most cost-effective way to control atmospheric ammonia levels. The system improved worker safety in this environment while improving egg production. This system has not yet been as widely adopted as has treatment of broiler litter with alum. However, it does provide egg producers with a cost-effective means of improving egg production while making the work place safer.

Selected Publications:

Wilson, M.G., P.A. Moore, Jr., T.C. Daniel and D.R. Edwards. 2000. Effects of applying alum to hen manure in a high rise layer operation on ammonia volatilization and phosphorus runoff. Proceedings of 2000 Southeastern Commercial Egg Producers Forum. pp. 57-63.

Wilson, M.G. 2000. Technologies for ammonia control. pp. 241-248 *In* (J.P. Blake and P.H. Patterson, eds.) Proceedings of the 2000 National Poultry Waste Management Symposium

Alum or phosphoric acid addition to composts to reduce ammonia emissions and phosphorus availability in runoff: Ammonia volatilization and phosphorus runoff are two of the biggest problems associated with composting animal manures. Various means of application of chemicals (mixing or applying over the top of the windrow), as well as rates of chemicals (5 and 10% for alum; 1 and 2% for phosphoric acid) were evaluated over a two-year period. Both alum and phosphoric acid reduced litter pH, which, in turn, reduced the amount of ammonia evolved. Phosphorus runoff studies were conducted with the compost. This research indicated that alum greatly reduced phosphorus runoff. Although poultry growers throughout the country are using alum to treat the poultry litter inside the poultry houses (where it has positive benefits on bird growth), adding chemical amendments to litter during composting has not yet become a standard practice.

Pelleting poultry litter: Pelleting of poultry litter facilitates transport, but this approach may also incur some environmental risks. Phosphorus solubility was changed with pelleting. Pelleted

poultry litters had the greatest soluble phosphorus content of all poultry litters analyzed and some of the highest phosphorus concentrations in runoff water. Thus, it is clear that the unexpected effect of pelleting poultry litter on phosphorus solubility must be included in decisions to fertilize with pelletized poultry litter.

Impact: Composting with alum or phosphoric acid treatments provide a means to reduce atmospheric nitrogen loading and non-point source phosphorus runoff to rivers and lakes. However, the economic benefits are not as great as when alum is applied in poultry houses where it affects bird performance. Pelleting poultry litter increased phosphorus availability. This finding needs to be considered when the material is land applied.

Selected Publications:

DeLaune, P.B., P.A. Moore, Jr., T.C. Daniel and J.L. Lemunyon. 2004. Effect of chemical and microbial amendments on ammonia emissions from composted poultry litter. J. Environ. Qual. (in press).

Aluminum chloride to reduce phosphorus solubility in swine manure and reduce phosphorus runoff: Much of phosphorus in runoff water from pastures fertilized with swine manure is soluble. Previous research showed that additions of aluminum sulfate (alum) to swine manure could reduce soluble phosphorus levels in the manure and reduce phosphorus runoff. Unfortunately, when alum is applied to liquid manures some of the sulfate may be used by bacteria for respiration, resulting in the formation of hydrogen sulfide, which would add to the odor and air quality problems. Aluminum chloride addition to liquid manures such as those in swine lagoons does not exacerbate air emissions and like alum can reduce phosphorus solubility and reduce runoff phosphorus**.** Aluminum chloride inhibits ammonia emissions as well.

Impact: This technology has been patented and licensed to General Chemical Corporation. If adapted by the industry, this practice would greatly reduce both phosphorus runoff and ammonia emissions from swine manure.

Selected Publications:

Smith, D.R., P.A. Moore, Jr**.**, B.E. Haggard, C.V. Maxwell, T.C. Daniel, K. Vandevander and M.E. Davis. 2004. Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure. J. Anim. Sci. 82:605-611.

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. (in-press).

Nutrients Component

Problem Area 3: Methods need to be developed to determine nutrient concentrations and nutrient availability in manure, byproducts, and soil treated with manure or byproducts.

Background: One of the most desirable uses of manure is application to agricultural land for crop production. Quick, accurate analytical methods are needed to provide producers and their advisors reliable estimates of bioavailable nutrient concentrations in manure, soil and soil treated with manure. A greater understanding of nutrient transformations and reactions in manure and soil will be required to develop these methods. These analytical tools will allow manure application rates to be targeted to crop needs and will allow proper nutrient credits for manure. In addition, methods are needed to predict the likelihood of movement of manure nutrients to surface water, ground water and air.

Accomplishments:

Rapid tests for manure ammonium N and organic-N: Nitrogen composition of manure is variable and a rapid test for ammonium-N and organic-N is needed to calibrate accurate manure fertilization rates based on nutrient content. A set of 107 dairy manures were tested for ammonium-N and total N using conductivity tests based on the chemical reaction between chlorine bleach and ammonium, and colorimetric test-strips with a portable strip reader. All procedures estimated ammonium-N with an accuracy of approximately 90%, but none of the methods accurately determined organic N. Rapid tests are useful for managing ammonium-N driven processes, such as ammonia volatilization, but ineffectual for managing organic-N driven processes, such as mineralization. ARS scientists then assessed the ability of near-infrared diffuse reflectance spectroscopy to determine ammonium-N and organic-N in dairy and poultry manures. Using either a fiber-optic probe or sample scanning, they found that wavelengths from 400 to 2400 nm allowed determination of both ammonium-N and organic-N with an accuracy of 90% or greater.

Impact: These results show that near-infrared spectroscopy has the potential to be used for rapid on-site determination of dairy or poultry manure ammonium-N and organic-N without the need for a slow chemical analysis. The consequence of these investigations has been a contract for the construction of a portable, filter-based, battery-operated near-infrared meter for the direct, on-site determination of ammonium-N and organic-N in dairy manures. This instrument will undergo field-testing in the spring of 2004. Producers and their advisors will be able to obtain rapid analysis of manure samples.

Selected Publications:

Van Kessel, J. S. and J. B. Reeves, III. 2002. On-farm quick tests for estimating nitrogen in dairy manure. J. Dairy Sci., 83:1837-1844.

Reeves, III, J. B. and J. S. Van Kessel. 2002. Near-infrared spectroscopic determination of carbon, total nitrogen, and ammonium-N in dairy manures. J. Dairy Sci., 83:1829-1836.

Development and application of dairy manure ^{15}N labeling techniques: Direct, accurate measurements of nitrogen fate are needed to improve manure management systems. Two techniques developed by ARS scientists to differentially label dairy manure with the stable isotope ^{15}N were the forage method where ^{15}N-enriched forage was fed to dairy cows and the urea method where ^{15}N-enriched urea was fed to the animals. The forage method labels urine and both fecal endogenous (mostly microbial) and undigested feed N components and the second method, the urea method, labels only urine and fecal endogenous N. ARS scientists showed that long-term manure N cycling studies greater than two years required manure enriched using the forage method, while shorter-term studies could use manure enriched using the less costly and less laborious urea method. A three year study of dairy manure application to corn showed 18% of manure ^{15}N was in the corn, 46% was in the soil and 36% was presumed to be loss as NH_3.

Impact: The ^{15}N labeling technique is a valuable research tool that can greatly improve the precision of determining dairy manure N cycling in soils and availability to crops. Field trial results using ^{15}N-labeled manure may reduce the risk associated with N crediting and improve manure management.

Selected Publications:

Powell, J.M., Z. Wu, K.A. Kelling, P. Cusick, and G. Muñoz. 2004. Differential ^{15}N labeling of dairy manure components for nitrogen cycling studies. Agron. J., (in press).

Muñoz, G.R., J.M. Powell and K.A. Kelling. 2003. Nitrogen budget and soil N dynamics after multiple dairy manure or fertilizer applications using unlabeled or ^{15}N-enriched dairy manure. Soil Sci. Soc. Am. J., 67:817-825.

Muñoz, G.R., K.A. Kelling, J.M. Powell, and P.E. Speth. 2004. Comparison of estimates of first-year dairy manure N availability or recovery using ^{15}N and other techniques. J. Environ. Qual. (in press).

Predicting manure nitrogen availability: Research with beef, dairy, swine, and poultry manures showed that temperature-related changes in manure nitrogen (N) availability can be accounted for by accumulating soil temperature over time (degree days). Combining the results of several experiments using different manures, soils, and temperature regimes, where soil N concentrations were measured over time, the consumption of ammonium N and the accumulation of nitrate N were closely tied to the accumulation of degree days. This implies that the impact of fluctuating temperatures can be predicted under field conditions using degree days, thereby providing an approach for synchronizing nutrient availability with crop nutrient demand.

A team of ARS scientists is conducting nationally coordinated research to develop predictions of manure nitrogen (N) availability. The same experimental design and research protocols were developed and used by participating scientists in Maine, Wisconsin, Nebraska, Oregon, Mississippi, Alabama, and Georgia. Laboratory incubations were conducted at each location with a minimum of 3 soils, 3 temperatures, 2 wetting/drying regimes, and 2 manure treatments.

A soil from the central U.S. was used by each scientist to allow comparisons across laboratories. Research conducted at each laboratory will be combined to develop tools to predict N availability across a wide range of soils, manures, and environments. Protocols were also developed and followed for monitoring manure N under field conditions at each location. This data will be used to compare laboratory predictions with field observations of N availability in each soil, climatic zone, and manure type.

Impact: This research will result in the development of tools that will allow producers and their advisors to make manure applications that will maximize the benefits of manure nutrients while minimizing water quality contamination.

Selected Publications:

Griffin, T.S**.**, C.W. Honeycutt, and Z. He. 2002. Effects of temperature, soil water status, and soil type on swine slurry nitrogen transformations. Biology and Fertility of Soils 36:442-446.

Griffin. T.S., and C.W. Honeycutt. 2000. Predicting nitrogen availability from livestock manures using growing degree days. Soil Science Society of America Journal 64: 1876-1882.

Mapping soil nitrogen with electromagnetic induction: Non-intrusive and rapid electromagnetic induction (EMI) methods were used to map nitrogen buildup at sites where application or processing of manure had occurred. The technique was verified at an abandoned compost site using known compost row locations and an intensive soil core sampling program. The technique differentiated ($P<0.05$) the center of the compost rows and the region between the rows for NO_3-N, Cl, and electrical conductivity (EC) to a depth of 1.5m. When coupled with GPS, the technique allowed location of abandoned compost sites and monitoring sites in a runoff control area. The technique also allows field mapping of nitrogen concentrations over space and time.

Impact: The technique provided a rapid assessment of nutrient concentrations and variability across a field. Maps generated by this technology are useful in precision farming applications. The maps could be used by producers to enhance N-use efficiency and to minimize N losses to the environment.

Selected Publications:

Eigenberg, R.A., R.L. Korthals and J. A. Nienaber. 1998. Geophysical electromagnetic survey methods applied to agricultural waste sites. J. Environ.Qual. 27:215-219.

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

Eigenberg, R.A., J. W. Doran, J.A. Nienaber, R.B. Ferguson and B.L. Woodbury. 2001. Electrical conductivity monitoring of soil condition and available N with animal manure and a cover crop. Agriculture, Ecosystems and Environment 1834:1-11.

Real-time measurement of phosphorus in manure: ARS scientists evaluated three instruments (commercial hand-held reflectometer, hydrometer, and an electrical conductivity meter) for determining dissolved and/or total P in 107 dairy manures collected in five NE States. The RQFlex (reflectometer) method is a viable option for on-site quick estimates of dissolved P that can be made more robust when complemented with pH measurements. The RQFlex measurements are correlated to laboratory measurements of dissolved P ($r^2 = 0.65$) for 95% of the samples.

Impact: These quick tools can be incorporated into a real-time P sensing system that enhances timely nutrient management decisions on the farm, allowing the producer more frequent determination of manure nutrient content with hand-held meters. This real-time tool enhances the utilization of liquid manures for producing optimal crop responses while minimizing soil P buildup.

Selected Publications:

Reeves, III, J. B. and J.S. Van Kessel, J. S. 2002. Spectroscopic analysis of dried dairy manures. Near- versus mid-infrared diffuse reflectance spectroscopy for the analysis of dried dairy manures. J. Near-Infrared Spectroscopy 10:93-101.

Lugo-Ospina, T.H. Dao, J.S. Van Kessel and J.B. Reeves III. 2004. Evaluation of quick tests for phosphorus determination in dairy manures. Environ. Pollution (in press).

Bioavailable organic phosphorus in manure: ARS scientists demonstrated that a large fraction of manure bioavailable organic phosphorus, phytate, is native to monogastric and ruminant livestock manure. Research established that phytate-P is present and that exogenous phytases increased water-soluble phosphorus in over 100 dairy and poultry manure samples from the Northeast US. Organic phytate is protected from enzymatic breakdown by polyvalent cations without a negative feedback on organic P mineralization because of the many biogeochemical sinks for the released orthophosphate in manure and soil. The differential protective effects of cations found in mineral dietary supplements increased phytate resistance to enzymatic dephosphorylation (from 40 up to 99% depending on cation to P molar ratios) that promotes its excretion in manure. Researchers developed an enzymatic fractionation method to determine bioavailable P or a phytase-hydrolyzable P (PHP) fraction in animal manure. Experimentation showed that bioavailability and potential ecological impact of phytate-P were regulated by pH-controlled enzyme activity and by the type and content of counterions associated with phytate. The enzymatic process, in effect, increases inorganic P and the risk of loss to the environment. Phosphorus immobilization strategies and remedial methods for sequestering excess inorganic dietary P should include conditions that favor the inhibition of dephosphorylation of organic P.

Impact: The research suggests that both reduction of mineral P supplementation and control of dietary phytase enzymes need to be considered when the target is reduction of water soluble P.

Selected Publications:

Dao, T.H. Polyvalent cation effects on myo-inositol hexakis dihydrogenphosphate enzymatic dephosphorylation in dairy wastewater. 2003. J. Environ. Qual. 32:694-701.

Dao, T.H. Organic ligand effects on the enzymatic dephosphorylation of myo-inositol hexakis dihydrogenphosphate in dairy wastewater. 2004. J. Environ. Qual. 33:349-358.

Predicting organic phosphorus mobilization and availability from manure: ARS researchers advanced the use of the log-normal probability density function to describe mineralizable C and N, and P release fluxes in manure and manure-amended soils and predicted flux densities based on knowledge of three parameters, $flux_{max}$, time to half-$flux_{max}$ and distribution width. This data description and modeling approach yields mineralization parameters in 14 to 20 days instead of the usual 12-months. The results of the log-normal method are in agreement with long-term incubation-leaching data ($P<0.001$). The use of log-normal distributions to describe nutrient release fluxes shortens laborious incubations and may increase the feasibility of routine/frequent measurements of labile nutrient pools and mineralization potential for the major manure constituents.

Impact: Use of the log-normal predictive model has been transferred to the NRCS-Soil Survey Staff, Lincoln, NE to be used in the assessment of mineralizable nutrients in US benchmark soils.

Selected Publications:

Dao, T.H, and M. Cavigelli. 2003. Mineralizable carbon, nitrogen, and water-extractable phosphorus release from stockpiled and composted manure, and manure-amended soils. Agron. J. 95:405-413.

Zhang, H., T.H. Dao, T.H., N.T. Basta, E.A. Dayton and T.C. Daniel. 2002. Remediation techniques for manure nutrient loaded soils. 32 p. National Center for Manure and Animal Waste Management, Raleigh, NC. White Papers on Animal Agriculture and the Environment. Chapter 13. Midwest Service Plan CD-ROM.
http://www.cals.ncsu.edu/waste_mgt/natlcenter/summary.htm.

Methods to determine water soluble phosphorus in manure and soil: Phosphorus runoff from land fertilized with animal manures is one of the biggest problems facing the animal industry. However, methods are lacking for the analysis of manure to determine the availability of phosphorus for runoff. ARS scientists developed and published a method for measuring water soluble phosphorus in manure. Subsequent research around the country has shown that phosphorus runoff from pastures is more closely correlated to water soluble phosphorus in the manure than any other variable. ARS scientists also have developed and published a method for measuring water soluble phosphorus levels in soil. This method, which utilizes a 1:10 extraction ratio (soil:water), extracts the soluble phosphorus which is more likely to be in runoff.

Impact: This research has greatly benefited other scientists, and agencies, such as the USDA/NRCS and EPA that are responsible for developing strategies for manure management to protect water quality. The method to measure water soluble phosphorus in manure is used to determine manure application rates as part of Arkansas' Phosphorus Index. A Federal Judge has ruled that this method must be used when writing nutrient management plans for farms in a critical watershed in Oklahoma. The soil test method, which was published in the SERA-17 phosphorus methods book, provides a standardized technique for measuring water soluble P in soils.

Selected Publications:

Self-Davis, M.L., P.A. Moore, Jr., and B.C. Joern. 2000. Determination of water and/or dilute salt extractable phosphorus in soil. In:Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters. Southern Cooperative Series Bulletin No. 396:24-26.

Nutrients Component

Problem Area 4: Management practices and decision tools are needed to integrate effective manure use into soil-crop-climate-livestock systems.

Background: Animal manures, applied in solid, semisolid and liquid forms contain essential nutrients that can meet crop requirements if applied to land in the proper manner at the right time and in suitable amounts. Manure generated annually in the US contains about 8.3 million tons of nitrogen (N) and 2.5 million tons of phosphorus (P) and many other nutrients such as potassium, sulfur, copper, calcium and magnesium. Manure also can improve soil quality by increasing soil organic matter reserves, resulting in improved water-holding capacity, increased water infiltration rates and improved structural stability. Manure can decrease the energy needed for tillage, reduce impedance to seedling emergence and root penetration, stimulate growth of beneficial soil microbial populations and increase beneficial mesofauna such as earthworms. The objectives of the research is to develop best management practices for manure application rate, placement, and timing to synchronize manure nutrient availability with crop nutrient demand.

Accomplishments:

Site-specific application of manure can augment its benefits to productivity: Site-specific manure application can be used to improve less productive sites within fields by increasing their nutrient and organic matter contents. In a five-year period in Nebraska, corn grain yield was 10.5 Mg ha^{-1} for site-specific beef cattle feedlot manure fertilization, 10.0 Mg ha^{-1} for uniform manure fertilization, 10.2 Mg ha^{-1} for synthetic fertilizer (NH_3), and 7.2 Mg ha^{-1} for the untreated check in irrigated fields. The grain yield increase due to site-specific manure application as compared with synthetic fertilizer was 300 kg ha^{-1} yr^{-1} (4.8 bu ac^{-1} yr^{-1}). In the rainfed fields, site-specific cattle or swine manure fertilization resulted in 400 kg ha^{-1} (6.4 bu ac^{-1} yr^{-1}) greater corn yield than uniform broadcast fertilizer (NH_3 and UAN). Spatial distribution of soil organic matter and P concentrations became more uniform following site-specific manure application as determined by geostatistics parameters. Emissions of greenhouse gasses (N_2O, CH_4, and CO_2) from soil were measured following manure and fertilizer applications. Significantly greater N_2O was emitted from soil receiving synthetic fertilizer (NH_3) than cattle feedlot manure.

Impact: Site-specific manure application enhances yields and improves soil properties. These results should encourage manure use by producers and their advisors.

Selected publications:

Eghball, B., C.J. Bauer, J.S. Schepers and C.A. Shapiro. 2001. Site-specific manure application effects on corn yield and nitrogen status. pp. 39-49. In Proceedings of North Central Extension-Industry Soil Fertility Conference (vol. 17), Nov. 14-15, Des Moines, IA, Potash and Phosphate Institute, Brookings, SD.

Eghball, B., D. Ginting, C.A. Shapiro, J.S. Schepers and C.J. Bauer. 2002. Manure as carbon source for soil improvement and crop production: Site-specific application. In A.J. Schlegel (ed.) Proceedings of the Great Plains Soil Fertility Conference 9:22-28.

Manure is a good source of lime: Soil pH can be increased by manure or compost application because feed rations for all animal species usually contain calcium carbonate. A study was conducted to evaluate the effects of phosphorus and nitrogen-based manure and compost application strategies on soil pH level. Composted and non-composted beef cattle feedlot manure was applied to supply N or P needs of corn for either a one- or two-year period. Manure and composted manure contained about 9 g $CaCO_3$ kg^{-1}, resulting in application rates of up to 1730 kg $CaCO_3$ ha^{-1} in 4 years. The surface soil (0-150 mm) pH was significantly decreased with ammonium nitrate application compared to soil in the unfertilized check or to soil receiving manure or compost. Soil pH was significantly increased with the N-based management strategy compared to initial soil pH. In contrast, 4 years of P-based manure and compost application did not increase soil pH because of the lower manure application rates.

Impact: These results point out additional benefits associated with manure application that should be of interest to producers with surface soil acidity problems.

Selected publications:

Eghball, B. 1999. Liming effects of beef cattle feedlot manure or compost. Commun. Soil Sci. Plant Anal. 30: 2563-2570.

Most crops, but not peanuts, in the SE benefit from poultry litter application: A four-year field study demonstrated that broiler litter fertilization at the recommended rate of 4.5 Mg ha^{-1} increased yields of cotton, pearl millet, wheat, and canola but decreased yield of peanut. Litter applications had little effect on soil nematodes, but *Rhizoctonia* limb rot (*Rhizoctonia solani* AG-4) of peanut increased. Lodging of canola, due to *Sclerotinia* spp., was doubled by application of broiler litter. Surface soil P, K, Cu, Zn, and Mn increased proportional to litter fertilization rate. Average crop value increase from application of a megagram of broiler litter was estimated to be \$42 ha^{-1} yr^{-1} when application was made to all crops and \$68 ha^{-1} yr^{-1} when none was applied to peanut. The mean cost of applied litter was approximately \$12 Mg^{-1}.

Impact: Poultry litter is a beneficial soil amendment and fertilizer for most crops in the Southeastern US. However, it apparently should not be added to peanuts. This is valuable information for developing best management practice recommendations.

Selected publications:

Gascho, G.J., R.K. Hubbard, T.B. Brenneman, A.W. Johnson, D. Sumner and G.H. Harris. 2001. Effects of broiler litter in an irrigated, double-cropped, conservation-tilled rotation. Agron. J. 93:1315-1320.

Manure management for cotton: Cotton is relatively heavily fertilized with N and is the most dominant crop in some states that also produce the majority of US poultry. Yet, little cotton is

fertilized with poultry litter. Farmers do not have well-established guidelines for poultry litter use for cotton production under different soil types, management practices, tillage and cropping systems. Cotton grown with broiler litter as the single source of nutrients had plant concentrations of N, P, K, Ca, Mg, Fe, Mn, and Cu within published sufficiency ranges. Zinc is the only nutrient that was insufficient for cotton. The fertilizer value of litter was determined in comparison to rates of conventional fertilization. In North Mississippi, 4.5 Mg ha^{-1} broiler litter was as productive as 90 kg ha^{-1} N in the form of ammonium nitrate, 90 kg ha^{-1} P_2O_5, and 135 kg ha^{-1} K_2O. However, at three on-farm sites fertilizing cotton with a combination of 4.5 Mg ha^{-1} broiler litter and 6.7 kg N ha^{-1} produced the highest cotton yields.

Impact: Poultry litter can be used beneficially in cotton production. Guidelines for poultry litter use in cotton can begin to be developed.

Selected publications:

Sistani, K.R., D.E. Rowe, J. Johnson and H. Tewolde. 2004. Supplemental nitrogen effect on broiler litter-fertilized cotton. Agron. J. (in press).

Tewolde, H**.**, K.R. Sistani and D. E. Rowe. 2004. Broiler litter as the sole nutrient source for cotton: N, P, K, CA, and Mg concentration in different plant parts. J. Plant Nutrition. (in press).

Forage varieties, species and their management all effect nutrient utilization from fields receiving manure applications: Best agronomic practices are needed for appropriate use of manure in forage management systems. In the South**,** bermudagrass was the best of six adapted, warm-season perennial grasses (common bermudagrass, Coastal bemudagrass, johnsongrass, eastern gamagrass, switchgrass, and indiangrass) for nutrient utilization (N, P and K) from fields regularly fertilized with swine effluent for eight years. Uptake ratios of N:P ranged from 4.7 to 9.3. Uptake of Ca, K, Mg, Cu, Fe, Mn, and Zn were as high or higher in common bermudagrass than the other grasses. Soil type had a large effect on nutrient removal rates. There was more than a doubling of the P removed with only modest differences in yields across different soils. Variability was largely a result of substantial moisture stress even with swine lagoon fertilization. In this context the performance of bermudagrasses exceeded that of the other four grasses 83% of the time in DM yield, 28% of the time in nutrient concentration, and 76% of the time in nutrient uptake. Systems that included Bermuda grass had high economic returns and high uptake of N and P.

A best management practice in the South is to plant a winter cover crop, usually annual ryegrass, for control of surface erosion. Ryegrass is harvested in the spring to increase the annual P removal rate by up to 25% over that of harvesting only the summer forage. A study was conducted to determine the effects of different cover crops on nutrient removal. Overseeding treatments included berseem clover, crimson clover, ryegrass, wheat, and a non-overseeded control. Changing from a single harvest of annual ryegrass to two harvests of berseem or red clover increased P, Zn, and Cu removal by 24, 40, and 72%, respectively. Residual effects of the winter legume crop increased bermudagrass production through the summer. This discovery gives producers in the southeastern US additional options for year-round nutrient management.

A single poultry litter application in late spring after the bermudagrass has broken dormancy was shown to be as effective as, the often recommended, split application. Obviously, the single application is more economical for the farmer. In a field where soil P was very high, the litter application date affected the amount of N, K, and Cu harvested in the hay, but P removed was constant.

Annual forages rather than perennials are used by some farmers in the South and may have advantages in quick establishment and erosion protection of disturbed fields. Of five warm-season annual grasses studied, brown top millet, pearl millet, sudangrass, sorghum-sudan, and crabgrass, grown in a swine effluent spray field, only sorghum-sudan and pearl millet had N and P uptake similar to common bermudagrass. Browntop millet and crabgrass dry matter yields and P uptake were less than half those of sorghum-sudan. This study identified annual forage grasses that can be used as alternatives to bermudagrass in summer hay production systems to manage nutrients in fields receiving manure.

Impact: Species and variety selection and timing decisions can by altered with little disruption to current practices, yet they can significantly influence nutrient removal from fields receiving manure and wastewater treatment. This research provides information for the development of nutrient management plans, and gives the farmer alternatives with known effectiveness for personalizing his farm management plan.

Selected publications:

Brink, G.E., D.E. Rowe, K.R. Sistani and A. Adeli. 2003. Bermudagrass cultivar response to swine effluent application. Agron. J. 95:597-601.

McLaughlin, M.R., T.E. Fairbrother and D.E. Rowe. 2004. Nutrient uptake by warm-season perennial grasses in a swine effluent spray field. Agron. J. 96:484-493.

Rowe, D.E. and T.E. Fairbrother. 2003. Harvesting winter forages to extract manure soil nutrients. Agron. J. 95:1209-1212.

Management of composted manure in irrigated crops: Animal feeding operations continue to move into areas, such as southern Idaho, where irrigation is used for crop production. Information is needed on how to use composted and non-composed manures in irrigated cropping systems on calcareous soils. ARS research showed that 2.5 T/A of dairy compost reduced the average N fertilizer requirement 100 lbs/A for potato, sugarbeet and malt barley production on irrigated calcareous soils. Surface runoff from soils receiving non-composed manure contained 2- to 4-fold more reactive P than from soils receiving compost for two consecutive growing seasons. Surface runoff from soils receiving manure had 2- to 4-fold higher ammonium-N and nitrate-N concentrations than non-manured soils receiving equivalent commercial nitrogen fertilizer. Delaying surface irrigation until spring after a fall manure application reduced runoff nitrogen losses 90% to 95%. Polyacrylamide (PAM), PAM+alum,

and PAM+hydrated lime applied to soil reduced soluble nutrients transported in surface runoff 10-fold, and eliminated leaching losses of ammonium-N, and soluble and total P.

Impact: This information directly impacted a growing composting industry by providing beneficial application guidelines for compost to important agronomic crops. It also illustrates the importance of preventing surface runoff following manure applications. The PAM studies show that soil incorporation of selected materials around feedlots or dairies can help reduce nutrient losses in runoff and leaching. This information is being used by the compost industry, animal feeding operations, dairies, producers, farmers, land-use planners, private crop and environmental consultants, NRCS, regulatory agencies, state agencies, and university personnel.

Selected Publications:

Entry, J.A. 2001. Soil microorganisms to assess the impact of pollution on health and productivity of wetland ecosystems. In: K. Reddy (ed.). 7th International Conference on Wetland Systems for Pollution Control. November 11-16, 2000. Buena Vista, FL. pp 1-8.

Entry, J.A. and R.E. Sojka. 1999. Polyacrylamide application to soil reduces movement of microorganisms in water. 1999 Irrigation Association Technical Conference Proceedings. Irrigation Association Press, Orlando, FL. pp 93-99.

Entry, J.A. and R.E. Sojka. 2003. The efficacy of polyacrylamide to reduce nutrient movement from an irrigated field. Transactions of the American Society of Agricultural Engineers. 46:75-83.

Beef cattle feedlot nutrient management model: ARS scientists are currently working with other engineers and animal scientists to replace the current manure production ASAE standards with computer model estimates for cattle feedlots. The nutrient fate model generates estimates of manure constituent totals based on fractional data contained in the Agricultural Waste Management Handbook. A beef animal production component is being added to the model. Nitrogen and phosphorus in solids and in liquid runoff during the four seasons of the year are also being built-in. These improvements are incorporated into the current nutrient fate model to generate estimates of manure production based on seasonal dietary and feedlot characteristics. The model now has user input screens that allow straightforward operation and customization. Model output shows the outcomes of various management decisions. The model is packaged as a run-time program and has been distributed to researchers, consultants and producers.

Impact: This tool demonstrated value in planning, operation, and research related to cattle feedlots. The tool is useful in predicting feedlot waste generation in both the solid and liquid phase, thus allowing environmental impacts to be considered at early steps in planning and designing such installations. The model also has value to the producer in developing a nutrient management plan, providing current estimates of nutrient production and the projected volume of waste to be managed. Also, the model has guided research into high priority areas where data is currently unavailable.

Selected publication:

Eigenberg, R.A., R.L. Korthals, J.A. Nienaber and G.L. Hahn. 1998. Implementation of a mass balance approach to predicting nutrient fate of manure from beef cattle feedlots. App. Engn. Ag. 14:475-484.

Dairy farm decision support systems and models available on the Internet: Software was developed to address a range of nutrient management decisions on dairy farms, including optimizing dairy herd and feed management, manure and fertilizer management, and assisting land use planners in dairy herd expansion. ARS scientists in cooperation with Cornell University and University of Wisconsin developed a six-part video seminar series to: (1) present and review the science and methodology supporting the major nutrient management tools being used in New York, Wisconsin and elsewhere; (2) exchange information and share ideas for tool improvement and expansion; (3) identify gaps in knowledge about nutrient management planning and identify future research and extension needs; and (4) provide content for a published proceedings that will systematically catalog tool criteria, providing a reference for consultants, researchers, educators, policy makers and other professionals that assist dairy farmers in nutrient management issues. The video series at Cornell University and University of Wisconsin covered eight nutrient management tools: DAFOSYM, PALMS, CROPWARE, N-cycle, Modified Yardstick, SNAP, WI P-Index, and CNCPS. Presentations by tool developers provided an overview of the scale and focus, application, knowledge and data transferability, outputs, and limitations.

Impact: The ability to obtain, learn about their properties, test and compare decision support tools and models from single web sites will enhance their utility and usability. This will benefit research, technology transfer, policy development and management.

Selected publication:

Presentations from this series can be downloaded at http://www.dfrc.ars.usda.gov/powell/

Nutrients Component

Problem Area 5: Methods to predict areas vulnerable to P losses and practices to reduce or eliminate these losses are needed.

Background: Effective management of N and P from manure and fertilizer is essential to protect ground and surface water quality. In the past, manure application rates were based on crop N requirements to minimize nitrate leaching to groundwater. The mean N:P ratio (4:1) in manure is generally lower than the mean N:P ratio (8:1) taken up by major grain and hay crops. Therefore if manure application based on N has occurred for many years, rapid buildup of P levels in soil create the potential for P losses to surface waters through runoff. The preferred approach to preventing P loss is to define, target and remediate source areas of P that combine high soil P levels, application of manure or fertilizer, high surface runoff and erosion potentials, and proximity to P-sensitive bodies of water. Research is needed to determine the relationship between P in soil and manure and movement of soluble P to water, assess the effect of manure and land management on P losses, delineate major hydrologic transport pathways in various landscapes, develop predictive tools to identify areas in a landscape susceptible to P losses, and develop comprehensive nutrient management practices at a farm and watershed scale.

Accomplishments:

Phosphorus Index: The scientific underpinnings of the P Index are 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 it to surface water. Thus, effective environmental management of P losses requires methods to acquire information on where these two factors overlap, and an in-depth understanding of how these factors interact to determine the potential for P loss.

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 P Index accounts for and ranks P source (soil, fertilizer, and manure P management) and transport factors (erosion, surface runoff, leaching, and distance of a field from stream) controlling P loss in overland and subsurface flow, and identifies sites where the risk of P movement is expected to be high.

ARS researchers developed the first universal test for water extractable P in fertilizers, manures and biosolids, which is now used by several State Analytical Laboratories to provide information for P Indices to account for the effect of different applied P source on P loss potential in runoff. Also, researchers conducted independent testing of the P Index to develop Comprehensive Nutrient Management Plans (CNMPs) for ten farms in Pennsylvania. They showed that while it was more expensive to write plans using the Index than the other options available, writers and farmers found the P Index the most flexible and practical strategy. Most importantly, the P Index targeted small but well-defined critical areas of P loss for change or conservation, thereby impacting overall farm operation to a lesser degree than more restrictive agronomic and

environmental soil threshold options. In all cases, farm economics were least negatively affected by CNMPs written with the P Index compared with soil P threshold options.

Impact: As a part of the USDA-USEPA initiative to implement CNMPs on all Concentrated Animal Feeding Operations (CAFOs), NRCS was charged with implementing a new nutrient management policy and standard that maximizes agronomic benefits while minimizing the environmental impact from applied nutrients, especially P. Every state had to select at least one of the following P-based approaches in revising their state Practice Standard: an agronomic P threshold, environmental P threshold, or a P Index.

The P Index has been officially adopted by NRCS nationally (47 states in the U.S.) for field staff to identify sensitive areas and target management alternatives and remedial measures to reduce the risk of P loss from farms. In addition, several other countries (i.e., Brazil, Denmark, Finland, Ireland, New Zealand, Norway, Sweden, and United Kingdom) have adopted this technology. The fact that the P Indexing approach has been so widely accepted and that there are many modifications and versions of P Indices in use, demonstrates the robustness and flexibility of this tool.

ARS researchers, in collaboration with NRCS, extension specialists, and farm consultants have developed a training curriculum for the use of the P Index in writing nutrient management plans. Over 1000 field agents and nutrient management consultants across the U.S. have received training. Further, if the P Index hadn't been available and adopted by so many states, EPA could not have required CAFOs in the new rule to include practices to minimize runoff of P in their nutrient management plans.

The Index has assisted NRCS and state regulatory agencies in improving the cost-effectiveness of nutrient management programs by prioritizing watersheds on the basis of vulnerability and sensitivity to P contamination of water resources, and targeting specific parts of agricultural landscapes for cost-share remediation. Wide-spread adoption and use of the P Index is resulting in the first significant reduction in the threat to water quality from non-point sources of P.

The overall significance of implementing the P Index, is clearly seen in terms of its' impact on the CAFO industry. According to the USEPA, there are about 15,500 CAFOs in the U.S. today, which produce close to 60% of all manure generated by operations that confine animals. By better targeting resources to the largest operations and areas at greatest risk of water quality impairment, CNMP strategies that include the P Indexing approach, will likely cost the CAFO industry $355 million rather than $980 million per year, according to the USEPA. It is estimated that this approach will lead to a reduction of 56 million pound of P and over 2.1 billion pounds of sediment released from CAFOs to the environment. Economic benefits of using this approach are estimated at $204 to $355 million and include increased recreational use of waters, better shellfish harvest, fewer fish kills, lower drinking water treatment costs, and reduced loss of livestock to disease.

Selected publications:

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

Gburek, W.J., C.C. Drungil, M.S. Srinivasan, B.A. Needelman and D.E. Woodward. 2002. Variable-source-area controls on phosphorus transport: Bridging the gap between research and design. Journal of Soil and Water Conservation 57:534-543.

Heathwaite, A.L., A.N. Sharpley and M. Bechmann. 2003. Conceptual basis for a decision support framework to assess phosphorus loss at the field scale across Europe. J. Soil Plant Nutrition 166:1-12.

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

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

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

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.

State P Indices validated: Researchers evaluated the utility of P Indices adopted by three states (Texas, Arkansas, and Iowa) to predict absolute and relative annual P loss on fields when manure was newly applied in instrumented watersheds. P Indices were compared with measured P transported in surface runoff from tilled and pasture fields under fallow, unfertilized conditions and after poultry litter application at various agronomic rates. The P Indices performed relatively well in determining areas susceptible to excessive P loss and predicting annual P loss, with 49 to 87% of the variability explained with the three P Indices. The P Indices also proved valuable in relating Index values to annual average and maximum PO_4-P concentrations in runoff.

Impact: This research is relevant to many resource agencies at the state and national level that have adopted P Indices.

Selected Publications:

Harmel, R.D., K.W. King, J.E. Wolfe and H.A. Torbert. 2002. Minimum flow considerations for automated storm sampling on small watersheds. Texas Journal of Science. 54:177-188.

King, K.W., R.D. Harmel, H.A. Torbert and J.C. Balogh. 2001. Impact of a turfgrass system on nutrient loading to surface water. J. Am. Water Res. Assoc. 37:629-640.

Harmel, R.D., P.B. DeLaune, B.E. Haggard, K.W. King, C.W. Richardson, P.A. Moore, Jr. and H.A. Torbert. 2002. Initial evaluation of a phosphorus index on pasture and cropland watersheds in Texas. American Society for Agricultural Engineers. Paper No. 02-2075.

Phosphorus Index – SE pastures: The USDA/NRCS and USEPA requested that states develop nutrient management plans using a Phosphorus Index (PI). ARS, university and USDA-NRCS scientists developed decision tools for the Phosphorus Index for the State of Arkansas using rainfall simulations. Variables such as soil test phosphorus levels, poultry litter application rates, fertilizer timing, inorganic P fertilizer applications, soluble P in manure were evaluated. Water-soluble phosphorus content in manure was the most important factor determining P runoff from pastures and soil test phosphorus was an ineffective predictor of P runoff for surface applied manure. Validation studies were conducted on six poultry/beef farms located in Arkansas and Oklahoma. Results from these studies indicated that this index accurately predicted the risk of non-point source phosphorus runoff (slope between observed and predicted P runoff was 1.16). The results were incorporated into USDA-NRCS 590 in Arkansas and it is used for writing nutrient management plans in the state.

Impact: Arkansas, because of this research, requires all nutrient management plans for animal farms to be written with this index. It has also influenced other states to utilize water-soluble phosphorus in manure in their P Index.

Selected publications:

DeLaune, P.B., P.A. Moore, Jr., D.K. Carman, T.C. Daniel and A.N. Sharpley. 2001. Development and validation of a phosphorus index for pastures fertilized with animal manure. [CD-ROM] In Proceedings of International Symposium Addressing Animal Production and Environmental Issues. Oct. 3-5, Raleigh, NC.

DeLaune, P.B. and P.A. Moore, Jr. 2003. Predicting annual phosphorus losses from fields using the phosphorus index for pastures. Better Crops 85:16-19.

P Index in clay soils: ARS scientists used both instrumented watersheds and rainfall simulations to examine P Indices in heavy clay soils that included both cultivation and pasture. Three factors commonly utilized in soil P Indices for manure management are manure rate, manure incorporation, and soil slope. In this project rainfall simulations were conducted to examine the impact of these three factors on runoff losses of P. Increased losses of NH_4-N and PO_4-P were observed with increasing manure application rate in the cultivated soils. The losses of NH_4-N and PO_4-P were observed in both increased concentration and increased loads of these nutrients. However, no significant loss of NO_3-N was observed under the cultivated conditions. Incorporation of manure greatly reduced (> 60%) losses of NH_4-N and PO_4-P, but increased soil slope did not significantly impact the level of runoff losses of NH_4-N and PO_4-P. Losses of NH_4-N from manure application in pasture approximated those with cultivation. Losses of PO4-P

from pasture were between those of surface application and those for incorporation in the cultivated field. While NO_3-N losses in the cultivated field were not significant, large losses were noted for NO_3-N as the application rate was increased in the pasture. Incorporation of manure greatly decreases the potential for N and P losses in surface runoff.

Impact: Soil properties and management influence P and N in runoff. Site-specific modifications to account for these effects enhance the accuracy of the P Index.

Selected publications:

King, K.W., R.D. Harmel, H.A. Torbert and J.C. Balogh. 2001. Impact of a turfgrass system on nutrient loading to surface water. J. Am. Water Res. Assoc. 37: 629-640.

Torbert, H.A., R.D. Harmel, K.N. Potter and M. Dozier. 2004. Evaluation of management practices for turkey litter applied to clay soils. Journal of Soil and Water Conservation. (in press).

Tillage practices and phosphorus losses: Effectiveness of manure incorporation in reducing phosphorus losses is influenced by the length of time that has expired since the manure was incorporated. Rainfall simulation tests were conducted to evaluate the effects of tillage practices on nutrient transport. When tests were run soon after beef cattle manure or compost were applied to a cropland site, runoff concentrations of dissolved P (DP) and bioavailable P were significantly greater under a no-till compared to a disked condition. However, total (TP) and particulate P concentrations in runoff were less under no-till conditions. Excessive concentrations of DP and TP in runoff from sites with high soil test P levels near the surface can be reduced through plowing. After the plowing operation, DP and TP concentrations of runoff were found to be similar on each of the treatments including those with previous excessive soil test P levels near the soil surface. Plowing should only be used as a remediation strategy, however, when the potential for soil erosion is minimized and soil test P levels in the lower soil profile are minimal.

Impact: Guidelines for manure application will need to account for multiple variables and site conditions. P Indices and other tools should have flexibility to address these variables and site conditions. Producers and managers will similarly need to be flexible in their practices to meet production and environmental goals.

Selected publications:

Eghball, B. and J.E.Gilley. 1999. Phosphorus and nitrogen in runoff following beef cattle manure or compost application. Journal of Environmental Quality. 28:1201-1210.

Gilley, J.E, B. Eghball, B.J. Wienhold and P.S. Miller. 2001. Nutrients in runoff following the application of swine manure to interrill areas. Trans. of the ASAE. 44:1651-1659. 2001.

Phosphorus from wastewater treatment plants: Nonpoint source pollution from land application of manure is often considered to be the prime cause of elevated phosphorus concentrations in Ozark streams. ARS scientists initiated a water-quality monitoring program targeting urban and rural wastewater treatment plants to assess other sources of P input to streams. Regional wastewater treatment plants had a profound effect on stream sediment and water phosphorus concentrations; dissolved P concentrations in Ozark streams were as great as 10 mg/L downstream from two regional wastewater treatment plants. Elevated phosphorus concentrations in one Ozark stream were traced over 45 km upstream to one municipal wastewater treatment plant discharging into a headwater stream.

Impact: Since this monitoring program was established, several regional wastewater treatment plants have voluntarily agreed to phosphorus management strategies to reduce effluent phosphorus concentrations to less than 1 mg L^{-1}. All major sources of P must be addressed to achieve the desired water quality improvement.

Easy to implement practices can lower soil P. Nutrient management plans require that land-applied nutrients not exceed the nutrients harvested in hay or other commodities when phosphorus soil concentrations are high. Crops vary in their ability to remove soil P. Planting crops that maximize P removal is an inexpensive and relatively easy way to address high soil P while still maintaining productive use of the land. Plant species and varieties as well as management practices affect P. Bermudagrass was more effective than other grasses in P removal. Irrigation of bermudagrass during droughty periods increased yields by 30% with proportional increases in P extracted by the harvested hay. Supplemental nitrogen fertilization with and without irrigation, increased the concentration of N in the plant but did not increase the P extracted from the land or increase hay yield. In the 12-month growing season found in much of the South, a winter cover crop often is used to protect land from erosion. Harvesting the cover crop in the spring increased the annual quantity of P removed. A single spring harvest of annual ryegrass increased annual P removal by 33%. Changing the cover crop to a legume, berseem clover, and harvesting it twice in the spring removed 24% more P, 40 % more Cu, and 72 % more Zn than a single harvest of annual ryegrass.

Impact: Harvesting a winter cover crop, changing species or varieties and using readily utilizable management practices are reasonable and easy strategies for the farmer to implement and are effective means to significantly increase the amount of phosphorus removed from the land.

Selected publications:

Brink, G.E., D.E. Rowe, K.R. Sistani and A. Adeli. 2003. Bermudagrass cultivar responses to swine effluent applications. Agron J. 95:597-601.

McLaughlin, M.R., T.E. Fairbrother and D.E. Rowe. 2004. Nutrient uptake by warm-season perennial grasses in a swine effluent spray field. Agron. J. 96:484-493.

Rowe, D.E. and T.E. Fairbrother. 2003. Harvesting winter forages to extract manure soil nutrients. Agron. J. 95:1209-1212.

Phosphorus dynamics in western, irrigated calcareous soils: The P Index has been developed and utilized more extensively in the mid-western and eastern US than in the west. Phosphorus transport and losses from western agricultural fields also are major factors causing eutrophication of receiving waters. ARS scientists conducted research on phosphorus dynamics in western, irrigated calcareous soils. Particulate P from soil erosion is the major P source transported in runoff from irrigated fields. Soluble P concentrations in leachate below the crop's rooting zone exceeded 1-mg/L in 30% of the samples. Soil P availability, suspended sediment, contact time, ionic strength, and divalent ion composition of irrigation water are needed to predict soluble P concentrations in runoff. P source availability coefficients for a variety of manure types in soils were related to their organic carbon contents. Soil pH, organic C, Fe and Mn concentrations associated with the soil's organic C affected P sorption on western calcareous soils. Polyacrylamide (PAM) and sediment ponds used together achieved more than a 90% reduction in P losses in surface irrigation. Using low phytate grains in swine production reduced manure total P concentrations and potential impact on the environment.

Impact: This information provides methods for predicting P losses from western, irrigated agricultural fields and developing guidelines for allowable P loading rates from different sources based on measurable soil and waste characteristics. The information also can be used to develop comprehensive nutrient management plans for dairies and other animal feeding operations, and is starting to be used in P effluent trading activities in the western irrigated river basins. The Idaho NRCS used this information to develop their 590 Nutrient Management Standard. The Idaho OnePlan used this information to help develop an on-line computer program to aid nutrient management planning.

Selected Publications:

Aase, J.K., D.L. Bjorneberg, and D.T. Westermann. 2001. Phosphorus runoff from two water sources on a calcareous soil. J. Environ. Qual. 30:1315-1323.
Bjornberg, D.L., D.T. Westermann, and J.K. Aase. 2001. Phosphorus transport during furrow irrigation. ASAE Paper No. 012012. St. Joseph, MI 49085-9659.

Bjorneberg, D. L., J.K. Aase and D.T. Westermann. 2000. Controlling sprinkler irrigation runoff, erosion, and phosphorus loss with straw and polyacrylamide. Trans ASAE 43:1545-1551.

Bjorneberg, D.L., D.T. Westermann and J.K. Aase. 2002. Nutrient losses in surface irrigation runoff. J. Soil Water Cons. 57:524-529.

Bjorneberg, D.L., D.T. Westermann, and J.K. Aase. 2000. Sediment and phosphorus dynamics during furrow irrigation. ASAE Paper No. 002027. St. Joseph, MI.

Nutrients Component

Problem Area 6: Conservation practices at the farm and watershed scale are needed to protect surface and ground water from manure nutrients.

Background: Significant environmental impacts can occur if manure is improperly managed at the production site and when applied to land. Nutrients, pathogens, trace elements, greenhouse gases, odor-causing volatile organic compounds, dust and sediment associated with animal production facilities and manure can degrade soil, water and air quality, and pose a threat to human and animal health. Therefore, conservation practices at the farm and watershed scale are needed to protect surface and ground water. The effectiveness of current conservation management practices including vegetative buffer zones, grass filter strips, riparian zones, and constructed wetlands need to be determined and other practices developed to protect environmental quality.

Accomplishments:

Restored riparian wetland effective for N and P removal: One of the most important functions of riparian (streamside) buffers is to keep nonpoint source (diffuse) pollution out of surface waters such as streams, rivers, and lakes. Although riparian buffers are being used to improve water quality through USDA cost-share programs such as the Conservation Reserve Program, there have been few studies of the effects of restored riparian buffers on water quality. ARS scientists determined the water quality effect of a restored forested riparian wetland adjacent to a manure application area and a heavily fertilized pasture in the Georgia Coastal Plain. To restore the riparian wetland, an area of wet pasture was converted to forest and permanent grasses in 1991. For the next 9 years, the amount of water and concentrations of nutrients- nitrogen (N) and phosphorus (P) in water entering and leaving the riparian wetland were monitored. Stream flow concentration of N and P leaving the riparian wetland buffer were one half and one quarter, respectively of their incoming concentrations in surface runoff from adjacent fields. Water budget for the wetland was estimated and nutrient budgets (nutrient inputs minus nutrient outputs) developed to estimate the percent of entering nutrients that were retained or removed by the wetland. The wetland retained or removed 59% of the N and 66% of the P that entered from the surrounding agricultural lands.

Impact: Restored riparian wetlands are an effective conservation practice for the removal of nonpoint sources of N and P pollution that move from liquid manure application areas and heavily fertilized pastures. Results from this research are important to land managers, particularly those applying animal wastes to upland cropped areas.

Selected publications:

Hubbard, R.K., G.L. Newton and G.J. Gascho. 2003. Nutrient uptake and growth response of grass in buffer systems receiving swine lagoon effluent. J. Soil Water Conserv., 58:232-242.

Hubbard, R.K. J.M. Sheridan, R. Lowrance, D.D. Bosch and G. Vellidis. 2004. Fate of Nitrogen from Agriculture in the Southeastern Coastal Plain. J. Soil Water Conserv. 59: (in press).

Vellidis, G., R. Lowrance, P. Gay, and R.K. Hubbard. 2003. Nutrient transport in a restored riparian wetland. J. Environ. Qual. 32:711-726.

Vegetated buffer systems effectively remove nitrate from swine wastewater. Overland flow application of swine lagoon wastewater to vegetated buffer systems consisting of 10 m grass and 20 m natural forest, or 20 m grass and 10 m natural forest, or 10 m grass and 20 m maidencane were effective in reducing nitrogen contamination in shallow groundwater (1.5 – 2.0 meters) in the southeastern coastal plain. Wastewater applications from 1993-2000 caused NO_3-N concentrations to increase at the upper two sampling positions (5 and 10 m downslope from the wastewater application pipe) but NO_3-N concentrations remained at the 1993 levels for the more distant sampling areas.

Impact: This research provides verification that confined animal producers in the southeastern coastal plain can effectively process up to 1600 kg N ha^{-1} yr^{-1} lagoon wastewater using several variations of simple buffer systems. University of Georgia extension personnel now recommend overland flow systems to animal producers with small operations who need a simple system for utilizing their wastewater.

Selected publications:

Hubbard, R.K. and G.L. Newton. 2002 Long-term impact of swine lagoon wastewater on shallow groundwater nitrogen levels in vegetated buffer systems. Proceedings of Water Environment Federation Animal Residuals conference, May 6-8, 2002, Washington, D.C. At www.biosolids.com.

Lowrance, R., R.K. Hubbard and R.G. Williams. 2001. Denitrification from a swine lagoon overland flow treatment system at a pasture-riparian zone interface J. Environ. Qual. 30:617-624.

Cost-effective best management practices for reducing P losses in runoff from manure-treated fields: Vegetative filters have been successfully used to reduce nutrient movement to surface waters. Narrow grass hedges placed at selected intervals along the contour can be established at a fraction of the cost of terraces and can serve as an effective surface water quality control practice. Stiff, erect grasses contained in the hedges promote sediment deposition and the formation of berms that diffuse and spread overland flow. A field study was conducted to evaluate the effects of 0.75m wide switchgrass hedges on the transport of P and N from a field receiving beef cattle feedlot manure under tilled and no-till conditions. A single grass hedge reduced runoff concentrations of dissolved P (DP) by 47%, bioavailable P (BAP) by 48%, particulate P (PP) by 38% and total P (TP) by 40% on the no-till plots receiving manure, compared with similar plots with no hedges. The corresponding reduction in concentrations as a result of a grass hedge for DP, BAP, PP, and TP on the disked plots were 21, 29, 43 and 38%,

respectively. Narrow grass hedges were found to be effective in reducing P and N losses in runoff from both manure and fertilizer application.

Impact: The transport of nutrients from land application areas can be significantly reduced by the use of narrow grass hedges. Grass hedges have been recognized as a standard practice by NRCS.

Selected publication:

Eghball, B. and J.E. Gilley. 2000. Narrow grass hedge effects on phosphorus and nitrogen in runoff following manure and fertilizer application. J. Soil Water Conserv. 55:172-176.

Renovating pastures with aerators to decreases phosphorus runoff: Researchers determined that pasture aerators reduced the amount of runoff from over-grazed pastures. At two sites in Arkansas located within the Piney Creek Basin three treatments were studied: unfertilized, 4 tons of poultry litter/acre, and 5,000 gal of swine manure/acre. Rainfall simulations after 1 day, 4 months and 12 months showed the time to runoff was significantly longer on land renovated with aerators. In addition, the volume of runoff was reduced by 45% and yields were increased by 27%.

Impact: As a direct result of this research, several NRCS county offices in Arkansas have purchased pasture renovators, which are rented out to farmers. In the future, this BMP will be included in the Arkansas P Index.

Selected publications:

DeLaune, P.B., and P.A. Moore, Jr. 2003. Predicting annual phosphorus losses from fields using the phosphorus index for pastures. Better Crops 85:16-19

Self-Davis, M.L., P.A. Moore, Jr., T.C. Daniel, D.J. Nichols, T.J. Sauer, C.P. West, G.E. Aiken and D.R. Edwards. 2003. Forage species and canopy cover effects on runoff from small plots. J. Soil Water Conserv. 58:349-359.

Management of constructed wetlands to maximize safe nitrogen removal: A 5-yr pilot study in North Carolina was conducted to determine the capacity of two wetland systems, 1) continuous plant cover (marsh) or 2) marsh-pond-marsh to treat swine lagoon wastewater. Both systems were planted to bulrush and cattails. Agronomic crops such as soybean and rice were also tested. Nitrogen loading rates were increased annually from 0.6 to 2.7 g/sq.m/d. The total soil N accumulation significantly increased with time in both systems. Although water tolerant agronomic plants such as saturation culture soybean and rice grew in lightly loaded constructed wetlands, the highest nitrogen removal was obtained with a wetland plant, bulrush. Continuous marsh wetlands were found to be substantially superior to marsh-pond-marsh wetlands for treatment of swine lagoon effluent both in terms of quantitative mass removal and lower ammonia emissions.

Ammonium–N accumulation in pore water was proportional to its concentration in lagoon wastewater. In both systems ammonium-N concentration in pore water was highly correlated with ammonium–N concentration in the inflow of each cell. As the total N loading rates increased annually in both wetland systems, soil pore water had higher levels of ammonium–N, but N removal efficiency of the wetlands sharply decreased at rates >2.5 g/sq.m/d. Ammonia volatilization from the emergent marsh areas of the constructed wetlands was only a small loss mechanism; it accounted for less than 16% of the nitrogen load. However, ammonia volatilization from the pond areas of the marsh-pond-marsh constructed wetlands accounted for greater than 40% of the nitrogen load when the ammonia concentration of the wastewater was greater than 25mg nitrogen L^{-1}. Accumulation of extremely high levels of ammonium–N (>200 mg/L) in soil pore water may negatively affect both plant growth and long-term ability of wetland systems to treat wastewater with high N levels.

These researchers did find that ammonia volatilization could be reduced by lowering the ammonia concentration of the wastewater by nitrification conversion of the ammonia to nitrate prior to wetland application. Ideally nitrogen would then be lost as dinitrogen gas by denitrification rather than ammonia volatilization. Before denitrification can occur ammonia needs to be converted to nitrate by nitrification. High levels of nitrate also are of concern to water quality. Therefore, the goal is to have quick conversion of nitrate once it is formed to dinitrogen gas. In these wetlands, oxygen was limiting for nitrification of ammonia. Three construction and operational aspects were particularly important to alleviate oxygen limitations: 1) surface flow wetlands needed sloped bottoms to permit intermit drainage and cyclic oxidation of the surface layer; 2) intermittent wastewater application allowed for oxidation and the associated nitrification at the up-slope areas; and 3) wetland plants with high oxygen transport to their root systems were beneficial in maintaining more oxidative conditions in the soil surface and detrital layers. Partial nitrification of the wastewater prior to wetland application by aeration also improved the efficiency of the wetlands to remove nitrogen via denitrification.

Proving that denitrification rather than simple ammonia volatilization could be the major mechanism of nitrogen loss would allow constructed wetland to be considered as a viable and sustainable method for removing nitrogen from swine lagoon effluent. Denitrification enzyme assay measurements had a mean rate of 9.5 kg ha^{-1} day^{-1} in the top 25 mm soil layer in the wetlands planted to bulrush during a three-year period. At low loading rates, the limiting factor was nitrate and the wetlands provided sufficient carbon for denitrification. However, carbon was limiting when very high rates (> 50 kg ha^{-1} day^{-1}) of wastewater were applied to wetland microcosms. The highest rates of denitrification were at the shallower up-slope in the wetlands, and denitrification was highly inversely related to water depth between the depths of 50 and 90 mm. Additional investigation into the denitrification potential of the detrital and floating sludge zones of the wetland showed that these areas had 10 and 100 time more denitrification capacity than the soil top-25mm layer, respectively, when nitrate was not limiting.

Impact: Constructed wetlands can be an important alternative for wastewater treatment especially in situation where sufficient land is not available to accommodate increased animal numbers or more rigorous nitrogen limits. The reliability and limits of constructed wetlands for treatment of swine lagoon effluent were effectively documented for farmers, action agencies, and

regulators. This research was the first to directly measure ammonia volatilization from constructed wetlands treating animal wastewater. It helps to answer concerns about the magnitude of ammonia volatilization from two popular types of wetland systems and highlights a method to reduce ammonia volatilization without compromising wetland treatment performance. Proving that denitrification rather than simple ammonia volatilization was the major mechanism of nitrogen loss allows constructed wetland to be considered as a viable and sustainable method for removing nitrogen from swine lagoon effluent. These results will be useful for farmers who are looking for cost-effective nitrogen removal alternatives/supplements to land application, for regulators who want to ensure that agricultural waste management practices do not degrade both air and water quality, and for NRCS personnel who are looking for wetland design modifications that will maximize nutrient removal potential. Currently, NCSU Extension is using USDA-ARS research data to conduct a demonstration of wetland treatment at full-scale in an Onslow Co, NC, hog farm as part of the NC General Attorney/Smithfield – Premium Standard Farms Agreement. This research will allow constructed wetlands to be properly considered as an alternative conservation practice.

Selected Publications:

Poach, M.E., P.G. Hunt, G.B. Reddy, K.C. Stone, T.A. Matheny, M.H. Johnson and E.J. Sadler. 2004. Ammonia volatilization from marsh-pond-marsh constructed wetlands treating swine wastewater. J. Environ. Qual. (in press).

Poach, M.E., P.G. Hunt, M.B. Vanotti, K.C. Stone, T.A. Matheny, M.H. Johnson and E.J. Sadler. 2003. Improved nitrogen treatment by constructed wetlands receiving partially nitrified liquid swine manure. Ecological Engineering 20: 183-197.

Szogi, A.A., P.G. Hunt and F.J.Humenik. 2003. Nitrogen distribution in soils of constructed wetlands treating lagoon wastewater. Soil Sci. Soc. Am. 67:1943-1951.

Szögi, A.A. and P. G. Hunt. 2001. Distribution of ammonium-N in the water-soil interface of a surface-flow constructed wetland for swine wastewater treatment. Water Sci. Tech. 44:157-162.

Szögi, A.A., P.G. Hunt, E.J. Sadler, D.E. Evans. 2004. Characterization of oxidation-reduction processes in constructed wetlands for swine wastewater treatment. Appl. Eng. Agr. (in press).

Szogi, A. A., P. G. Hunt, and F. J. Humenik. 2000. Treatment of swine wastewater using a saturated-soil-culture soybean and flooded rice system. Trans. ASAE 43:327-335.

Hunt, P. G., A. A. Szogi, F. J. Humenik, J. M. Rice, T. A. Matheny and K. C. Stone. 2002. Constructed wetlands for treatment of swine wastewater from an anaerobic lagoon. Trans. ASAE 45:639-647.

Hunt, P.G., T. A. Matheny and A.A. Szogi. 2003. Denitrification potential in constructed wetlands used for the treatment of swine wastewater. J. Environ. Qual.32:727-735.

Passive feedlot runoff control and treatment system: Small beef cattle feeding operations need a cost-effective solution for managing feedlot runoff. 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 for hay production. The system consisted of a grass approach, a terrace with a debris basin, and a vegetative filter strip. 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 water was measured exiting the vegetative filter strip during the three-year period of this study. Therefore the discharge water was effectively contained and used for hay crop production. Estimated total nitrogen load in the discharge water entering the vegetative filter strip was equivalent to or less than the total nitrogen removed by the crop.

Impact: This system will provide smaller beef cattle feeding operations with a robust, cost-effective system to meet requirements of EPAs NPDES Permit Regulations and Effluent Guidelines for CAFOs. The regulations require use of the best practical control technology currently available to contain all runoff resulting from a 25-year, 24-hour rainfall event.

Selected Publications:

Woodbury, B.L., J.A. Nienaber and R.A. Eigenberg. 2002. Operational evaluation of a passive beef cattle runoff control and treatment system. Applied Eng. In Agric. 18:541-545.

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

Nutrients Component

Problem Area 7: The effects of long-term land application of manure and byproducts needs to be determined.

Background: Long-term land application of manure or byproducts can supply plant nutrients and improve soil physical, chemical and biological properties. However, there are concerns that long-term buildup of nutrients, salts, trace elements, and organics in the soil may pose a risk to human health and the environment. Research is needed to determine changes that occur in the soil with long-term application of manure or byproducts to document any risks that may result and to develop management practices to overcome the risks.

Accomplishments:

Long-term application of alum-treated poultry litter: ARS researchers initiated a 20-year study in 1995 to determine the effects of poultry litter, alum-treated poultry litter and ammonium nitrate on soil properties to determine which fertilizer type was more sustainable. Land application of alum-treated litter greatly reduced phosphorus leaching from soils compared to untreated litter. Soil samples taken from 0-5, 5-10, 10-20, 20-30, 30-40 and 40-50 cm depths showed that water-soluble, extractable and total phosphorus levels were much greater in sub-surface soil layers with untreated poultry litter fertilization. The study also showed that while neither litter source affected soil aluminum, the application of ammonium nitrate greatly increased exchangeable aluminum levels in the soil, due to reductions in soil pH. Tall fescue yields were higher with alum-treated litter than ammonium nitrate or normal poultry litter. These data indicate that alum-treated poultry litter is a more sustainable fertilizer source than normal litter or ammonium nitrate.

Impact: This research provides a best management practice that can be used by farmers in areas where phosphorus leaching is a problem. It also shows that adding alum to poultry litter is a very sustainable approach to controlling phosphorus leaching and runoff. This was the first time a manure amendment had been shown to reduce phosphorus leaching.

Selected Publications:

Moore, P.A., Jr., P.B. DeLaune, T.C. Daniel and D.R. Edwards. 2004. Effects of alum-treated poultry litter, untreated litter and ammonium nitrate on metal availability and runoff from pastures. Page 45 In Sustainable Land Application Conference. Lake Buena Vista, FL.

Influence of long-term manure application on runoff and soil loss: While it is generally accepted that improved soil properties associated with manure application lead to changes in runoff and soil erosion, few studies have quantified these impacts. Water quality models used to assess watershed management and estimate total maximum daily load must accurately predict loading rates from fields where manure has been applied. ARS scientists took information available in the literature to quantify effects of manure application on runoff and soil loss resulting from natural precipitation events, and to develop regression equations relating runoff

and soil loss to annual manure application rates. At sites where manure was applied annually, runoff was reduced from 2 to 62%, and soil loss decreased from 15 to 65% compared to sites where manure was not applied. Measured runoff and soil loss values were reduced substantially as manure application rates increased. Regression equations were developed relating runoff and soil loss to manure application for rates ranging from 11 to 45 Mg ha^{-1} and slope lengths varying from 21 to 24 m.

Impact: Results from this investigation documented the value of manure as a soil amendment to reduce runoff and soil loss. The equations developed in this study can be used by NRCS, extension personnel or consultants to estimate environmental impacts of manure application. The results can be used in water quality models to account for the influence of long-term manure application on runoff and erosion.

Selected Publications:

Gilley, J.E. and L.M. Risse. 2000. Runoff and soil loss as affected by the application of manure. Trans. of the ASAE. 43:1583-1588.

Gilley, J.E., B. Eghball, J.M Blumenthal and D.D. Baltensperger. 1999. Runoff and erosion from interrill areas as affected by the application of manure. Trans. of the ASAE. 42:975-980.

P Leaching in sandy soils and riparian zones: Research was conducted by ARS scientists to determine if P leaching is a problem in sandy Coastal Plain soils that have received long-term manure application. Shallow ground water monitoring wells (3 to 8 m deep) were installed in a field in the Coastal Plain region of North Carolina with a long history (10 years) of swine manure application. Monthly sampling of these wells over a 6-year period showed dissolved P (DP) concentrations between 40 and 480 ug/L. Nearby control wells had very low DP concentrations (< 40 ug/L). Monitoring wells also were installed at the boundary of this spray field with a riparian zone, and at a riparian zone contact with a nearby black water stream. Ground water collected from wells at the spray field edge were enriched in DP (annual means between 70 and 120 ug/L), however, wells at the riparian zone/stream contact were low in DP concentrations (annual means between 0 and 15 ug/L). The majority of stream samples were also very low in DP concentrations (mean < 5 ug/L).

Impact: This study revealed that deep P leaching occurred as a result of continuous applications of swine manure effluent to sandy soils. Riparian zones, located adjacent to the swine manure spray field, were found to be effective at reducing subsurface DP concentrations resulting in minimal DP entry into the black water stream. The finding of deep P leaching in sandy soils and reduction in ground water DP concentrations by a forest-covered riparian zone was incorporated into the North Carolina P Index program.

Selected Publications:

Novak, J.M, D.W. Watts, P.G. Hunt and K.C. Stone. 2000. Phosphorus movement through a Coastal Plain soil after a decade of intensive swine manure applications. J. Environ. Qual. 29:1310-1315.

Novak, J.M., D.W. Watts, P.G. Hunt, K.C. Stone and M.H. Johnson. 2002. Riparian zone impact on phosphorus movement to a Coastal Plain black water stream. J. Soil Water Conserv. 57:127-133.

Novak, J.M., K.C. Stone, A.A. Szogi, D.W. Watts and M.H. Johnson. 2004. Dissolved phosphorus retention and release from a Coastal Plain in-stream wetland. J. Environ. Qual. (in press*)*.

Arsenic risk from long-term application of poultry litter: ARS scientists conducted research to determine if arsenic (As) in poultry litter would pose an environmental risk in the Southeastern U.S. compared to other commonly used soil amendments or agricultural chemicals. They found that As in poultry litter ranged from 0.3 to 13 ug/g. At a litter application rate of 4000 kg/ha, poultry litter would introduce from 13 to 100 times less As to the soil system than the commonly used cotton herbicide, monosodium methyl arsenic acid (MSMA) applied at the registered label rate.

Impact: The USDA-NASS statistics for 2001 indicated that 11 percent of the cotton acreage in the U.S. was treated with MSMA at an average application rate of 1.5 kg/ha-yr. MSMA would be a greater potential source of As to water supplies in the Southeastern U.S. than poultry litter. However, lowering As level in poultry diet would be a worthwhile step to prevent long-term buildup of As in soil.

Long-term application of manure/compost to irrigated corn silage: ARS scientists annually applied an average of 700 kg ha^{-1}manure or composted manure to irrigated corn silage for a 10-yr period using production goals to estimate yearly N and P crop needs. Commercial fertilizer was used to provide the N requirements of the non-manured control treatment. Additional treatments were designed to provide only the P needs, with N supplemented with commercial fertilizer to meet crop needs. **P**hosphorus availability to the crop was dramatically underestimated for both compost and manure (70% instead of 22%). Replicates of all treatments were seeded with a winter cover crop each fall after harvest to retain available nitrate within the root zone and minimize nitrate leaching which was found to be an effective management practice. By means of annual soil sampling to determine nutrient carry-over, crop production goals were attained when weather variables permitted (no drought or hail) without loss of nitrate through deep percolation.

Impact: These findings demonstrate that manure and compost can be effectively and safely used in a crop fertilization program if properly managed, offsetting waste management and fertilizer costs without reduction of crop yield or imposing an environmental hazard.

Selected Publications:

Ferguson, R.B., J.A. Nienaber, R.A. Eigenberg and B.L. Woodbury. 2003. Long-term effects of beef feedlot manure application on soil properties and accumulation and transport of nutrients. Proc. Int'l. Symp. on Animal, Agricultural and Food Processing Wastes (ISAAFPW 2003), 1-9. Raleigh, NC.

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

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

Selected Publications:

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

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

Nutrients Component

Problem Area 8: Remediation strategies that minimize off-site impacts of excess nutrients and trace elements in soils are needed.

Background: Remediation strategies that minimize off-site impacts of excess nutrients and trace elements in soils are needed. Unfortunately, misapplication and over application of manures and byproducts, and industrial and mining activities have led to situations where soils are contaminated by nutrients and trace elements. These sites would benefit from remediation so they no longer are sources of pollution and can again be used productively. Manures and municipal and industrial byproducts can be an integral part of remediation strategies for soils contaminated by non-agricultural activities.

Accomplishments:

Reducing soil phosphorus by addition of drinking water treatment byproducts: Application of manure or other residuals with high levels of P relative to other nutrients, especially N, or excessive additions have led to soils with high enough levels of P to require or benefit from remediation strategies. Water treatment residue rich in Al, a Fe-rich titanium ore processing byproduct, and alkaline calcium rich fluidized bed ash from coal combustion were tested at different rates on high P soils. At moderate rates the applied drinking water treatment residue was especially effective in lowering P solubility in water or in the Bray-1 soil extractant. The Fe-rich byproduct was less effective than the drinking water byproduct. In another study a drinking water residual produced from addition of "polyhydroxy aluminum" was mixed with poultry litter and applied as fertilizer. Corn was grown for two seasons. Some reduction in water-soluble soil P was observed, and the corn yield was not reduced by this treatment. Additions of alum-treated drinking water residuals to sandy soils, commonly used for manure application, increased P retention 3 to 6 fold.

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

Selected Publications:

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

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

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

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

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

Selected Publications:

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

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

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

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

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

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

Biosolid treatments to decrease the bioavailability of lead in soil: Pb contamination at mine and smelter sites, or in urban soils (from paint and automotive emissions) comprise a risk to wildlife or children by soil ingestion. Our earlier research had shown that certain biosolids composts rich in Fe could strongly reduce the absorption of Pb from soil fed to rats. Further tests were conducted and Fe and P were clearly important in Pb inactivation. In cooperation with US-EPA and others, we tested different phosphate amendments and high-Fe biosolids compost for inactivation of Pb in soils at an abandoned mine site near Joplin, MO. A three-year field test was conducted during which the bioavailable fraction of soil Pb was measured by chemical extractions or feeding tests. After three years, a human feeding test was conducted to test how well phosphate reduced soil Pb bioavailability, which was reduced by 69%. The human test used stable isotopes of Pb in the contaminated soil. This approach was extended to urban soils in the inner-city area of Baltimore, MD. High Fe composted biosolids permitted for use on lawns and gardens was applied at about 200 t/ha including 10% limestone added to the compost. Before application, lawns were compacted and poorly vegetated; in that condition, one is advised to remediate or remove soils with over 400 mg Pb/kg. Where the compost was incorporated, lawn grass grew strongly, reducing soil transfer and Pb bioavailability; vegetated soils with up to 1200 mg Pb/kg do not require removal or further remediation. This approach could be used to reduce soil Pb risk to urban children at low cost.

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

Selected Publications:

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

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

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

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

High phosphorus accumulating plant species and cultivars to remediate soils with high phosphorus levels: Cool-season annual ryegrass (*Lolium multiflorum*) and warm-season crabgrass (*Digitaria ciliaris*) are annual forages commonly grown in the southeastern region of the US to provide year-round pasture for a forage-livestock system. The P uptake efficiency of five ryegrass cultivars grown during the winter and spring followed by annual crabgrass during summer was evaluated in Mississippi on a highly P enriched Ruston silt loam soil. The ryegrass was grazed during winter then harvested once in early June. Ryegrass cultivars varied in biomass production and P uptake. In general, crabgrass was more effective in P removal than ryegrass cultivars tested. Overall, the combination of ryegrass followed by crabgrass provides an effective forage-livestock management system in the southeastern states.

The effect of different forage species on surface runoff one day after cutting and after six weeks growth post-harvest was also investigated. Five forage species tested were: switchgrass, Caucasian bluestem, bermudagrass, eastern gamagrass, and tall fescue. Poultry litter was surface-applied annually at 8.97 Mg ha^{-1}. Rainfall simulations (5.0 cm hr^{-1}) were used to produce runoff events during spring, summer, and fall to examine seasonal variations. Runoff volumes were reduced by full canopies relative to cut canopies for all seasons, by an average of 18% for all species except bermudagrass. Comparison of runoff volumes between the different species showed that tall fescue had significantly less (30 mm) runoff for three of the four runoff events. There were no differences in runoff between the other four species, for any runoff event. Infiltration was on average 19% greater in tall fescue plots for all runoff events, compared to the other four species. This study showed that tall fescue was effective at reducing runoff volumes and increasing infiltration, thereby reducing edge of field P and N losses from pastures.

Impact: Planting specific plant species and cultivars provides producers with an inexpensive practice to remove phosphorus from the soil and prevent its transfer to water bodies.

Furthermore, these pasture management practices can also lead to increased forage and greater profits. The results of the runoff research will be incorporated into the Arkansas P Index. It will allow growers to get credit for less P runoff when tall fescue is used.

Selected Publications:

Brink, G.E., D.E. Rowe, K.R. Sistani, and A. Adeli. 2003. Bermudagrass cultivar response to swine effluent application. Agron. J. 95:597-601.

McLaughlin, M.R., T.E. Fairbrother, and D.E. Rowe. 2004. Nutrient uptake by warm-season perennial grasses in a swine effluent spray field. Agron. J. 96:484-493.

Self-Davis, M.L., P.A. Moore, Jr., T.C. Daniel, D.J. Nichols, T.J. Sauer, C.P. West, G.E. Aiken, and D.R. Edwards. 2003. Forage species and canopy cover effects on runoff from small plots. J. Soil and Water Conservation 58:349-359.

Rowe, D.E. and T.E. Fairbrother. 2003. Harvesting winter forages to extract manure soil nutrients. Agron. J. 95:1209-1212.

Delorme, T.A., J.S. Angle, F.J. Coale, and R.L. Chaney. 2000. Phytoremediation of phosphorus-enriched soils. Int. J. Phytoremediation 2:173-181.

Practices to rehabilitate sites previously used for composting: Composting is an effective method for treating wastes. However, the soil beneath a site that has been used for extended periods for composting can accumulate nutrients and metals. A process was developed to remediate these sites. It consisted of tillage and growing crops for at least one year, followed by alfalfa. Alfalfa's deep roots remove excess nitrate deep in the soil profile. A site used for composting in eastern Nebraska showed that leaching of K, Na, NO3 and salts (EC) were time dependent and they moved deeper into the soil profile with increasing years of composting. Increased levels of K and Na in the topsoil caused soil dispersion and crusting, poor germination, and lower first-year crop yields. Barley, wheat or sorghum can be used as the first-year-crop. In the second year of cropping, the grain crops and alfalfa resulted in similar yields in the windrow and inter-windrow areas indicated effectiveness of cropping and field cultural practices in rehabilitating these sites.

Impacts: These results will provide guidelines to livestock producers and others who compost manure or other organic residuals to rehabilitate earthen sites used for composting. The site can be used for composting again after rehabilitation is completed.

Selected Publications:

D. Ginting, B. Eghball, D. T. Walters, C. A. Francis, T. J. Klopfenstein, C. B. Wilson and G. E. Erickson. 2004. Crop performance and soil properties of sites previously used for composting beef cattle manure. pp. 78-80. In D. Brink (ed.) 2004 Beef Cattle Report. University of Nebraska Cooperative Extension.

Nutrients Component

Problem Area 9: Alternative uses for manure and other byproducts need to be developed.

Background: Alternative uses for manure and other byproducts are needed in areas where supply exceeds available land and land application would cause significant environmental risk. Manure can be used for energy production by burning, methane generation and conversion to other fuels. Methods to reduce the weight, volume or form of manure such as composting or pelletizing will reduce transportation costs and create a more valuable product. Treated organic wastes (e.g., biosolids and manures) can be mixed, blended or co-composted with industrial or municipal byproducts to produce value-added materials for specialized uses.

Accomplishments:

Blends of manures and other byproducts to produce higher value products: Methods to co-utilize animal manure with organic or inorganic byproducts to improve manure value and safety, and to develop manure-based products for outside markets have been developed. Manures were blended with industrial and municipal byproducts containing iron (pigment sludge), aluminum (water treatment sludge), calcium (gypsum wall board) and carbon (municipal paper trash) and composted. Byproducts were added at a rate of 2 moles of cation to 1 mole of total P. Water soluble P was decreased 70-90 % by the byproduct addition. Composting of the blended materials had no effect on Mehlich 3 extractable P, but reduced slightly the water-soluble P levels. Composting manure or biosolids with high paper and carbon content material such as municipal refuse resulted in less volatile nitrogen loss during composting and, hence, a higher nitrogen content in the final product. Blending byproducts with manure resulted in significantly lower soluble or fertilizer P content in the compost in the case of iron, aluminum, and calcium additions and greater fertilizer N in the case of carbon addition. Good quality compost, especially biomineral compost, has the capacity to suppress root rots caused by various disease agents such as “red stele” of strawberry. ARS scientists in cooperation with a recycling firm in Houston, Texas produced a landscaping mulch, EnviroGuardPlus, by blending wastepaper with manure. The product can be used as a mulch and fertilizer source by homeowners, and for erosion control and grass establishment on embankments, golf courses and roadsides.

Impact: Blended or tailor-made composts will benefit agriculture, industry and municipalities by adding value to diverse byproducts either through conserving N and/or by reducing the soluble P content of the byproduct. The blended product has a higher nitrogen-to-phosphorus ratio so that addition to fields at the N requirement of the crop will not add phosphorus in excess to plant needs or, alternatively, when the product is added at the N requirement of the crop, sufficient or near sufficient N is added for crop growth. These results will help build partnerships between diverse industries to develop value-added products that will benefit the environment and save landfill space.

Selected Publications:

Sikora. L. J. 1999. MSW Compost Reduces Nitrogen Volatilization During Dairy Manure Composting. Compost Science & Utilization. 7, No. 4 : 34-41.

Dao, T.H., L.J. Sikora, A. Hamasaki and R.L. Chaney. 2001. Manure phosphorus extractability as affected by aluminum and iron byproducts and aerobic composting. J. Environ Qual. 30:1693-1698.

Sikora, L.J. 2004. Effects of industrial byproducts containing high aluminum or iron levels on plant residue composition. Comm. Soil Sci Plant Anal. 35:921-936.

Edwards, J.H., L.D. Norton, G.E. Aiken and T.R. Way. 2001. Utilization of organic byproducts to reduce soil extractable P from repeated application of manure. Symposium on Management of Swine and Poultry Waste. Mississippi Water Resource Institute 31:300-313.

Using ash from poultry litter burning as a fertilizer: Burning for energy has been suggested as one approach to the problem of excess poultry litter. ARS scientists have conducted research to determine if the ash from poultry litter burning can be used as a fertilizer for agriculture crops. Phosphorus in poultry litter ash was less water-soluble than phosphorus in poultry litter, but the ash was as effective as potassium phosphate fertilizer for wheat production.

Impact: Poultry litter ash can be used as P and K fertilizer for agricultural crops. Energy companies that are burning or plan to burn poultry litter have been very interested in the results of this research.

Selected Publications:

Codling, E.E.; R.L. Chaney and J. Sherwell. 2002. Poultry litter ash as a potential phosphorus source for agricultural crops. J. Environ. Qual. 31: 954-961.

Tailor-made remediation mixtures: ARS scientists have developed and tested a method to remediate metal toxic sites using bisolids and alkaline byproducts. This approach called "Tailor-Made Remediation Mixtures" has been successfully used at a number of contaminated sites in the U.S. and abroad (see Problem Area 8 for greater detail). To apply this technology, one needs to find locally available organic resources (biosolids, manure, composts, etc.) and alkaline byproducts or limestone.

Impact: The "tailor-made" remediation mixtures approach has been supported by US-EPA Superfund managers to be designated a Presumptive Remedy for remediation of metal contaminated soils. The cost savings are at least 100-fold less that of the currently used practice of soil removal and replacement, which costs $1M per acre-foot. There are over 50,000 sites nationwide that could benefit from this *in-situ* remediation procedure using tailor-made biosolid or manure mixtures or composts.

Selected Publications:

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

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

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

Algal turf scrubbers (ATS) technology to recover nutrients from manure: Algal biotechnologies have the potential to greatly concentrate nutrients from animal manures by cultivating algae in engineered ponds or raceways. ARS scientists examined one algal technology, termed algal turf scrubbers (ATS), for its ability to remove N, P, and COD from raw and anaerobically digested dairy manure effluents and to generate a beneficial biomass. Laboratory-scale ATS containing natural mixtures of algae were operated by continuously recycling wastewater, adding manure effluents daily, and harvesting algal biomass weekly. In the best case, algal biomass contained about 50% of manure N and P, and had a crude protein content of about 44%. The daily dry matter yield of 16 g/ sq. M is equivalent to annual uptake rates of 4090 and 876 kg/ ha-year for N and P, respectively. Algal biomass recovered from manure treatment systems has a variety of potential on- and off-farm uses. Although it has primarily been considered as an alternative high-grade protein source in animal feed, algal biomass with a balanced N:P ratio was shown to be a potentially valuable organic fertilizer. Growth chamber studies showed that 20-day old cucumber and corn seedlings grown with algae-amended potting mixes were equivalent to plants grown with a commercial fertilizer with respect to seedling biomass and nutrient content.

Impact: There has been high interest and many inquiries about the algal technology from the dairy and swine industries because these industries recognize the benefit of on-farm treatment of manure and re-utilizing the nutrients in manures through alternative products.

Selected Publications:

Kebede-Westhead, E., C. Pizarro and W. W. Mulbry. 2003. Production and nutrient removal by periphyton grown under different loading rates of anaerobically digested flushed dairy manure. J Phycology 39: 1275-1282.

Wilkie, A. C. and W. Mulbry. 2002. Recovery of dairy manure nutrients by benthic freshwater algae. Bioresource Technology 84: 81-91.

Emissions Component

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, odor-causing volatile organic compounds, hydrogen sulfide, methane, oxides of nitrogen and pathogens. The research is conducted at swine, poultry, dairy cattle and beef cattle production operations by ARS scientists from 10 laboratories and their cooperators. Management practices and control technologies for emissions reduction are being developed at three points in the production system: at the production facility, at manure storage areas, and at manure and byproduct field application sites. The research is coordinated across locations and is designed to: (1) develop new methods and improve existing methods to measure particulate matter and gaseous emissions from animal production operations; (2) develop and determine the effectiveness of management practices to reduce emissions; and (3) develop tools to predict emissions and their dispersion across a range of animal production systems, management practices and environmental conditions. Measurement and prediction of emissions from animal production operations will help provide the scientific background for state and federal regulatory and management decisions.

Research within the Emissions Component of the Manure and Byproduct Utilization National Program is conducted in six Problem Areas. These Problem Areas were identified with input obtained from customers, stakeholders and partners at a workshop prior to the start of the current five-year National Program cycle. Research accomplishments described in this report may address more than one Problem Area and therefore may be repeated at multiple points in the report. The six Problem Areas are listed below.
(Problem Area 10). Develop methods to measure and quantify emissions from livestock facilities based on physical and chemical properties, including size and composition of particulates and aerosols. (Problem Area 11). Elucidate mechanisms responsible for emissions, and identify the underlying substrates and processes with an emphasis on the role of microorganisms. (Problem Area 12). Determine emission rates in relation to manure production, handling, storage, processing, and land application. (Problem Area 13). Determine the effect of environmental conditions on generation and transport of emissions. (Problem Area 14). Determine the impact of emissions on human health, animal health and the environment. (Problem Area 15). Develop and evaluate cost-effective methods to reduce problem emissions.

Emissions research is currently conducted by the following ARS locations: Ames, Iowa; Beltsville, Maryland; Bushland, Texas; Clay Center, Nebraska; Fayetteville, Arkansas; Florence, South Carolina; Lincoln, Nebraska; Madison, Wisconsin; Mississippi State, Mississippi; and Watkinsville, Georgia.

Emissions Component

Problem Area 10: Develop methods to measure and quantify emissions from livestock facilities based on physical and chemical properties, including size and composition of particulates and aerosols.

Background: Particulate matter and a number of gases including ammonia, hydrogen sulfide, volatile organic compounds, methane and oxides of nitrogen are emitted from animal production facilities, manure storage areas and manure field application sites. A number of different measurement techniques are needed to quantify the variety of emissions from animal production systems. Many instruments are not capable of dealing with the low concentrations of emissions often encountered in natural environments. Reliable, sensitive, reproducible methods are needed to accurately measure emissions across a range of animal production systems and environmental conditions.

Accomplishments:

Detection of volatile organic compounds: Quantifying the concentration of volatile organic compounds in the atmosphere surrounding swine production buildings and manure storage systems is needed to understand differences among management scenarios. Studies were conducted to evaluate differences in VOC's across a range of production units with varying ventilation and manure storage systems. Thermal desorption tubes linked with a gas chromatograph/mass spectrometer were used to quantify volatile organic compounds emitted. Thirteen VOC's were common across all production units. These compounds are shown in the following table along with those detected by other researchers. These compounds varied by the type of building and manure handling system demonstrating that each building complex can have a unique set of VOC emissions.

Key Odorants in Swine Manure and Aerial Emissions

Compound	Formula	Characteristic	Reference 1	2	3	4
Acetic Acid	$C_2H_4O_2$	Pungent/Vinegar	X	X	X	X
Propionic Acid	$C_3H_6O_2$	Fecal	X	X	X	X
Butyric Acid	$C_4H_8O_2$	Fecal/Stench	X	X	X	X
Isobutyric Acid	$C_4H_8O_2$	Fecal	X	X	X	X
2-Butanol	$C_4H_{10}O$	Alcohol			X	X
Isovaleric Acid	$C_5H_{10}O_2$	Fecal	X	X	X	X
n-Valeric Acid	$C_5H_{10}O_2$	Fecal	X	X	X	X
3-Methyl Butanol	$C_5H_{12}O$	Alcohol			X	
Isocaproic Acid	$C_6H_{12}O_2$	Stench				X
n-Caproic Acid	$C_6H_{12}O_2$	Fecal				X
Benzyl Alcohol	C_7H_8O	Alcohol				X
Heptanoic Acid	$C_7H_{14}O_2$	Pungent				X
2-Phenyl Ethanol	$C_8H_{10}O$	Roses			X	
Phenol	C_6H_6O	Aromatic	X	X	X	X
p-Cresol (4-Methyl phenol)	C_7H_80	Fecal	X	X	X	X

o-Cresol (3-Methyl phenol)	C_7H_80			X		
3-Ethyl Phenol (m-Ethyl phenol)	$C_8H_{10}O$			X		
4-Ethyl Phenol	$C_8H_{10}O$	Pungent	X	X	X	X
Hydrogen Sulfide	H_2S	Rotten Eggs	X	X	X	X
Methyl Mercaptain	CH_4S	Garlic, Putrid	X			
Dimethyl Sulfide	C_2H_6S	Stench	X			
Dimethyl Disulfide	$C_2H_6S_2$	Putrid Vegetables	X			X
Dimethyl Trisulfide	$C_2H_6S_3$	Nauseating	X		X	X
Ammonia	NH_3	Sharp/Pungent	X	X	X	X
2-Amino Acetophenone	C_8H_9NO	Fruity/Ammonia				X
Indole	C_8H_7N	Fecal/Stench	X	X	X	X
2-Methyl Indole	C_9H_9N	Stench		X		
3-Methyl Indole (Skatol)	C_9H_9N	Fecal/Nauseating	X	X	X	X
4-Methyl Indole	C_9H_9N	Stench		X		

[1]Hobbs et al., 1995; [2]Gralapp et al., 2001; [3]Yasuhara et al., 1984; [4]Zahn et al., 2001

Gralapp, A. K., W. J. Powersand D. S. Bundy. 2001. Comparison of olfactometry, gas chromatography, and electronic nose technology for measurement of indoor air from swine facilities. Trans. ASAE 44:1283-1290.
Hobbs, P. J., T. H. Misselbrookand B. F. Pain. 1995. Assessment of odors from livestock wastes by a photoionization detector, an electronic nose, olfactometry and gas chromatography-mass spectrometry. J. Agric. Eng. Res. 60:137-144.
Yasuhara, A., K. Fuwa and M. Jimbu. 1984. Identification of odorous compounds in fresh and rotten swine manure. Agric. Biol. Chem. 48: 3001-3010.
Zahn, J. A., A. A. DiSpirito, Y. S. Do, B. E. Brooks, E. E. Cooper and J. L. Hatfield. 2001. Correlation of human olfactory responses to airborne concentrations of malodorous volatile organic compounds emitted from swine effluent. J. Environ. Qual. 30:624-634.

Nuisance odors associated with land application of biosoliods have led to increased regulatory oversight by state governments and opposition from citizen groups. The intensity and character of odors associated with biosolids is related to conditions at the wastewater plant, dewatering and stabilization procedures, storage and handling, and application procedures at the site. ARS scientists have identified odorous chemicals associated with waste handling processes within the plant, and a number of biosolids stabilization procedures, i.e., liming, heat-drying, composting. They found that dimethylsulfide and dimethyldisulfide are the most prevalent and most odorous chemicals associated with biosolids, hydrogen sulfide and methyl mercaptan also are dominant in anaerobically digested materials, and trimethylamine contributes a “fishy” odor in lime stabilized biosolids.

Developing management practices to reduce emissions of odorous compounds requires collection and accurate analysis of air samples. New sample collection and analytical methods have been developed by ARS scientists utilizing solid phase microextraction and multi-dimensional gas chromatography with mass spectrometry (GC-MS). Analysis of complex ambient air samples for volatile organic chemicals is a challenging task because gases represent different compound classes with differing polarities, generally requiring different chromatographic columns for optimal separation and low detection limits. The new methods allow improved detection and separation of a number of polar and non-polar volatile organic compound classes using only one instrument. Solid phase microextraction (SPME) utilizes thin, fused silica fibers coated with adsorbents to extract organic chemicals from headspace or gas

samples in proportion to their concentration. Extremely low detection limits, in the range of published olfactometric detection limits, can be achieved when this approach is coupled with GC-MS analysis.

Analytical Detection Limits and Human Odor Threshold Values

Chemical Name	CAS Number	Formula	Odor Threshold (ppb)	Detection Limits (ppb)
Methyl mercaptan	74-93-1	CH4S	1.10	50
Ethyl mercaptan	75-08-1	C2H6S	1.10	15.4
Propyl mercaptan	107-03-9	C3H8S	1.30	10.4
Butyl mercaptan	109-79-5	C4H10S	1.40	12.0
Carbon Disulfide	75-15-0	CS2	95.5	0.80
Dimethyl sulfide	75-18-3	C2H6S	2.24	4.60
Dimethyl disulfide	624-92-0	C2H6S2	12.3	813
Trimethyl amine	121-44-8	C3HN	2.40	5.30
Para-cresol	106-44-5	C7H8O	1.86	33.1*
Acetic acid	64-19-7	C2H4O2	145	163*
Propionic acid	79-09-04	C3H6O2	35.5	20.1
Butyric acid	107-92-6	C4H8O2	3.89	16.0
Iso-butyric acid	79-31-2	C4H8O2	19.5	17.6
Valeric acid	109-52-4	C5H10O2	4.79	1.60
Isovaleric acid	503-74-2	C5H10O2	64.0	35.7

Impact: This research on key odorants in manure and biosolids is valuable because it helps define the specific types of VOC's prevalent in swine production units and identifies the compounds that contribute to odor present around buildings. This research has helped state air quality agencies understand the range of VOCs present in the air within and exiting swine production buildings. These analytical techniques also have allowed the effectiveness of odor control technologies to be assessed. Samples characterized for VOCs also were evaluated by an odor panel to demonstrate that interaction among VOCs is an important component of odor perception. Odor assessments varied with type and amount of VOCs and composition of the air sample. Odor assessments and VOC measurements need to be linked.

This new SPME with GC-MS analysis method allows a number of volatile fatty acids, volatile sulfur compounds, p-cresol, indole and skatole in the headspace over waste water and manure samples to be determined. This work will allow quantification of key odorants, identification of unknown odorants present in the headspace or condensed phase of numerous types of waste systems, and evaluation of new odor control technologies. The new method will be used by environmental scientists and chemists to provide positive identification and quantitative data on emission of odorous compounds from biosolids and manures.

Selected Publications:

Zahn, J.A., A.A. DiSpirito, Y.S. Do, B.E. Brooks, E.E. Cooper and J.L. Hatfield. 2001. Correlation of human olfactory responses to airborne concentrations of malodorous volatile organic compounds emitted from swine effluent. J. Environ. Qual. 30:624-634.

Zahn, J.A., J.L. Hatfield, D.A. Laird, T.T. Hart, Y.S. Do and A.A. DiSpirito. 2001. Functional classification of swine manure management systems based on effluent and gas emission characteristics. J. Environ. Qual. 30:625-647.

Millner, P.D. and L.L. McConnell. 2000. Odor and other air quality issues associated with organic and inorganic by-products. In Land Application of Agricultural, Industrial and Municipal By-Products, W. A. Dick, ed., SSSA, Madison, WI, No. 6, p. 289-314.
Kim, H., C. Nochetto and L.L. McConnell. 2002. Gas phase analysis of trimethylamine, proprionic acid and butyric acid, and sulfur compounds using solid phase microextraction. Anal. Chem. 74:1054-1060.

Kim, H., S. Murthy, C. Peot, M. Ramirez, M. Strawn, C-H. Park, and L.L. McConnell. 2003. Examination of mechanisms for odor compound generation during lime stabilization. Water Environ. Res. 75:121.

Murtry, S., H. Kim, C. Peot, L.L. McConnell, M. Strawn, S. Thomas and I. Dolak. 2003. Evaluation of odor characteristics of heat-dried pellets. Water Environ. Res. 75:523-531.

Particulate matter emissions: Particulate matter samples often are collected at single locations and are assumed to represent a range of agricultural systems. PM samples with a 10 μm cutoff were collected weekly throughout the year at seven locations ranging from a rural area to a location adjacent to a large swine grow-finish unit. Particulate samples were analyzed for their composition using FTIR-PAS spectroscopy. Total mass loads of particulates were lowest in the rural settings; however, swine operations were not consistent in their effect on particulate mass emitted. Siting of the facility and windflow patterns had a large impact on particulate loads adjacent to the facility. Analysis of the composition of the particulates revealed large differences between particulates collected in a rural area and adjacent to a swine production unit. Compounds found on particulates near swine production units included carboxylic acids, alcohols, phenols, ketones, mercaptans, thioethers, and amines and are similar to compounds detected in vapor phase samples. These findings suggest that organics attached to particulate matter may undergo long-range transport and dispersion.

ARS scientists developed an inexpensive laboratory technique to measure the dust-producing potential of cattle feedlot surface material. They found that the potential to produce dust varied spatially within feedlot pens and was controlled by the moisture and organic matter content of the surface material. This technique utilized a modified blender to produce dust from feedlot surface material and then capture the airborne particulate matter for further analysis. The relationship between moisture content and dust production was nonlinear with a sharp transition between dust emitting and dust free, which was defined as the moisture threshold. Moisture thresholds ranged from 6.5% to 20% moisture across a single feedlot pen surface. Based upon

the results of a variety of feedlot surface samples, a model was developed to predict the moisture threshold for controlling dust from the organic matter content of the feedlot surface.

Impact: There has been little quantitative information on mass load of particulate matter adjacent to swine production units compared to rural areas without animal production facilities. This information contributes to an understanding of the impact of swine production units on air quality and the role of malodorous compounds on particulates in the dynamics of air quality and livestock. These data are used by swine producers and their advisors to understand seasonal variations in particulate matter loadings to the atmosphere. In addition, the Air Quality Division of the Iowa Department of Natural Resources is using the information to help understand the potential range of PM values in rural communities.

The new technique for measuring dust producing potential of cattle feedlot surfaces complements existing large-scale dust measurement methods by allowing fine scale (< 1 m^2) investigation and intervention of dust emission "hot spots". This small-scale detail will help fine-tune current sprinkler practices to better control dust emissions from feedlots and minimize water demand. The technique will also enhance research concerning dust-associated pathogens, odor compounds, and help to critically evaluate the effect of future dust emission control strategies on potential dust production prior to large-scale feedlot studies. The technique simplifies evaluation of dust control strategies by researchers and speeds the application of promising technologies.

Selected Publications:

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

Non-invasive measurement of trace gas emissions: ARS scientists cooperated with Canadian scientists to optimize the use of tunable diode laser spectroscopy to measure methane and nitrous oxide emissions and to develop a tunable diode laser spectrometer for measuring ammonia. These studies were the first to use non-interference techniques to directly measure trace gas emissions from waste lagoons and showed that previous estimates used by regulatory agencies developed from other measurement techniques were not accurate. These studies were also the first to measure the production of dinitrogen gas by biological or chemical denitrification in anaerobic waste management systems suggesting that lagoons are not simply "holding structures" for wastes but are treatment facilities as well.

In order to evaluate trace-gas emissions from cropping and animal production systems, many types of gas-concentration and atmospheric-transport technologies must be used. Often, there are no available techniques to evaluate emissions without destroying the emissions source. ARS scientists have cooperated with colleagues from the University of Alberta, CSIRO (Australia), and Agriculture and Agri-Food Canada, to develop new instrumentation for measuring trace-gas concentrations and atmospheric-transport technologies for trace-gas emissions measurement. ARS has worked with other scientists and manufacturers in the development of new sensors to measure trace-gas concentrations under field conditions such as open and closed-path laser

spectrometry. New transport technologies have been developed along with suitable complementary sensors to accurately determine appropriate emissions. ARS scientists have developed techniques to determine trace gas emissions from animal confinement systems and animals under grazing conditions. These techniques are described in the following sections and include: the micrometeorological mass-difference technique, the integrated horizontal flux technique and the backward Lagrangian stochastic analysis technique.

Impact: Techniques and instrumentation developed by ARS scientists are used by scientists in the U.S and abroad to determine trace-gas emissions factors for animal feeding operations. The animal production industry has recommended use of some of these techniques in the emissions monitoring program associated with the EPA-livestock industry consent decree. The US-EPA has used enteric methane emissions factors determined by ARS to significantly reduce the U.S. inventory contribution of greenhouse gas emissions.

Selected Publications:

Harper, L.A., O.T. Denmead, J.R. Freney and F.M. Byers. 1999. Direct measurements of methane emissions from grazing and feed lot cattle. J. Anim. Sci. 77:1392-1401.

Harper, L.A., R.R. Sharpe and T.B. Parkin. 2000. Gaseous nitrogen emissions from anaerobic swine lagoons: Ammonia, nitrous oxide, and dinitrogen gas. J. Environ. Qual. 29:1356-1365.

Sharpe, R.R. and L.A. Harper. 2002. Nitrous oxide and ammonia emissions from a soybean field fertilized with swine effluent from a waste holding lagoon. J. Environ. Qual. 31:524-532.

Harper, L.A., R.R. Sharpe and J.D. Simmons. 2004. Ammonia Emissions from Swine Houses in the Southeastern United States. J. Environ. Qual. 33 (in press).

Micrometeorological methods: ARS has been a leading innovator in the development of new atmospheric transport technologies to evaluate trace-gas emissions from animal and cropping systems. ARS scientists have designed a new technology, called the micrometeorological mass difference (MMD) technique, to measure methane emissions from cattle under pasture or feedlot conditions. This technique has been used by ARS and CSIRO in Australia, to develop nationwide inventories of enteric emissions from the countries' animal production industries. It has also been used by Italy to measure carbon dioxide emissions. ARS scientists also have designed another new technology to evaluate trace-gas emissions from confined animal production systems called the modified integrated horizontal flux (MIHF) technology. ARS and Agriculture and Agri-Food Canada evaluated this technique for global change and other trace-gases emitted from animal production systems. The MMD technique was the first truly non-invasive methodology for measuring methane emissions from animals under natural conditions. Results from these non-invasive studies have shown previous measurements using calorimeter chambers to be relatively insensitive to feedstuffs quality and animal activity, suggesting that current world animal-emission estimates generally based on calorimetric measurements can be improved.

ARS scientists have cooperated with colleagues from the University of Alberta, Alberta, Canada, to develop the backward Lagrangian stochastic (bLS) analysis technique. This technique has been used to determine trace-gas emissions from lagoons using open-path laser spectrometers measuring concentrations directly over the lagoon surface. Emissions determined by the bLS technique compared well to other classical non-interference measurement techniques. The bLS technique also has been used to determine emissions from whole farm systems, including buildings and adjacent lagoons, by taking long-path concentration measurements downwind of the structures. A further use of this technique has been to evaluate ammonia and methane emissions from a large (one-mile square) beef feedlot and a nearby retention pond. Open-path laser spectrometers were used to obtain concentrations at the lagoon and two places within and downwind of the feedlot. Emissions determined from the different locations were the same and both compared well with flux-gradient emissions determined nearby in the feedlot. The technique determined 15-min emissions thus allowing effects of management and animal activity to be observed, such as the result of animal urination on ammonia emissions and enteric emissions from ruminating periods on methane emissions.

Impact: The use of the MMD technique served as a basis for establishing guidelines for Australia's efforts to reduce global greenhouse gases from their large animal industry. An ARS scientist was asked to coauthor the report to the Australia National Greenhouse Gas Inventory Committee on verification of greenhouse gas emissions from Australia. The MIHF technique is currently in use to develop Canada's global change emissions inventory and to evaluate best management practices by which Canadian agriculture will reduce its global change emissions. The bLS technique has the potential to be a significant new technology for accurately evaluating emissions from whole farms and individual components on a farms. These new methodologies have provided major advances in measurement technologies for evaluating global warming and air-quality gas emissions under both natural and agricultural systems. Development and application of micrometeorological methods will allow area-integrating, scale-appropriate, non-interfering assessment of ammonia and other trace-gas emissions from large CAFOs.

Selected Publications:

Wilson, J.D., T.K. Flesch and L.A. Harper. 2001. Micro-meteorological methods for estimating surface exchange with a disturbed windflow. Agric. Forest Meteorol. 107:207-225.

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: (in press).

Desjardins, R., O.T. Denmead and L.A. Harper. 2004. Evaluation of a micrometeorological mass balance method employing open-path lasers for measuring methane emissions from on-farm animal operations. J. Environ. Qual. (in press).

Testing instrumentation for ambient ammonia determination: ARS has cooperated with USEPA and Battelle Labs to evaluate eight different instruments for ambient ammonia determination at a swine grow-finish unit and a beef cattle feedlot in Iowa through EPA's

Environmental Technology Verification (ETV) program. The evaluation was conducted for four weeks at each site with each instrument operated in the manner prescribed by the manufacturer. Each instrument was put through a series of tests to quantify accuracy, repeatability, and precision using a combination of known concentrations and interference gases. Ambient concentrations were determined by acid extraction methods with intensive measurements made during the second and third week of the study with the instrument stability and accuracy checks in the first and fourth week. Complete analyses of all of the data are in the final stages with the reports for each instrument in final review.

ARS scientists and university cooperators collaborated in the evaluation of a low-cost passive ammonia sampler for measuring gaseous ammonia in a wide range of natural and agricultural settings, and compared it to traditional samplers. The passive sampler requires no power and uses acid-coated filter discs to trap ammonia after the ammonia has diffused across a known distance. Results show that the Ogawa sampler can successfully estimate gaseous ammonia concentrations over a wide range of concentrations and conditions, varying from low-level ambient concentrations (2 ug NH_3-N m^{-3}) in natural environments to very high concentrations (10 mg NH_3-N m^{-3}) inside poultry houses. The large operating range is achieved by adjusting the exposure time from 5 minutes to 14 days and assuring that quantifiable amounts of ammonia are trapped. Reproducibility averaged +/- 10% over the range of conditions tested.

Impact: This is the first attempt to evaluate ammonia sensors under ambient conditions in the ETV program and the first partnership among EPA, Battelle, and USDA to conduct these tests. Rigorous evaluation of instruments proposed for use in ambient ammonia monitoring is critical to providing accurate and reliable data across a range of concentrations and atmospheric conditions. Information from these tests will be placed on the ETV website and used by prospective buyers of instrumentation to make informed decisions.

The Ogawa passive samplers, because of their ease of deployment, wide operational range, and low-cost can provide a basis for monitoring ammonia management practices in agriculture. Improving ammonia management in animal production facilities can produce economic benefits for the farmer and environmental benefits for conservationists.

Selected Publications:

Roadman, M.J., J.R. Skudlark, J.J. Meisinger and W.J. Ullman. 2003. Validation of Ogawa passive samplers for the determination of gaseous ammonia concentration in agricultural settings. Atmos. Environ. 37:2317-2325.

Emissions Component

Problem Area 11: Elucidate mechanisms responsible for emissions, and identify the underlying substrates and processes with an emphasis on the role of microorganisms.

Background: Generation of gases at animal production operations is primarily the result of microbial processes either in the gut of the animal or in manure during handling and storage. Elucidating microbial processes at all stages of manure generation, handling, storage and use will lead to an improved understanding of mechanisms controlling gas emissions. This will in turn allow development of efficient management practices and control technologies for emissions reduction**.**

Accomplishments:

Microbial ecology – swine gastrointestinal tract and manure storage pits:
ARS research has focused on understanding the microbial ecology of the swine gastrointestinal tract and manure storage pits, identifying the organism's present and determining relevant metabolic activities. This will serve as a prelude to the development of methods to promote favorable microbiological changes to reduce undesirable emissions.

Utilizing pure culture isolation techniques for anaerobic bacteria as well as culture-independent molecular biological procedures (direct 16S ribosomal RNA gene sequencing), the predominant microbial populations of swine feces and stored manure were identified. The populations were primarily low mole % (G+C), Gram-positive bacteria. Examples of genera identified include Clostridium, Lactobacillus, and Streptococcus. Although in many cases similar to known genera, the large majority of the pure cultures and 16S rDNA sequences could not be identified to the species level, and a number of completely unidentified bacteria were isolated. This work represents the first detailed analyses of the bacterial populations of swine feces and manure.

It is difficult to determine changes in bacterial populations in feces and stored manure in response to alterations in diet, pit additives, etc. One approach to determine these changes involves using direct 16S ribosomal RNA isolation. This approach is called group specific amplified ribosomal-DNA restriction analysis (GS-ARDRA). PCR primer sequences were evaluated for their specificity to ribosomal DNA from selected bacterial groups by optimizing annealing temperatures and determining specificity using a set of primer target and non-target organisms. A number of primer sets were identified targeting the following groups: *Bacteroides-Prevotella*, clostridial clusters I and II, clostridial clusters IX and XI, clostridial clusters XIVa and XIVb, *Lactobacillus*, *Desulfovibrionaceae* and *Streptococcus-Lactococcus*, as well as an universal primer set to represent total populations. GS-ARDRA was applied to swine fecal and manure storage pit samples obtained on two separate occasions. Fecal and manure storage pit samples obtained on the same day were more similar to each other than to any other samples. Results were consistent with 16S ribosomal DNA sequencing data from bacterial isolates and clones obtained from swine feces and manure storage pit. The GS-ARDRA technique was able to rapidly detect gross bacterial community differences among swine fecal and manure storage pit samples and determine groups of interest for more detailed examination.

Impact: These results will benefit the scientific community by allowing researchers to rapidly screen a large number of samples and determine which bacterial groups warrant more detailed analysis. Researchers can then develop intervention strategies for reducing emissions by focusing on the predominant bacterial populations in stored swine manure.

Selected Publications:

Whitehead, T.R. and M.A. Cotta. 2001. Characterization of microbial populations in swine feces and manure storage pits by 16S rDNA gene sequence analyses. Anaerobe 7:181-187.
Cotta, M.A. and T.R.Whitehead. 2003. Isolation, characterization, and comparison of bacteria from swine feces and manure storage pits. Environ. Microbiol. 5:737-745.
Ziemer, C.J., M.A. Cotta and T.R.Whitehead. 2004. Application of group specific amplified rDNA restriction analysis to characterize swine fecal and manure storage pit samples. Anaerobe (in press).

Inhibition of microbial activity: Testing of compounds for inhibition of microbial activity in *in vitro* swine manure slurries was initiated. Previous work in our laboratory indicated that the major bacterial populations of stored swine manure were Gram-positive bacteria. Monensin, an ionophore normally fed to ruminants where it is inhibiting to Gram-positive bacteria, was tested in *in vitro* swine manure slurries. Gas production (methane, carbon dioxide, hydrogen) was reduced significantly within 24 hr of monensin addition as compared to control slurries. Production of volatile fatty acids was also altered. Subsequent work on pure bacterial cultures from swine manure showed that many of the cultures produced compounds associated with swine odor, but few of the isolates were capable of producing significant amounts of ammonia. Therefore, additional pure cultures of bacteria were isolated from stored manure and shown to be capable of growing on various protein sources and producing large amounts of ammonia. These bacteria are termed hyper-ammonia producing bacteria. When monensin was tested with the Gram-positive hyper-ammonia producers, growth and ammonia production was almost completely inhibited by the compound.

Impact: These results show that compounds that inhibit Gram-positive bacteria may be promising candidates for odor reduction. The selective inhibition of microbial activity in stored manure could greatly benefit the pork industry by potentially reducing ammonia and other emissions from stored swine manure.

Selected Publications:

Cotta, M.A., R.L. Zeltwanger and T.R. Whitehead. 2001. Effects of Monensin on microbial activity in *in vitro* swine manure slurries. International Animal Agriculture and Food Science Conference. Indianapolis, Indiana.

Whitehead, T.R. and M.A. Cotta. 2004. Isolation and identification of hyper-ammonia producing bacteria from swine manure storage pits. Curr. Microbiol. 48:20-26.

Identification of sulfate-reducing bacteria in swine feces and stored manure: Specific emissions from large-scale animal facilities, such as hydrogen sulfide, have been identified as potential targets for regulation by state and federal agencies. Research was conducted to identify sulfate-reducing bacteria, which produce hydrogen sulfide, in swine feces and stored swine manure. Initial results indicated very low levels of these bacteria in feces, but much higher concentrations in stored manure. Identification by pure culture and culture-independent (16S ribosomal RNA gene based) methods indicated the presence of both known and unidentified genera of sulfate-reducing bacteria.

Impact: This is the first study to identify sulfate-reducing bacteria in stored swine manure. The information generated will allow researchers to determine levels of such bacteria in manure and develop methods to reduce those levels, thus reducing hydrogen sulfide emissions.

Substrates for odor formation in feces: As manure ages, a variety of malodorous products (alcohols, volatile fatty acids, and aromatic-ring containing compounds) accumulate and may be emitted. The biochemical origins of odor compounds, however, are not well understood. ARS scientists determined that the primary substrates for odor formation in swine and cattle fecal slurries, in cattle feedlot manure and soil pan incubations were starch and protein, whereas there was no evidence that cellulose served as a source for production of odorous compounds. Furthermore, the relative contribution of fecal starch and protein differed between feedlot cattle and swine with most odor compound production in cattle feces coming from starch fermentation, while odor compound production in swine feces came from equal parts protein and starch.

Impact: These insights into the mechanism of odor compound production will ultimately allow development of diet formulations that minimize odor compound production.

Potential for denitrification in beef feedlot soil: A major pathway for nitrogen loss to the atmosphere is through ammonia volatilization. However, another important pathway, not well understood, is biological denitrification. The potential for denitrification in beef feedlot soil was shown to vary greatly with location, depth, and season. Some locations maintained denitrification potentials of 132 mmol g $soil^{-1}$ hr^{-1} equivalent to those of summer cultivated soils, even when ambient temperatures neared $0^{o}C$. The surface soil maintained the highest level of microbial activity and this decreased to near zero at 10 cm depth. While dinitrogen gas is the end product of denitrification, volatile intermediaries like the greenhouse gas N_2O can be lost to the atmosphere.

Impact: Documentation of potential feedlot surface denitrification would provide base-line information to develop management strategies that favor denitrifying to the exclusion of greenhouse gas intermediaries. This would allow control of N_2O losses from feedlot surfaces.

Selected Publications:

Woodbury, B.L., D.N. Miller, J.A. Nienaber and R.A. Eigenberg, R.A. 2001. Seasonal and spatial variations of denitrifying enzyme activity in feedlot soil. Transactions of the ASAE 44:1635-1642.

Reducing enteric emissions from beef cattle: ARS scientists focused on techniques to measure and reduce enteric methane emissions from grazing cattle. Several treatments were studied including normal medium-quality forage, several types of high-quality forage, forage with a protein ration, and forage with ionophore treatment. Measurements were made using a non-interference technique called the micrometeorological mass-difference (MMD) technique, giving enteric emissions measurements from the animals under normal grazing conditions where grazing selection of herbage was not perturbed. Enteric methane emissions were reduced (in relation to productive gain) with increase in forage quality and grain feeding in a feedlot confinement operation. The addition of an ionophore produced a decrease in methane emissions of 55% compared to a control (medium-quality) grazing situation. Addition of an ionophore to animals receiving a protein supplement produced a decrease by 62%.

Impact: Addition of ionophores to grazing animals diet may increase production efficiency by reducing the energy lost by animals due to methanogenesis if appropriate methods for delivery of the additive are developed.

Selected Publications:

Harper, L.A., O.T. Denmead, J.R. Freney and F.M. Byers. 1999. Direct measurements of methane emissions from grazing and feed lot cattle. J. Anim. Sci. 77:1392-1401.

Reducing ammonia emissions from swine wastewater: ARS scientists developed innovative methods to enhance biological removal of N in wastewater containing high ammonia concentration through the use of bacterial immobilization technology. Treatment systems to manage nitrogen in wastewater depend on microbial transformations of nitrogen from ammonium to nitrate forms (nitrification) and from nitrate to nitrogen gas (denitrification). The nitrification step converts nitrogen to a form that will not be emitted to the environment as ammonia gas. However, it is difficult to maintain a high population of nitrifying bacteria in animal wastewater with high ammonia and biochemical oxygen demand. ARS scientists adapted a Japanese municipal wastewater treatment technology to enhance removal of ammonia from swine wastewater. The research showed that with proper acclimation techniques, cultures of nitrifying bacteria could be adapted to high-ammonia strength wastewater and immobilized and used effectively to treat very concentrated (2600 ppm ammonia-N) animal wastewater. Nitrification rates of 650 grams of N per cubic meter of reactor per day with virtually no ammonia losses were obtained in a pilot study treating lagoon swine wastewater. A second pilot study successfully demonstrated the use of immobilization technology to efficiently treat N after solid-liquid separation of flushed swine manure. Odors also are eliminated in the process.

Impact: The technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The technology is currently being used as part of a system of treatment technologies to manage swine wastewater on a 4300 head swine finishing facility in North Carolina. The entire system can serve as a viable alternative to anaerobic lagoons.

Selected Publications:

Vanotti, M.B. and P.G. Hunt. 2000. Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets. Trans. ASAE 43:405-413.

Vanotti, M.B., P.G. Hunt, J.M. Rice and F.J. Humenik. 2000. Nitrifying high-strength wastewater. Industrial Wastewater, Sept./Oct. pp. 30-36. Water Environment Federation, Alexandria, VA.

Emissions Component

Problem Area 12: Determine rates of emissions in relation to manure production, handling, storage, processing, and land application.

Background: Emission rates of gases and particulate matter from animal production facilities, manure storage areas and field application sites are not well documented. In addition, emission rates vary widely with time, animal production system, life stage of the animal, and environmental conditions. Scientifically sound estimates of emission rates of ammonia, hydrogen sulfide, VOCs and other gases from animal production operations are not available for use in regulatory and management programs to control emissions.

Accomplishments:

Non-invasive measurement of trace gas emissions: ARS scientists helped develop concepts, designed new and/or modified existing atmospheric transport technologies, and participated in cooperative research efforts with USDA, university, and international scientists to non-invasively determine trace gas emissions from animal feeding operations. New non-interference micrometeorological measurement techniques were used for evaluation of ammonia, nitrous oxide, and methane emissions from anaerobic lagoons, field application sites, and confinement housing. ARS scientists also developed micrometeorological principles to measure ammonium nitrate and ammonium sulfate aerosol transport in cropping systems and developed a measurement technique to evaluate ammonia loss during spray application of animal wastes. These scientists did systems' analyses of the production systems and found a significant amount of previously-unknown nitrogen emissions in these systems. Based on these findings, procedures were developed for measuring dinitrogen and nitrous oxide production and emissions in anaerobic waste lagoons that led to the hypothesis of chemical and biological denitrification in these systems, accounting for most of the unaccountable nitrogen for waste treatment lagoons and for the whole-farm. ARS scientists developed the first total nitrogen mass-balance of a swine feeding operation showing that much of the nitrogen entering the swine system left the operation as benign dinitrogen gas instead of air-quality or global-change trace gases. The acquisition of verifiable emissions from these systems allowed ARS scientists, in cooperation with U.S. and international scientists, to develop ammonia emissions models for prediction of emissions from lagoons and animal housing. These models are being used in lieu of expensive measurement techniques.

Impact: Ammonia emissions and emission factors derived by ARS research are being used, along with other developed emission factors, by the Division of Air Quality, North Carolina, and the North Carolina State Legislature to enact appropriate laws to regulate trace gas emissions. These ammonia emissions and emission factors were some of the first derived in the U.S. using non-interference techniques and were the first internationally to show nitrogen gases other than ammonia (dinitrogen and nitrous oxide) were emitted from anaerobic lagoons. These studies also showed that atmospheric nitrous oxide may be consumed by lagoons in certain circumstances. Studies by ARS were also some of the first to evaluate confinement house trace gas emissions in the U.S., leading to a better understanding of trace gas emissions from confined animal

production systems. These studies represented the first attempt to evaluate and establish a total nitrogen balance (incoming feed nitrogen and outgoing animal, plant, waste, and atmospheric nitrogen) for an entire animal feeding operation. The emissions determined were realistic and did not show more nitrogen leaving the operation than entered; or that significant nitrogen pools remain unidentified. As a result of the development of realistic emissions inventories, ARS was asked to develop total nitrogen balance for other swine and beef-feeding operations.

Selected Publications:

Sharpe, R.R. and L.A. Harper. 1999. Methane emissions from an anaerobic swine lagoon. Atmos. Environ. 33:3627-3633.

Harper, L.A., R.R. Sharpe and T.B. Parkin. 2000. Gaseous nitrogen emissions from anaerobic swine lagoons: Ammonia, nitrous oxide, and dinitrogen gas. J. Environ. Qual. 29:1356-1365.

Sharpe, R.R. and L.A. Harper. 2002. Nitrous oxide and ammonia emissions from a soybean field fertilized with swine effluent from a waste holding lagoon. J. Environ. Qual. 31:524-532.

Harper, L.A., R.R. Sharpe and J.D. Simmons. 2004. Ammonia Emissions from Swine Houses in the Southeastern United States. J. Environ. Qual. 33: (in press).

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: (in press).

Variability in ammonia emissions from swine production facilities: Previous ammonia emissions measurements from livestock production units have been made over relatively short periods of time and don't represent the entire animal production cycle. Ammonia concentrations were measured at four locations adjacent to a swine grow-finish unit. These measurements were made continually for a week and then repeated every other week throughout the cycle of removing pigs from the barn at market weight through repopulation with small animals through the complete production cycle. Large variations in ammonia emissions were found within and among days. Part of the variation was induced by management of the building and the presence of animals. Ammonia concentrations were affected by the turbulence structure adjacent to the building. These results demonstrate that emission rate calculations will require determination of turbulence as part of the measurement technique. Concentrations varied from 950 ppb at 6 m downwind of the exhaust fans to 23 ppb at 33 m downwind at a height of 1 m above the ground. Concentrations decreased very little with the 6 and 12 m height above the ground at the 33 m position. Typical concentrations adjacent to the exhaust fans were around 200 ppb with a decrease to less than 20 ppb at the 12 m height. Concentrations changed rapidly over a half-hour period and suggested the need to develop fast-response ammonia sensors to quantify the emissions from livestock production buildings.

These extreme variations in the ammonia concentrations with position adjacent to the building served as the impetus for Lidar studies of air-flow around buildings to document the turbulence

structure induced by the building. These studies were conducted in cooperation with the University of Iowa and the Los Alamos National Laboratories. A particulate and water vapor Lidar were positioned adjacent to a swine grow-finish unit. Measurements were made of the particulate and water vapor plumes emitted from the building throughout the day over the course of a four-week period. Concurrent measurements were made of the turbulence around the site with sonic anemometers at five different positions to capture the turbulent exchange in a number of different wind directions. Observations from the Lidar unit showed that vertical velocities of air ranged between 1 and 5 m s^{-1}, which is much larger than expected. These data are being evaluated to determine how to develop guidelines for measuring emission rates from production buildings and how to quantify atmospheric exchanges adjacent to buildings to couple with dispersion models.

Impact: Information on ammonia emissions from buildings is critical to understand the dynamics of emission rates and the potential source term for dispersion models. An improved understanding of ammonia emissions will allow development of improved management systems to reduce these emissions. The information will help air quality regulators understand the extreme variation present around swine production units.

Selected Publication:

Hatfield, J.L. and R.L. Pfeiffer. 2002. Measurement of ammonia emissions from swine production facilities and from manure application to cropland. Report to National Pork Board, Project 58-3625-2-444. 9 pages.

Ammonia emissions from a beef cattle feedyard: The flux-gradient micrometeorological method along with gas washing and wet chemistry were successfully used to determine ammonia emissions from a commercial beef cattle feedyard in summer and winter. Measurements of wind speed, air temperature, and atmospheric ammonia concentration were used to estimate ammonia emissions. Nitrogen lost as ammonia ranged from 900 to 2700 kg d^{-1} during summer trials and from 500 to 600 kg d^{-1} during a winter trial.

Impact: Accurate determination of ammonia emission rates collected over a wide range of seasonal and environmental conditions will allow calculation of ammonia emission factors for beef feedyards. This information will benefit beef cattle producers and air quality regulators, who will need more accurate, scientifically determined emission factors for ammonia.

Hydrogen sulfide emitted from b**eef cattle feedlots:** Total reduced sulfur (TRS) in the vicinity of beef cattle feedlots was monitored and compared to Nebraska regulatory thresholds. This study was prompted by a Nebraska Department of Environmental Quality request for voluntary compliance by livestock producers to the Nebraska Total Reduced Sulfur Regulations. Research showed that TRS levels in the vicinity of beef cattle feedlots did not exceed Nebraska regulatory thresholds. Rainfall and wet surface conditions had minimal impact on TRS levels.
Impact: Data from this study became the basis for a request by the Nebraska Cattlemen Association to the Nebraska Department of Environmental Quality to exempt beef feeding operations from the voluntary compliance to Title 129-Air Quality Regulations. An exemption

was granted by the Nebraska Department of Environmental Quality. Cattle producers and feedlot operators benefited from this research by exemption of compliance with a regulation where demonstration of compliance would have been difficult and expensive.

Selected Publication:

Koelsch, R.K., B.L. Woodbury, D.E. Stenberg, D.N. Miller and D.D. Schulte. 2004. Total reduced sulfur concentrations in the vicinity of beef cattle feedlots. Applied Engineering in Agriculture 20: 77-85.

Ammonia losses from land application of manure: There is a paucity of U.S. data on field ammonia volatilization, despite the EPA guideline to develop ammonia control strategies for CAFOs. Ammonia volatilization from land application of manures was studied with micro-meteorology and wind tunnel techniques. Dairy slurries had the highest emission rates with about 40% of the slurry ammonium-N lost within 6 hours and about 50% lost the first day. The corresponding average ammonia fluxes were about 3.4 kg NH_3-N ha^{-1} hr^{-1} over the first 6 hours and 1 kg NH_3-N ha^{-1} hr^{-1} over the first day. Ammonia emissions from dairy slurries were small beyond the second day. Poultry litters, on the other hand, had substantially lower emission rates amounting to losses of about 3.5% of the litter ammonium-N (0.5 kg NH_3-N ha^{-1} hr^{-1}) during the first 6 hours and 6% lost (0.2 kg NH_3-N ha^{-1} hr^{-1}) over the first day. Poultry litters continued to lose ammonia at a nearly constant rate over 2 weeks, with a typical daily emission rate of 3% of the litter ammonium-N (0.1 kg NH_3-N ha^{-1} hr^{-1}). ARS scientists, using micrometeorological techniques in the humid Southeast found that the total percentage of ammonia emissions from field application of swine wastes effluent was quite small, about 2% of the total nitrogen input into the swine operations. Nitrous oxide losses were also quite small representing about 0.1% of the total nitrogen input.

Impact: These results have shown that ammonia volatilization from land applied manure can be a major N loss process. The results also document the time-line for ammonia volatilization and suggest the most useful ammonia conservation strategies for land-applied manures. For example, ammonia control strategies for dairy slurries must be employed soon after application to avoid rapid initial loss of ammonia. Data from this research also can contribute to the development of a decision support module for improving estimates of ammonia volatilization from land application of manure. This information will contribute to the development of improved nutrient management plans.

Selected Publications:

Thompson, R.B. and J.J. Meisinger. 2001. Measurement and management of ammonia volatilization from dairy slurries. pp. 301-310. In G. B. Havenstein (ed.) Addressing animal production and environmental issues. Proc. International symposium Oct 3-5, 2001, Raleigh, NC.

Meisinger, J.J., C.J. Schomburg, P. M. Zara and R.B. Thompson. 1999. Ammonia emissions from field applications of poultry litter. pp. 176-184. In Atmospheric nitrogen compounds II:

Emissions, transport, transformations, deposition and assessment. June 7-9,1999. Raleigh, NC. N. Carolina Dept. Environ. and Nat. Res. and N. Carolina Dept. Marine, Earth & Atmos. Sci.

Methane and nitrous oxide emissions: Methane and nitrous oxide are greenhouse gases that can be emitted from manure storage and field application systems. A study was conducted to compare the effects of different land use patterns on methane emissions. One of the treatments evaluated in this study was a land surface covered with broadcast swine manure. The mean methane flux for cultivated corn/soybean systems receiving liquid swine manure in a year ranked in the 100th percentile for annual rainfall (1436 mm), was 0.16 g methane/m2/y. In a more typical year with respect to rainfall, mean methane flux from the same fields was 0.06 g methane/m2/y. Cultivated corn/soybean fields not receiving liquid swine manure had mean methane fluxes of 0.13 and - 0.06 g methane/m2/y in the wet and normal year, respectively. Increased methane fluxes observed in the swine manure-amended fields usually occurred soon after manure application, and it is hypothesized that a majority of the increased methane flux was due to out-gassing of dissolved methane in the liquid swine manure. Landfills and swine manured fields were net emitters of methane over the two years of the measurement period. Differences between the two years of the study were due to differences in rainfall. Estimated net methane flux for Iowa was 139,000 Mg per year.

Soil emissions of N_2O, CO_2, and CH_4 were measured (mostly during the growing season) from 1999 to 2001 on irrigated and rainfed sites cropped to continuous corn. The soils in both sites were treated annually with beef feedlot manure, swine manure (rainfed only), N-fertilizer, and no-treatment check since 1998. In the irrigated site, growing season N_2O flux in 1999 was 38.4 g N ha^{-1} d^{-1} higher in the fertilizer (anhydrous ammonia) than the cattle manure, and cattle manure was 18.8 g N ha^{-1} d^{-1} higher than the check (8.6 g N ha^{-1} d^{-1}). In the 2000 growing season, N_2O flux of the fertilizer treatment was 28.9 g N ha^{-1} d^{-1} higher than the cattle manure and cattle manure was 42.9 g N ha^{-1} d^{-1} higher than the check (11.8 g N ha^{-1} d^{-1}). In the rainfed site, N_2O flux was similar among treatments except within 10 d after manure and N fertilizer applications where the effects of manure and N fertilizer were in the order: 119 g N ha^{-1} d^{-1} for swine manure, 71 for fertilizer, 43 for cattle manure, and 35 for the control treatment.

Impact: This information provides direct evidence of the amount of methane and nitrous oxide that can be released from agricultural systems. These data can be used to help develop improved inventories of greenhouse gas emissions from land surfaces. These data can help policymakers understand the dynamics of greenhouse gas emissions from different systems and indicate potential mitigation strategies.

Selected Publications:

Chan, A.S.K. and T.B. Parkin. 2000. Evaluation of potential inhibitors of methanogenesis and methane oxidation in a landfill cover soil. Soil Biol. Biochem. 32:1581-1590.

Chan, A.S.K. and T.B. Parkin. 2001. Effect of land use on methane flux from soil. J. Environ. Qual. 30:786-797.

Chan, A.S.K. and T.B. Parkin. 2001. Methane oxidation and production activity in soils from natural and agricultural ecosystems. J. Environ. Qual. 30:1896-1903.

Compston, S.R., C.P. West, T.J. Sauer and T.B. Parkin. 2001. Nitrous oxide emissions from poultry litter-amended bermudagrass pastures. American Forage and Grassland Council Proceedings. Springdale, AR April 22-25, 2001, Vol. 10, pp. 126-130.

Eghball, B., D. Ginting, C.A. Shapiro, J.S. Schepers and C.J. Bauer. 2002. Manure as carbon source for soil improvement and crop production: Site-specific application. *In* A. J. Schlegel (ed.) Proceedings of the Great Plains Soil Fertility Conference 9:22-28.

Ginting, D., A. Kessavalou, B. Eghball and J.W. Doran. 2003. Greenhouse gas emissions and soil indicators four years after manure and compost applications. J. Environ. Qual. 32:23-32.

Ginting, D., B. Eghball, C.A. Shapiro and A. Kessavalou. 2004. Nitrous oxide emission from soil after manure and fertilizer applications. J. Environ. Qual. (in press).

Emissions Component

Problem Area 13: Determine the effect of environmental conditions on generation and transport of emissions.

Background: Environmental conditions have a major impact on emission rates of gases and particulate matter. Variations within a day and among days interact with land surface characteristics to influence transport of emissions. Gaseous exchange processes between animal production operations and the atmosphere are complicated. For example, the turbulence structure at the surface of a lagoon depends on the wind direction, vegetation around the lagoon, layout of the site, topography, and prevailing atmospheric conditions. New approaches will be needed to determine environmental impacts on transport and dispersion of gases and particulate matter from animal production operations.

Accomplishments:

Influence of climatic factors on emissions of ammonia from swine lagoons:
ARS scientists have used non-interference techniques to measure ammonia emissions from swine waste-processing lagoons. Ammonia is a diffusive gas (as opposed to a biological gas such as methane) and these investigations have shown that there are four important physical and chemical parameters that must be carefully observed and considered in the measurement process. These factors include the ammonium concentration of the aqueous solution, the temperature of the solution, the pH of the solution, and the turbulence of the air creating the transport process of the diffusive gas. These studies have shown that the climatic effect of turbulence is the strongest factor effecting emissions on a short-term basis (two to three weeks). The climatic effect of turbulence accounts for about 70% of the transport influence. On a long-term (6 to 12 months) basis, aqueous temperature is the next most dominant effect, influencing partial pressure of ammonia in aqueous solution. At about $3^{o}C$, ammonia emissions cease regardless of turbulence or its chemical factors. The solution concentration and pH both influence the partial pressure of ammonia in solution, but most studies show that these factors are relatively constant in steady-state waste processing lagoons. Initial design features for the waste-management system usually determine these concentrations. These studies suggest that ammonia emissions from lagoons can be reduced by management practices that reduce turbulence, decrease pH and manage temperature.

Impact: Determination of the effect of climatic and physical factors on lagoon ammonia emissions has led to the development of two statistical emissions models that are limited in scope (limited by the data upon which the models were developed) but are quite accurate in the geographic area where they were developed. A process model has been developed and tested on available data and found to give good results compared to measured ammonia emissions, regardless of geographical aspects. Understanding the influence of climatic factors on ammonia emissions has led to the development of improved and more appropriate measurement technologies for determining ammonia emissions.

Selected Publications:

DeVisscher, A., L.A. Harper, P.W. Westerman, R.R. Sharpe and O. Van Cleemput. 2002. Ammonia emissions from anaerobic swine lagoons: Model development. J. Appl. Meteorol. 41:426-433.

Harper, L.A., R.R. Sharpe and T.B. Parkin. 2000. Gaseous nitrogen emissions from anaerobic swine lagoons: Ammonia, nitrous oxide, and dinitrogen gas. J. Environ. Qual. 29:1356-1365.

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: (in press).

The influence of microclimate on emissions from manure storage systems: Manure storage systems, e.g., earthen or concrete storage or lagoons, are placed adjacent to swine production buildings. There is little understanding of the microclimate that exists around and within manure storage systems and the magnitude of these changes throughout a year. A study was conducted on the microclimate around lagoon systems in Iowa, Arkansas, and North Carolina. Microclimatic variables measured were air temperature, relative humidity, windspeed, and wind direction. Solar radiation was measured at one location at each site.

Microclimate surrounding manure storage is dependent upon the interaction of the building location, windspeed, wind direction, and the surrounding vegetative cover. The microclimate within the manure storage unit is dependent upon the general atmospheric conditions and the time of year. Production complexes for animals create a unique microclimate for the manure storage system that affects the energy exchange rate between the surface of the manure storage system and the atmosphere. When the buildings shelter the manure storage from wind movement there is less movement from the surface of the manure storage unit to the atmosphere compared to conditions when the air moves directly across the manure storage unit. The emission rate from manure storage systems cannot be estimated by a general measurement of windspeed at the location because of the effect of buildings on exchange rates. At the Iowa location, crop growth during the year also provided a sheltering effect on exchange rates. Understanding these processes demonstrate why production units produce different environmental impacts and dispersion characteristics.

Impact: These findings can be used to assess the potential impact of tree barriers on the gas exchange processes at a swine production complex. Understanding and documenting these microclimatic processes contributed to an understanding variation in emission rates from different production units, and how these rates vary throughout the year. This information has helped producers and regulators be more aware of the changes and potential atmospheric impacts from the complex structures around a swine production facility. This information has been valuable in the development of monitoring studies for emissions from different manure storage systems and to demonstrate the magnitude of changes that occur in emission rates throughout a year.

Selected Publications:

Hatfield, J.L. 2002. Minimizing the environmental impact of the pig industry. Proceedings of the 17th IPVS Congress, Ames, Iowa. June 2-5, 2002. pp. 95-104.

Hatfield, J.L., J.H. Prueger, R.M. Cionco, T.J. Sauer, R.L. Pfeiffer, L.E. Hipps and J.A. Zahn. 2000. Air flow and microclimate around earthen manure storage units. Proc. Air Pollution from Agricultural Operations. ASAE. St. Joseph, MI. pp. 124-131.

Dispersion of gases from swine production facilities: Fluxes of gases from swine production sites are due to the concentration of the particular gas and the rate of exchange with the atmosphere. Measurement of the concentration of gases is relatively simple with the primary assumption that the measurement location for the instrument samples the mean concentration in the plume. However, there has been no direct measurement of the shape of the plume around livestock buildings or the variation in the shape of the plume over short intervals. Evidence collected from previous studies of windflow and eddy diffusivity across rough terrain suggested that the turbulence structure surrounding swine production units would be extremely complex. A Lidar system was positioned adjacent to a swine grow-finish unit to measure both particulate and water vapor release from this complex of buildings. These measurements allowed the entire plume of water vapor and particulates to be measured from the building and for several hundred meters downwind. Five sonic anemometers and CO_2 and H_2O vapor sensors were placed at 10 m height in an array around the building complex to sample turbulence of the air and concentration of gases under a range of wind directions.

The plume of particulates and water vapor varied with windspeed and wind direction and did not behave as a Gaussian plume in terms of shape and size. During one series of days when the buildings were warmer than the surrounding air the plumes rose vertically into the air and showed very little movement downwind. Vertical velocities of particulate plumes ranged from 1 to 5 m $s^{-1,\ which}$ are larger than expected velocities from current theories on dispersion. On other days the plumes moved downwind but varied in depth and mean concentration of particulates and water vapor. An interesting observation was that the plumes of particulates and water vapor increased dramatically with increased animal activity within the buildings.

Impact: These observations document the complexity of sampling adjacent to swine production barns and the need to quantify plume dynamics before realistic measurements can be made of the atmospheric concentrations of gases or particulates. Quantifying these changes with varying windspeed and wind direction will provide new insights into the linkage of agricultural sources into dispersion models. The information demonstrates the need for improved measurement methodologies for livestock buildings. This information will benefit producers and scientists because we now have a better understanding of where measurements of atmospheric emissions need to be made to quantify emission rates from livestock buildings.

Selected Publications:

Cionco, R.M., J.H. Prueger, J.L. Hatfield and L.E. Hipps. 2000. Dispersion modeling of atmospheric compounds across a valley in southern Utah. August 14-18, 2000.
Flesch, T.K., J.H. Prueger and J.L. Hatfield. 2002. Turbulent Schmidt number from a tracer experiment. Agric. Forest Meteorol. 111:299-307.

Ammonia emissions from a beef cattle feedyard: Profiles of wind speed, air temperature, atmospheric ammonia concentration, and other meteorological variables were measured at a commercial beef cattle feedyard during two summer trials and one winter trial. Ammonia emission rates were determined using the flux-gradient method. During the winter trial, ammonia flux rates averaged 360 g ha^{-1} h^{-1} in the daytime and 260 g ha^{-1} h^{-1} during nighttime. During the summer, ammonia flux rates were more variable, ranging from 400 to 1600 g ha^{-1} h^{-1} during nighttime and from 400 to 2400 g ha^{-1} h^{-1} during daytime. Variability in the summer was influenced by temperature, substrate moisture and precipitation.

Impacts: Although more research is required in this area, correlation of environmental conditions with ammonia emissions and elucidation of mechanisms involved will lead to development of more accurate process based models. Cattle feeders and regulators could potentially benefit from more accurate, scientifically determined emission rates and predictive models.

Ammonia emissions in a broiler house: Gas fluxes from broiler litter, including ammonia, nitrous oxide, carbon dioxide, and methane, were measured using a photoacoustic multigas analyzer and flux boxes. Samples were collected systematically throughout the house along a set grid. Litter samples, taken at the same grid points, were used to determine litter pH, moisture, total Kjeldahl nitrogen, ammonium, nitrate, phosphate and total metals. Twenty-eight flocks had been grown on the litter prior to the summer flock sampling with chicks in the house at one (placement) and 21 (mid-growout) days of age. At one day of age during half-house brooding, average NH_3 flux was 498 mg/m^2 hr for the brood area and 372 mg/m^2-hr for the vacant end of the house. At day one, brood litter temperatures exceeded temperatures in the nonbrood half of the house by 3.3 C, and yielded an increase in ammonia flux of 126 mg/m^2 hr over the nonbrood area. Brood litter temperatures were 4 C less than nonbrood at day 21 which produced a decrease in average ammonia flux of 174 mg/m^2-hr for the brood area. Contour plots demonstrated a peak area for NH_3 flux in mid-growout approximately 7 m past the midpoint of the house (towards the fans) and correlated to high pH (~8), high litter moisture (~33%), and high CO_2 flux (12500 mg/m^2-hr). The results show the importance of small environmental changes on pollutant gas concentrations in the broiler house.

Impact: This research offers an applied approach to assess ammonia emissions and to quantify factors affecting generation of emissions and how these parameters can be controlled. By understanding litter property relationships to gas fluxes, scientists can develop recommendations such that growers have alternative management strategies for controlling gas emissions while maintaining economically viable production systems.

Selected Publications:

Miles, D.M., P.R. Owens, D.E. Rowe and S.L. Branton. 2004. Litter gaseous flux for broiler chicks at one day of age. Poult. Sci. 83 (supplement 1): (in press).

Owens, P. R., D.M. Miles, and D.E. Rowe. 2004. Using geostatistics to determine the variability of nutrient species in a poultry house. Poult. Sci. 83 (supplement 1) (in press).

Emissions Component

Problem Area 14: Determine the impact of emissions on human health, animal health and the environment.

Background: Emissions of gases and particulate matter from animal production operations have been associated with decreased quality of life in rural communities including potential health effects on animals, workers, and neighbors. Ammonia emissions result in nutrient deposition onto the landscape resulting in potential ecological impacts while emissions of methane, nitrous oxide and ammonia can contribute to global climate change. Linkage between emissions from animal production operations and environmental or health impacts will require an integrated approach including several scientific disciplines and organizations. Determination of the impact of emissions from livestock sources will require accurate emission data, validated dispersion models, and accurate information concerning emissions from non-livestock sources.

Accomplishments:

Ammonia reduction in broiler houses: Phosphorus runoff and ammonia emissions are two of the biggest problems facing the animal industry. An ARS scientist discovered that alum (aluminum sulfate), when added to poultry litter in commercial broiler houses, greatly lowers ammonia levels in the houses and results in significantly healthier birds. Birds grown in alum-treated houses are significantly heavier (0.15 lb), have better feed conversion (6 points), lower mortality (0.3%), reduced condemnation (0.5%), and heating costs during winter months are significantly lower (11% less propane is used since less ventilation is required to remove ammonia). Alum also kills pathogens in the litter, such as *Campylobacter* and *Salmonella*.

Impact: The use of alum in poultry houses is very cost effective; producers make an additional two dollars for every dollar spent. As a result, roughly 600 million broilers were grown with alum during the past year. Several of the nation's largest broiler complexes are cost-sharing this practice with the growers, mainly because of improvements in feed conversion and condemnation. Alum treatment of poultry litter is an approved practice funded by USDA-NRCS through the Environmental Quality Incentives Program.

Selected Publications:

Moore, P.A., Jr., T.C. Daniel and D.R. Edwards. 2000. Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminum sulfate. J. Environ. Qual. 29:37-49.

Smith, D.R., P.A. Moore, Jr., B.E. Haggard, C.V. Maxwell, T.C. Daniel, K. Vandevander and M.E. Davis. 2004. Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure. J. Anim. Sci. 82:605-611.

Ammonia reduction in laying hen houses: An ARS scientist developed and successfully tested a liquid alum delivery system for reducing ammonia levels in high-rise laying hen houses. High-rise laying hen houses have the highest level of ammonia of all animal rearing facilities.

Due to logistical constraints, it is not possible to use dry alum in the facilities as is done in broiler houses. Hence a liquid alum delivery system was designed, developed, installed and tested in a high-rise laying hen house. Data on ammonia levels, egg production, egg quality and manure chemistry were collected in a commercial hen house. This patented system has been shown to reduce ammonia levels from over 90 ppm to less than 10 ppm for just a few dollars a day. The alum scrubs the ammonia out of the air, rather than preventing it from volatilizing. This improves worker safety in this environment, while improving egg production by the birds. The system was turned on for a month and off for a month over an 8 month period. When the system was on, egg production was 3.3% higher (35,722 vs 34,574 doz/wk). Feed conversion was also much better when the system was on (2.94 vs 3.02). On average the system used about $110 worth of alum per week, however, increased hen performance was valued at $536/week; resulting in a net return of $426/week. Therefore, this system appears to be a cost-effective method of controlling ammonia emissions from hen houses.

Impact: While this system has significant potential, it has not been widely adopted, as has treatment of broiler litter with alum. However, it does provide egg producers with a cost-effective means of improving egg production while making the work place safer.

Selected Publication:

Wilson, M.G., P.A. Moore, Jr., T.C. Daniel, and D.R. Edwards. 2000. Effects of applying alum to hen manure in a high rise layer operation on ammonia volatilization and phosphorus runoff. Proceedings of 2000 Southeastern Commercial Egg Producers Forum. pp. 57-63.

Particulate matter emissions from beef cattle feedyards: ARS scientists collected dust particles, over 8 day periods in both summer and winter, from upwind and downwind locations at four large beef cattle feedyards. Mean dust concentrations of particles PM10 or larger were significantly greater at positions downwind from the feedlot, while concentrations of PM2.5 size dust particles were the same at upwind and downwind locations. The mean upwind PM10 collection was 1.5 mg/24 hour period compared to 3.3 mg/24 hour period downwind. The mean PM2.5 collection was 0.4 mg/24 hour period at both upwind and downwind locations.

Impact: These results suggest that feedyards are not significant generators of PM2.5 dust particles that are respirable and can negatively impact animal and human health, but are sources of larger PM10 particles. Cattle feeders, residents near feedyards, and the public in general can benefit from knowledge of dust emissions from feedyards that may influence human and animal health and the environment.

Selected Publication:

Chirase, N.K., C.W. Purdy and J.M. Avampato. 2004. Effect of simulated ambient particulate matter exposure on performance, reactal temperature and leukocytosis of young Spanish goats with or without tilmicosin phosphate. J. Animal Science (in press).

Influence of particulate matter associated nutrients on native shortgrass prairie: A native shortgrass prairie downwind from a 25,000 head beef cattle feedyard was degraded after a

feedyard was established. Plant composition, soil phosphorus and soil nitrogen were measured as a function of distance from the feedyard. Desirable perennial grasses were much reduced near the feedyard and increased with distance from the feedyard. Weedy annual species dominated near the feedyard and decreased with distance from the feedyard. Soil nutrients and dust deposition were greatest near the feedyard and decreased with distance from the feedyard. Nutrient-rich dust blown from the feedyard contributed to degradation of the native shortgrass prairie over 30 years; however, the negative impacts were confined to areas less than 500 m downwind from the feedyard. Local environmental impacts of fugitive nitrogen and other plant nutrients from a feedyard were limited in extent and confined to the sensitive native shortgrass prairie ecosystem.

Impact: This discovery could potentially benefit cattle feeders and adjacent landowners by establishing the extent of local environmental impacts of nutrient-rich fugitive dust and identifying ecosystems sensitive to nutrient additions.

Selected Publication:

Todd, R.W., W. Guo, B.A. Stewart and C. Robinson. 2004. Vegetation, phosphorus, and dust gradients downwind from a cattle feedyard. J. Range Management (in press).

Pathogen emissions from beef cattle feedyards: CAFOs produce a large amount of manure that can impact the environment if not managed properly. Environmental issues at CAFOs could include odor, pathogens, endotoxin (ET), and dust. Movement of ET and human pathogens with dust emission was investigated. No culturable Gram-negative enteric bacteria were found in the air of feedyards when two and six stage biological cascade impactors were used and none was found when passive control plates containing various types of media were faced into the wind.

Impact: Feedyards generate nuisance dust, but this research demonstrated that the feedyards in this investigation had no culturable enteric pathogens such as *Escherichia coli* O157:H7 and *Salmonella spp* in the air that could be translocated to downwind neighbors and livestock. The feeder calf industry, neighbors, the public at large, Public Health, and EPA are beneficiaries of this research.

Selected Publications:

Purdy, C.W., D.C. Straus, N. Chirase et al. 2002. Effects of aerosolized endotoxin in feedyard dust on weanling goats. Small Ruminant Research. 46:133-147.

Purdy, C.W., D.C. Straus, N. Chirase et al. 2002. Effects of aerosolized feedyard dust that contains natural endotoxins on adult sheep. Am J. Vet. Res. 63:28-35.

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

Emissions Component

Problem Area 15: Develop and evaluate cost-effective methods to reduce problem emissions.

Background: Lowering the emission rate of gases and particulate matter from animal production operations can improve air quality. Management practices and control technologies need to be developed to reduce gaseous emissions from animal production facilities, manure storage areas and manure field application sites. Emission reduction could be achieved through modification of animal diet, improved manure handling and storage, chemical amendments, and systems of treatment technologies. The air quality benefits of these practices and control technologies will have to be documented.

Accomplishments:

Effect of animal diet on ammonia emissions: ARS scientists studied the effect of reducing crude protein in beef cattle diets on ammonia losses from feedyard surfaces. Ammonia losses from a 5-meter diameter simulated feedyard surface were determined in summer, fall and spring using the integrated horizontal flux method. Reducing crude protein in beef cattle diets from 13% to 11.5% significantly reduced nitrogen lost from manure as ammonia in summer, fall or spring, but not in winter; annual mean reduction was 24%. Potential ammonia emissions from beef cattle manure decreased with decreasing dietary protein concentration primarily due to decreased urinary nitrogen excretion. These results demonstrate that ammonia emissions from feedyards can potentially be decreased by modification of the diet as long as the dietary modifications do not adversely affect animal performance.

Impacts: Reducing crude protein in diets can potentially decrease feed costs and ammonia emissions, benefiting cattle feeders and the environment.

Selected Publication:

Cole, N. A., R.N. Clark, R. Todd, C.R. Richardson, A. Gueye, L.W. Greene and K. McBride. 2004. Influence of dietary crude protein on potential ammonia emissions from beef cattle manure. Proc. 3rd Inter. Symp. On Air Pollution from Agricultural Operations III. ASAE, St Joseph, MI. ASAE Publ # 701P1403: pg 183-188.

Alum treatment of poultry litter to reduce ammonia emissions: Phosphorus runoff and ammonia emissions are two of the biggest problems facing the animal industry. ARS scientists discovered that alum (aluminum sulfate), when added to poultry litter in commercial houses, greatly lowers ammonia levels in the houses and results in significantly healthier birds. Birds grown in alum-treated houses weigh more, utilize their feed better, there is less bird death, and heating costs during winter months are significantly lower (due to less ventilation required to remove ammonia vapors). The use of alum in poultry houses is very cost effective; producers make an additional two dollars for every dollar spent. In the past year, it was estimated that more than 600 million broiler chickens were produced on alum-treated litter, which will undoubtedly result in less pollution of our nation's soil, water and air in addition to facilitating the production of healthier chickens at lower cost.

Impact: During the past year the USDA Natural Resources Conservation Service has developed a Conservation Practice Standard of treating poultry litter with alum. While poultry producers are the main benefactors of this research, alum treatment of poultry litter also will protect the environment.

Selected Publications:

Moore, P.A., Jr., T.C. Daniel and D.R. Edwards. 2000. Reducing phosphorus runoff and inhibiting ammonia loss from poultry manure with aluminum sulfate. J. Environ. Qual. 29:37-49.

Smith, D.R., P.A. Moore, Jr., B.E. Haggard, C.V. Maxwell, T.C. Daniel, K. Vandevander and M.E. Davis. 2004. Effect of aluminum chloride and dietary phytase on relative ammonia losses from swine manure. J. Anim. Sci. 82:605-611.

Ammonia reduction in laying hen houses: An ARS scientist developed and successfully tested a liquid alum delivery system for high-rise laying hen houses. High rise laying hen houses have the highest level of ammonia of all animal rearing facilities. Due to logistical constraints, it is not possible to use dry alum in the facilities as is done in broiler houses. Hence a liquid alum delivery system was designed, developed, installed and tested in a high-rise laying hen house. This system has been shown to reduce ammonia levels from over 90 ppm to less than 10 ppm for just a few dollars a day. The alum scrubs the ammonia out of the air, rather than preventing it from volatilizing. This is the most cost-effective way to control atmospheric ammonia levels. This methodology improves worker safety in this environment, while improving egg production by the birds.

Impact: Although this system has significant potential benefit, it has not been widely adopted, as has treatment of broiler litter with alum. However, it does provide producers a cost-effective means of improving egg production while making the work place safer.

Selected Publication:

Wilson, M.G., P.A. Moore, Jr., T.C. Daniel and D.R. Edwards. 2000. Effects of applying alum to hen manure in a high rise layer operation on ammonia volatilization and phosphorus runoff. Proceedings of 2000 Southeastern Commercial Egg Producers Forum. pp. 57-63.

Controlling emissions and pathogens with plant oils: Laboratory studies indicate antimicrobial plant oils are effective additives to cattle and swine manure for control of odor emissions and fecal coliforms. Additions of thymol, carvacrol, or eugenol at 0.15 to 0.2% inhibit essentially all microbial metabolism in these manure slurries whereby no volatile fatty acids or gaseous products are produced. Concentrations of 0.1% destroyed the fecal coliforms that represent the majority of pathogenic microorganisms in manure slurries. Results from eugenol addition to cattle and swine manure were unique because eugenol stops volatile fatty acid production (odor), yet allows lactate accumulation. This effect rapidly lowers pH, and will likely conserve nutrients such as ammonia in manure slurries. Preliminary field trials in cattle feedlot

pens indicated that thymol in a granular form, reduced odor production (58%) and fecal coliforms (89%).

Impact: Plant oils are natural compounds classified as GRAS (generally recognized as safe). Thus, if further field trials are successful and the economics are favorable an effective biological agent may be available for use by cattle and swine producers to reduce odor and pathogens in manure. This technology has been submitted to the Patent Office in Washington, D.C. Swine and cattle producers and their surrounding communities will benefit from improved air-quality. Consumers may benefit from the potentially safer meat supply delivered to the slaughter plant. This technology may be compatible with other solutions to improve air quality.

Selected Publications:

Varel, V. H. and D.N. Miller. 2001. Plant-derived oils reduce pathogens and gaseous emissions from stored cattle waste. Appl. Environ. Microbiol. 67:1266-1370.

Varel, V. H. 2002. Carvacrol and thymol reduce swine waste odor and pathogens; stability of oils. Current Microbiol. 44:38-43.

Biological removal of nitrogen from wastewater: ARS scientists developed innovative methods to enhance biological removal of N in wastewater containing high levels of ammonia through the use of bacterial immobilization technology. Treatment systems to manage nitrogen in wastewater depend on microbial transformations of nitrogen from ammonium to nitrate forms (nitrification) and from nitrate to nitrogen gas (denitrification). The nitrification step converts nitrogen to a form where it will not be emitted to the environment as ammonia gas. However, it is difficult to maintain a high population of nitrifying bacteria in animal wastewater with high ammonia and biochemical oxygen demand. ARS scientists adapted a Japanese municipal wastewater treatment technology to enhance removal of ammonia from swine wastewater. The research showed that with proper acclimation techniques, cultures of nitrifying bacteria could be adapted to high-ammonia strength wastewater and immobilized and used effectively to treat very concentrated (2600 ppm ammonia-N) animal wastewater. Nitrification rates of 650 grams of N per cubic meter of reactor per day with virtually no ammonia losses were obtained in a pilot study treating lagoon swine wastewater. A second pilot study successfully demonstrated the use of immobilization technology to efficiently treat N after solid-liquid separation of flushed swine manure. Odors are also eliminated in the process.

Impact: The technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The research has moved from bench to pilot to full-scale treatment systems. The technology is currently being used as part of a system of technologies to treat swine wastewater at a 4300 head finishing facility in North Carolina.

Selected Publications:

Vanotti, M.B. and P.G. Hunt. 2000. Nitrification treatment of swine wastewater with acclimated nitrifying sludge immobilized in polymer pellets. Trans. ASAE 43:405-413.

Vanotti, M.B., P.G. Hunt, J.M. Rice and F.J. Humenik. 2000. Nitrifying high-strength wastewater. Industrial Wastewater, Sept./Oct. pp. 30-36. Water Environment Federation, Alexandria, VA.

Control of ammonia emissions from wetlands: ARS scientists determined that ammonia volatilization from emergent marsh areas of constructed wetlands was not the primary loss mechanism; it accounted for less than 16% of the nitrogen load. However, ammonia volatilization from the pond areas of the marsh-pond-marsh constructed wetlands accounted for greater than 40% of the nitrogen load when the ammonia concentration of the wastewater was greater than 25mg nitrogen L^{-1}. Ammonia volatilization can be reduced by lowering the ammonia concentration of the wastewater by nitrification conversion of ammonia to nitrate prior to wetland application. Partial nitrification of the wastewater prior to wetland application also improved the efficiency of the wetlands to remove nitrogen via denitrification.

Impact: This research was the first to directly measure ammonia volatilization from constructed wetlands treating animal wastewater. It helps to answer concerns about the magnitude of ammonia volatilization from two popular types of wetland systems and highlights a method to reduce ammonia volatilization without compromising wetland treatment performance. These results will be useful for farmers looking for cost effective nitrogen removal alternatives/supplements to land application, for regulators who want to ensure that agricultural waste management practices do not degrade air and water quality, and for NRCS personnel looking for wetland design modifications that will maximize nutrient removal potential.

Selected Publications:

Poach, M.E., P.G. Hunt, G.B. Reddy, K.C. Stone, T.A. Matheny, M.H. Johnson and E.J. Sadler. 2004. Ammonia Volatilization from Marsh-Pond-Marsh Constructed Wetlands Treating Swine Wastewater. J. Environ. Qual. (in press).

Poach, M.E., P.G. Hunt, M.B. Vanotti, K.C. Stone, T.A. Matheny, M.H. Johnson and E.J. Sadler. 2003. Improved Nitrogen Treatment by Constructed Wetlands Receiving Partially Nitrified Liquid Swine Manure. Ecological Engineering 20: 183-197.

Poach, M.E., P.G. Hunt, E.J. Sadler, T.A. Matheny, M.H. Johnson, K.C. Stone, F.J. Huminek and J.M. Rice. 2002. Ammonia volatilization from constructed wetlands that treat swine wastewater. Trans. ASAE 45: 619-627.

Lagoon biocovers for emissions reduction: Ammonia and hydrogen sulfide emissions from manure storage systems are considered an environmental and potential health problem. Cost-effective measures to reduce these emissions are needed to help producers operate their current manure storage systems in the US. The effectiveness of a biocover to reduce ammonia and hydrogen sulfide emissions from a swine manure lagoon was evaluated across several months. A

polymer biocover was placed over a lagoon and ammonia and hydrogen sulfide concentrations measured above the surface. The longer the biocover was on the surface the more effective the reduction in emission rates due to the development of a stable anaerobic layer. Ammonia emissions from the covered lagoon decreased by 54% over a three month period while hydrogen sulfide emissions decreased by 58%. The biocover enhanced the rate of anaerobic digestion in the lagoon by 25% compared to the control. Placement of a biocover over a lagoon is an effective method of reducing ammonia and hydrogen sulfide emissions.

A study was conducted on two lagoons in northern Missouri to evaluate the effectiveness of a biocover to reduce emissions of ammonia, methane and non-volatile hydrocarbons from a swine lagoon. Measurements were made throughout the year on the leeward, windward, and center of the lagoon. Ammonia concentrations were reduced by 30% over the year by the biocover while hydrogen sulfide decreased by 50%. Methane only showed a small decrease due to the biocover. This study combined a micrometeorological method with concentration measurements at different locations around the lagoons and demonstrated the complexities in measuring emissions from systems that are not identical in topography and position on the landscape. Microclimate differences between the two lagoons induced variation in the emission rates that were difficult to detect at times through the study. This information provides insight into the dynamics of emissions from manure storage systems and how these emission rates can be altered through management.

Impact: Covering lagoons can provide a cost-effective method for reducing emissions from lagoon systems and benefit producers that need alternative methods to reduce emissions. Detailed comparisons across lagoons will help define the effectiveness of different lagoon management practices. This information will help researchers, air quality regulators, and producers understand more about the complexities of comparing management and treatment systems for manure management.

Selected Publication:

Zahn, J.A., A.E. Tung, B.A. Roberts and J.L. Hatfield. 2001. Abatement of ammonia and hydrogen sulfide emissions from a swine lagoon using a polymer biocover. Journal of the Air and Waste Management Association 51:562-573.

Systems of treatment technologies: Systems of treatment technologies are needed that capture nutrients, reduce emissions of ammonia and nuisance odors, and kill harmful pathogens. ARS scientists have developed a system of swine wastewater treatment technologies that accomplishes many of these tasks. The system greatly increases the efficiency of liquid-solid separation by injection of polymer to increase solids flocculation. Nitrogen management to reduce ammonia emissions is accomplished by passing the liquid through a module where immobilized bacteria transform N. Subsequent alkaline treatment of the wastewater in a P module precipitates recoverable P and kills pathogens. Treated wastewater can be recycled to clean hog houses or for crop irrigation. The system has been pilot tested and is currently going through full-scale demonstration and verification as part of the Smithfield Foods-Premium Standard Farms/North Carolina Attorney General agreement to replace current lagoons with

Environmentally Superior Technology. The full-scale demonstration facility was installed in Goshen Ridge, a 4,300-head finishing farm in Duplin County, NC. The system has been successfully stabilized and brought to steady-state operation with treatment performance that exceeded design expectations; it separated 97% of suspended solids, 99.9% of BOD, 98.9% of TKN and 94.8% of total P. Odorous compounds in the waste were reduced > 99% by treatment. In less than one year, the anaerobic lagoon that was replaced with the treatment system was converted into an oxic pond with ammonia concentration lower than 30 ppm.

Impact: The system has the potential for major positive impact as a functional advance in the treatment of animal waste. Beneficiaries of this work are pork and dairy producers, industrialists, entrepreneurs, policy makers, environmental and health regulators, NRCS, and the general public.

Selected Publications:

Vanotti, M.B., A.A. Szogi, and P.G. Hunt. 2001 (inventors). Patent application entitled 'Wastewater Treatment System' filed 7/13/2001, Serial 09/903,620 US Patent and Trademark Office.

Vanotti, M.B. 2003. Evaluation of Environmental Superior Technology: Swine Waste Treatment System for Elimination of Lagoons, Reduced Environmental Impact, and Improved Water Quality. Year 3 Progress Report For the NC Attorney General – Smithfield Foods / Premium Standard Farms / Frontline Farmers Agreements. http://www.cals.ncsu.edu/waste_mgt/3-year%20Smithfield%20Report/pi%20report%20pdfs/super%20soil%20original.pdf

Managing ammonia emissions from land applied manures. There is a paucity of U.S. data on field ammonia volatilization, despite the EPA guideline to develop ammonia control strategies for confined animal feeding operations. Ammonia volatilization from land application of manures was studied with micro-meteorology and wind tunnel techniques. Results show that dairy 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. Research showed that, compared to unincorporated surface applications, chisel plowing reduces ammonia losses about 80% and a tandom disk reduces losses about 90%. Moldboard plowing was shown to virtually eliminate all ammonia losses, but leaves the soil vulnerable to erosion due to no surface residues. Research on ammonia losses from dairy slurries after collection, showed that adding 6.25% zeolite or 2.5% alum to dairy slurry reduced ammonia emissions by about 50%. Alum treatment retained ammonia by reducing the slurry pH to 5 or less. In contrast, zeolite adsorbed ammonium thereby reducing dissolved ammonia gas.

Impact: These results will influence ammonia control policies by providing real-world ammonia loss data and identifying the most useful ammonia conservation strategies for land applied manures. Data resulting from these studies has contributed to the development of an ammonia volatilization decision support system that has already been used to update ammonia loss

estimates in Maryland's Nutrient Management Program. These results will be useful to NRCS and private consultants as they develop nutrient management plans.

Selected Publications:

Thompson, R.B. and J.J. Meisinger. 2002. Management factors affecting ammonia volatilization from land-applied cattle slurry in the Mid-Atlantic USA. J. Environ. Qual. 31:1329-1338.

Lefcourt, A.M. and J.J. Meisinger. 2001. Effect of adding alum and zeolite to dairy slurry on ammonia volatilization and chemical composition. J. Dairy Sci. 84:1814-1821

Meisinger, J.J. and W.E. Jokela. 2000. Ammonia volatilization from dairy and poultry manure. pp. 334-354. In Managing nutrients and pathogens from animal agriculture, March 28-30, 2000, Camp Hill, PA. Northeast Region Agr. Eng. Serv. NRAES-130. Ithaca, NY.

Jokela, W.E. and J.J. Meisinger. 2004. Manage manure to reduce ammonia loss and improve nitrogen utilization for corn silage production. Univ. Vermont Coop. Ext. Serv. Bulletin. Burlington, VT. (in press).

Pathogens Component
(Includes Pharmaceutically Active Chemicals)

Pathogens can contaminate the environment from improper collection, storage, management, treatment and land application of sewage, slaughter offal, sludge, slurry and manure, as well as from wild and domesticated animals. Even if not affected by the pathogen, vectors (e.g., birds, rodents, insects, etc.) can also spread pathogens in the environment. Other sources include: dust, aerosols, irrigation and runoff water, workers, plant residues, and the soil. Inappropriate use of manure, water or other wastes containing pathogenic or parasitic agents is considered to be an important factor in the occurrence and epidemiology of water- and food-borne diseases. Furthermore, contaminated waters and feedstocks can directly contribute to the re-colonization of farm animals by pathogens that may then continue the cycle. The lack of knowledge about pathogen survival in manure, improperly treated biosolids, wastewater, soil, water and air, and about the adequacy of various waste management techniques to reduce the levels of pathogens clearly points to the need for research on these issues.

Although many pathogens threaten the safety of our food and water, certain foodborne and waterborne microorganisms are of particular public health concern and have been the focus of much of this research. The following pathogens have been targeted for immediate attention by the Federal Food Safety Initiative Consortium: *Salmonella* species, *Campylobacter jejuni/coli*, *Escherichia coli* O157:H7 and other related strains; the parasite *Cryptosporidium parvum*; and enteroviruses. In addition, the recurring incidence of foodborne illness outbreaks caused by *Listeria monocytogenes* and the potential for more extensive involvement of *Mycobacterium paratuberculosis* and *Yersinia enterocolitica* indicate the need for additional research on the involvement of these microorganisms in the farm-to-table pathway of disease agent spread.

Pharmaceutically active chemicals, such as hormones, endotoxins and antibiotics, are also present in many manures, biosolids and other byproducts. These chemicals can have deleterious effects on human and ecosystem health and well-being. Moreover, both pathogenic and nonpathogenic microorganisms can become resistant to antimicrobial agents. Antibiotic resistant strains may be shed in manure and other byproducts and disseminated beyond the production and treatment areas. The extent of persistence of such strains and pharmaceutically active chemicals needs to be established.

The Pathogen Component of the Manure and Byproduct Utilization National Program was designed to address critical questions and issues regarding the fate of pathogens and to lesser extent during this reporting period of the Manure and Byproduct Utilization National Program pharmaceutically active chemical fate. Specific problems areas in the Pathogen Component identified as a result of a stakeholder workshop in 1998were:

1. Methods development for the detection of pathogens
2. Loading rate and survival determination
3. Transport and dissemination in the environment
4. Treatment technologies to reduce pathogens
5. Risk assessment.

There is intentional overlap among these problem areas, since the logic was to holistically determine the occurrence, transport and survivability of pathogens from manures and byproducts, evaluate the risks they posed and develop effective methods to destroy them. Therefore, accomplishments may be applicable to more than one problem area.

Although there was some historical research on these topics within ARS primarily because of food safety and animal health concerns, much of the research on this topic has commenced within the last five years. Scientists were redirected into this topic and new scientists were hired. In fact, at over half the locations where pathogen research is conducted (see below), the researchers were hired in the last 3 – 5 years and they are starting the first efforts on pathogens at these locations. These positions were located at these sites because there was and remains research on other aspects of manure and byproduct utilization.

Pathogen research is conducted at the following locations:

- Albany, California
- Ames, Iowa (both the National Soil Tilth Lab and the Swine Center)
- Beltsville, Maryland
- Beaver, West Virginia
- Kimberly, Idaho
- Lincoln, Nebraska
- Mississippi State, Mississippi
- Riverside, California
- Watkinsville (Athens), Georgia

Some of the research reported here as well as other research on pathogens is conducted in projects assigned primarily to other National Programs, primarily Food Animal Production, Food Safety and Water Quality and Management. Therefore, it is possible that not all the applicable research was captured in this report despite our efforts to be as comprehensive as possible.

Pathogens Component

Problem Area 16: Methods for sensitive detection and accurate quantitation of pathogens in complex matrices such as manure and soil need to be developed.

Background: Many of the pathogens that have emerged over the past 10 years cannot be easily detected and quantified in complex environmental samples such as manure, compost, soil, and foods. Currently accepted indicator organisms often are not adequate indicators for the matrices and situations now encountered. The study of pharmaceutically active chemicals in the environment often requires methods development. Application of current standard methods to the variety of matrices involved in determining the exposure, fate and transport of pathogens and pharmaceutically active chemicals will require adaptation of current methods and development of new methods for detection and quantification. The goals of this research are:

- To develop new techniques and adapt existing techniques for the detection of pathogenic bacteria and protozoans and pharmaceutically active chemicals in agricultural matrices such as manure and soil.
- To standardize techniques for sampling and detection of each pathogen in all environmental matrices encountered in agriculture (manure, soil, runoff water and ground water) with respect to sample size, limit of detection, storage, etc., so that studies can be compared.
- To develop sensors (biological, molecular, chemical) for the rapid detection of pathogens and pharmaceutically active chemicals in agricultural systems.

Accomplishments:

Large numbers of *E. coli* appear to be necessary for source tracking. The temporal variability of genetic fingerprints (ribotypes) of *E. coli* from a herd of long-yearling steers was assessed. We fingerprinted *E. coli* from 24 different yearling steers at four sampling times over a year to find out if common genetic fingerprints could be identified so that a system could be developed to track the source of manure contamination. Extensive clonal variability was discovered. Based on this variability we estimated that a host origin database for any animal source of *E. coli* would require a minimum of 900 to 1000 different genetic fingerprints for the method of microbial source tracking to be effective at identifying environmental isolates.

Impact: The results of this investigation suggests that *E. coli* may not be the appropriate choice of identifying organism for an effective method designed to identify sources of fecal contamination in surface water. This information is relevant to federal and state agencies concerned with the protection of recreational and drinking water sources, TMDL regulations for fecal organisms, and commercial estuarine resources.

Selected Publication:

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

Immunological and PCR based methods were developed for quantitative detection of generic, enteropathogenic, and enterohemorrhagic *E. coli* in enrichment samples. Methods were developed for the quantitative detection of pathogenic *E. coli* (including *E. coli* O157) in surface and ground water. An immunological method, based on immunomagnetic electrochemiluminescence (IM-ECL), was developed which allows for quantitative detection of *E. coli* O157 within a range of 10^2 to 10^5 cells per mL. In conjunction with concentration, the limit of sensitivity is 25 cells per 100 mL. Enrichment prior to analysis allows for detection of as few as1 cell per 100 mL, although results are only semi-quantitative.

A quantitative real-time (TaqMan) PCR methodology to quantify *E. coli* O157:H7 and other pathogens in manure, soil, waste and irrigation water and other environmental samples was developed. This method enables the collection of a large data set with a quality, reliable, and high through-put technology. 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 Shiga toxin *Escherichia coli* O157:H7 (STEC). Experiments were conducted to validate the fidelity of these primers and probes to specifically detect very low levels of *E. coli* O157:H7 and STEC in soil and other difficult matrices. It was further demonstrated that the common quenching dye used for detection of *E. coli* O157:H7 in food and clinical industries does not work well in soil because of background fluorescence. Tests were conducted to validate a dark quencher dye (Black Hole Quencher) that works better with wider light spectrum. These assays were optimized to specifically quantify very low levels; >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 from 3 to 5 days for culture-based methods of detection and quantification of *E. coli* O157:H7 in environment to less than 24 h from the time samples get to the laboratory. This time can be used for appropriate measures to be taken to monitor contaminated water and fresh produce and develop effective strategy for pollution control. This method is also beneficial in monitoring the prevalence of *E. coli* O157:H7 in soil and for assessing the effect of management practices in reducing the level of *E. coli* O157:H7 in streams and in their immediate environment.

Impact: This work represents a considerable advancement in pathogen quantification in different ecosystems. These methods will allow for routine monitoring of surface and ground water soil and food for the occurrence/prevalence of pathogenic *E. coli*. This data will be valuable for public health departments, water utilities, and home-land surveillance/security.

Selected Publications:

Shelton, D.R. and J.S. Karns. 2001. Quantitative Detection of *Escherichia coli* O157 In Surface Waters By Using Immunomagnetic Electrochemiluminescence. Applied and Environmental Microbiology. 67:2908-2915.

Higgins, J.A., M.C. Jenkins, D.R. Shelton, R. Fayer, and J.S. Karns. 2001. Rapid Extraction of DNA from *Escherichia coli* and *Cryptosporidium parvum* for Use in PCR. Applied and Environmental Microbiology. 67: 5321-5324.

Higgins, J.A., S. Nasarabadi, J.S. Karns, D.R. Shelton, M. Cooper, A. Gbakima, and R.P. Koopman. 2002. A handheld real time thermal cycler for bacterial pathogen detection. Biosensors and Bioelectronics. 18:1115-1123.

Shelton, D.R., J.S. Van Kessel, M.R. Wachtel, K.T. Belt, and J.S. Karns. 2002. Evaluation of Parameters Affecting Quantitative Detection of *Escherichia coli* O157 in Enriched Water Samples Using Immunomagnetic Electrochemiluminescence. Journal of Microbiological Methods. 55:717-725.

Karns, J.S. and D.R. Shelton. 2003. Real-time PCR assays for the quantitation of enteropathogenic *E. coli* in water. Annual American Society for Microbiology Meetings, May 20, Washington, D.C. 2003.

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.

Bacterial community diversity under different manure management practices was characterized by 16S rDNA sequencing. Knowledge on microbial community structure as influenced by manure management practices is crucial in developing biological strategies for on-farm pathogen control. Bacterial communities in manure lagoons from two dairies with different manure management practices were characterized by 16S rDNA sequencing of 500 clones. None of the known foodborne pathogens were detected from over 150 diverse bacterial species identified from these samples. This study suggests that sensitive molecular methods are necessary to determine the bacterial community diversity and to confirm the absence of pathogens of concern.

Impact. Characterization of bacterial communities from manure lagoon by 16S rDNA sequencing techniques revealed high species diversity that would not have been detected by traditional cultural methods. This study also did not find any known foodborne pathogens in dairy lagoons.

Selected Publication:

McGarvey, J.A., W.G. Miller, V.S. Ravva, and L.H. Stanker. 2004. Identification of bacterial populations in dairy waste waters using 16S rDNA sequences and other genetic markers. Annual American Society of Microbiology Meetings, May 23-27, 2004, New Orleans, LA**.**

A group specific amplified ribosomal-DNA restriction analysis (ARDRA) method was developed to rapidly assess the microbial community in swine fecal and manure samples. Although the use of 16S rDNA sequencing methods gives high resolution of the diversity of microbial species in an environment, it is very time consuming and too costly to be used for routine screening of samples. Methods for initial analysis of manure samples should be rapid and able to give a broad view of the microbial ecology. The advantages of ARDRA are that it is rapid, reproducible, relates to microbial diversity, and provides improved, although not complete, information on microbial communities compared to culture methods. By targeting specific groups of bacteria, in these samples, GS-ARDRA has the potential for correlation of banding patterns to chemical and physical factors of the environment. Furthermore, the suite of bacterial target groups could be expanded or altered to fit specific experimental objectives or as knowledge of fecal and manure microbial communities increases. The group specific amplified ribosomal-DNA restriction analysis technique developed was able to rapid detect gross bacterial community differences among swine fecal and manure storage pit samples and determine groups of interest for more detailed examination.

Impact: This rapid initial screening will be valuable in analyzing a greater number of samples in conjunction with experimental objectives such as dietary or other management interventions.

Selected Publications:

Cotta, M. A., C. J. Ziemer, and T. R. Whitehead. 2001. Differentiation between Microbial Populations of Swine Feces and Stored Manure by Group Specific Amplified rDNA Restriction Analysis. 9th International Symposium on Microbial Ecology. Abstract p.349. Amsterdam, The Netherlands.

Ziemer, C. J., M. A. Cotta, and T.R. Whitehead.2000. Application of Group Specific Amplified R-DNA Restriction Analysis to Differential Among Swine Fecal and Waste Storage Pit Samples. 25th Conference on Rumen Function. Chicago, IL.

Ziemer, C. J., and S. R. Steadman. 2003. Evaluation of the specificity of *Salmonella* PCR primers using various intestinal bacterial species. Letters in Applied Microbiology. 149:1472-1480.

A microbial community profiling system was developed. Analysis of how microbial communities change in response to the effects of environmental (e.g., seasonal variations, water, temperature, etc.), interventions, treatments and management practices would be useful in determining pathogen fate. Furthermore, studies that focus on monitoring indicator microorganisms or single pathogenic species provide a false sense of security in view of the fact

that other non-monitored pathogenic bacterial species could potentially evolve unchecked. To address these issues a novel microbial profiling system that includes an imaging system for culture plates, image acquisition systems, and software developed using Visual Basic 6.0®, ImageEnX® for basic image handling function, and Excel Controller® for managing read write operations in Microsoft Excel® was developed. The system allows for colony size measurements, tallying and grouping observed colony morphologies, and offers the possibility for comparative time analysis of culture plate(s). At the end of an analysis, the system calculates; (Shannon-Weiner and Simpson's) diversity indices from the tallied frequencies of the observed colony types. This system was used to characterize shifts in *Enterobacteriaceae* communities in manures under different management practices and to determine the impact of potential interventions on reducing members of this group. It was also used to identify surrogate indicator bacteria in surface runoff water from untreated controls and broiler litter amended runoff troughs. *E. coli* isolated at a rate of 1.6% of the total Gram-negative population was the only species useful in differentiating between treatments; other Gram-negative species characterized were initially present in runoff from untreated controls. Enterococci on the other hand provided a more reliable indicator for manure-amendment. Microbial profiling of isolated enterococci revealed that *E. faecium* was the more prevalent species (66%) among confirmed enterococci.

Impact: Validation and application of the developed microbial profiling approach will greatly aid in the evaluation of the efficacy of manure treatment strategies.

Selected Publication:

Balaa, M.F.A., G.E. Brink, A. Adeli, and D.E. Rowe. 2003. Development of a model system to study the impacts of manure management practices on microbiological runoff water quality. International Poultry Scientific Forum. Atlanta, Georgia, January 20-23.

Bovine enterovirus (BEV) can serve as a marker for the presence of fecal contamination. Water quality indicator microorganisms are needed which can be used to identify fecal contamination of surface waters. Real time PCR was used to survey a variety of environmental and veterinary samples for the presence of bovine enterovirus (BEV). BEV was detected in calves at the University of Maryland Wye Angus beef cattle farm (Wye Island, MD), pasture runoff and cattle watering troughs, water samples and oyster tissues from the nearby Wye River, as well as feces from deer and geese feces sharing the pasturage.

Impact: These data demonstrate that BEV can serve as a marker for the presence of manure-derived pathogens in the environment.

Selected Publication:

Ley, V., J.A. Higgins, and R. Fayer. 2002. Bovine enteroviruses as indicators of fecal contamination. Applied and Environmental Microbiology. 68:3455-3461

Pathogens Component

Problem Area 17: The environmental loading rate of bacterial and protozoan pathogens and the factors effecting the survival of various types of fecal pathogens need to be determined.

Background: Fecal pathogens are not expected to survive long in soil, water and air because they have not evolved to flourish in these environs. However, previous studies have shown that this is not always the case and some pathogens may survive for extended periods (more than a year) under certain conditions. It is difficult to study the survival of these organisms in the field or on a watershed scale because of the sporadic nature of their occurrence in animal manures. Determining the survival of specific bacterial pathogens relative to easily detected indicator organisms (such as fecal coliforms) using different loading rates at the laboratory and lysimeter scale will be essential for understanding the risk to human health posed by use of animal manures and other byproducts as soil amendments and fertilizers. Nevertheless, despite the difficulties associated with measurements and studies in the natural environment, these also must and will be conducted. The goals of research on this problem area included:

- Determining the effect of manure composition, storage and treatment on pathogen survival.
- Determining the effect of soil structure, pH, temperature, etc. on pathogen survival
- Determining the survival and transport of pathogens in agricultural soils managed under different agricultural practices.
- Relating the survival of various pathogens to the survival of more easily measured indicator organisms.

Accomplishments:

Naturally shed oocysts for the first time were recovered from a pasture soil, enumerated and assessed for potential infectivity after an outbreak of cryptosporidiosis. Nine neonatal calves that were borne at different times between late fall and mid-winter in Georgia, had acute and lethal cryptosporidiosis, and shed billions of *C. parvum* oocysts in an open pasture. Several weeks after the last calf had died, oocysts were extracted from the soil on which they had been shed, enumerated and tested for infectivity. All the oocysts were found to be potentially infectious. Furthermore, our results indicate that *C. parvum* under conditions of rain events with runoff can threaten surface water.

Impact: To the best of our knowledge this is the first time that naturally shed oocysts have been recovered from a pasture soil, enumerated and assessed for potential infectivity after an outbreak of cryptosporidiosis.

Selected Publication:

Jenkins, M.B., J.A. Stuedemann, and L.L. Hawkins. 2004. Recovery from pasture of viable *Cryptosporidium parvum* oocysts shed by neonatal calves—a case study. Sci. Tot. Environ. (in press).

***E. coli* O157:H7 survived more than 45 days in rhizosphere soil, which was determined with a newly developed real time PCR method.** Survival of *Escherichia coli* 0157:H7/pGFP *(E. coli* with green fluorescent protein) in different matrices (i.e., soil, rhizosphere, phyllosphere, manure, wastewater) was determined by a real-time PCR method. The *eae* gene of *E. coli* O157:H7 was used as the target gene since it is more conserved than the *stx* I&II genes in detecting *E. coli* O157:H7. The probe was incorporated into real-time PCR containing DNA extracted from water and soil artificially contaminated with *E. coli* 0157:H7. A detection limit for *E. coli* O157:H7 of about 1.4 x 10^3 CFU g^{-1} 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 traditional culture methods on mTSA during the first two weeks of inoculation. It was determined that *E.coli* 0157:H7 survived longer than 45 days in the rhizosphere but for significantly less time in non-rhizosphere soil and irrigation water. This suggests that human pathogens have the capability to exploit available nutrient resources under conditions in which the physical environment does not limit their activities, and therefore can survive in large numbers as part of the total bacterial community.

Other research on the fate of enteric pathogenic bacteria in soil columns fertilized with manure demonstrated appreciable vertical movement of *E. coli* O157:H7 in both disturbed and intact soil columns. In most cases, the number of bacteria recovered in leachate and soil exceeded the number added, indicating that some growth of the bacteria occurred in the soil. Experiments with intact soil cores and cover crop plants showed that the presence of plant rhizospheres could enhance survival of *E. coli* O157:H7 in soil and that this effect is dependent upon both soil type and plant type.

Impact: A sensitive method to measure the actual fate of *Escherichia coli* 0157:H7 is available so that researchers and regulators no longer need to only use less reliable indicator organisms. The real-time PCR assay can be a useful tool for the rapid quantification and monitoring of *E. coli* 0157:H7 in irrigation water and fresh produce. *E. coli* 0157:H7 can survive for extended periods of time in the rhizosphere and threaten food safety. These studies suggest that there should be a time period between manure application and crop harvest especially for root crops and foods that are eaten raw. In addition some practices (e.g., cover cropping) may enhance pathogen survival in the soil.

Selected Publications:

Ibekwe, A. M. and C. M. Grieve. 2004. Changes in developing plant microbial community structure as affected by contaminated water. FEMS Microbiology Ecology. In Press.

Ibekwe, A.M., P. M. Watt, P. J. Shouse, and C. M. Grieve. Real-time PCR-based quantification of survival of Escherichia coli O157:H7 on plants affected by contaminated irrigation water. Canadian Journal of Microbiology (Submitted).

Gagliardi, J. G. and J. S. Karns. 2000. Leaching of *Escherichia coli* O157:H7 in diverse soils under various agricultural management practices. Appl. Environ. Microbiol. 66: 3512-3517.

Gagliardi, J. V. and J.S. Karns. 2002. Persistence of *E. coli* O157:H7 in soil and on plant roots. Environmental Microbiology, 4:89-96.

Predominant bacterial populations of stored swine manure and swine gastrointestinal tract identified. Utilizing pure culture isolation techniques for anaerobic bacteria as well as culture-independent molecular biological procedures (direct 16S ribosomal RNA gene sequencing), the predominant microbial populations of swine feces and stored manure were identified. The populations were primarily low mole % (G+C), Gram-positive bacteria. Examples of genera identified include Clostridium, Lactobacillus, and Streptococcus. Although in many cases similar to known genera, the large majority of the pure cultures and 16S rDNA sequences could not be identified to the species level, and a number of completely unidentified bacteria were isolated.

Impact: This is the first detailed analysis of the bacterial populations of swine feces and manure. Control of pathogens and other problems associated with wastes such as malodors can be addressed more mechanistically if the microbial composition and ecology of the manure is known as it is produced, stored, managed and utilized. These results will allow researchers to focus on intervention strategies for reducing pathogens and emissions by the predominant bacterial populations of stored swine manure. Ultimately producers will gain by the development of reliable effective control methods.

Selected Publications:

Whitehead, T. R. and M. A. Cotta. 2001. Characterization of Microbial Populations in Swine Feces and Manure Storage Pits by 16S rDNA Gene Sequence Analyses. Anaerobe. 7:181-187.
Cotta, M. A., and T. R .Whitehead. 2003. Isolation, Characterization, and Comparison of Bacteria from Swine Feces and Manure Storage Pits. Environ. Microbiol. 5:737-745.
Whitehead, T. R., M. A. Cotta, M. D.Collins, and P. A. Lawson. 2004. *Hespellia stercorisuis* gen. nov., and *Hespellia suis* sp. nov., Isolated from Swine Manure Storage Pits. Int. J. System. Evol. Microbiol. 54:241-245.
Whitehead, T. R., and M.A. Cotta. 2004.Isolation and Identification of Hyper-Ammonia Producing Bacteria from Swine Manure Storage Pits. Curr. Microbiol. 48:20-26.

E.coli O157:H7 failed to establish in manure lagoon microcosms re-inoculated repeatedly during 45 days of incubation. The concept of continuous fecal shedding of pathogens in dairies and their subsequent flushing into manure lagoons was evaluated in model laboratory microcosms by four repeat re-inoculations of a dairy isolate of *E. coli O157:H7* (MM158) marked with rifampicin and nalidixic acid. This organism was chosen because of its longer survival in non-aerated manure waters. Although the populations declined slowly during the first inoculation, the subsequent re-inoculations resulted in a rapid decline. D-values (days required for 90% decline) declined from 7.9 to 0.9 days during the four re-inoculations to the aerated manure water that was incubated under aeration by mixing. The introduced populations declined from 10^6 cfu/mL to undetectable levels in 5 days after the 4^{th} re-inoculation as compared to 17 days after the first inoculation. The rapid decline of introduced populations in manure microcosms suggests the failure of acclimation of *E.coli* O157:H7 in manure lagoons on repeat

introductions. The use of microcosm studies was judged to be acceptable because we had observed that native bacteria from manure lagoon waters survive longer in laboratory microcosms while the introduced pathogens decline rapidly. It is critical to evaluate if introduced pathogens have a competitive advantage over native organisms to survive and proliferate in manure lagoons that may lead to outbreaks. Survival of native organisms tagged with rifampicin was monitored in manure lagoon microcosms incubated under laboratory conditions. The native organisms survived over 2 months in manure water (D=21.3 days), while the inoculated pathogens failed to survive longer than couple of weeks (D=3.2 days).

***E.coli* O157:H7 and *Salmonella* failed to proliferate in aerated and non-aerated manure lagoon waters.** It is critical to determine if human pathogenic *E.coli* O157:H7 and *Salmonella* survive in dairy lagoons. Laboratory scale microcosms of manure water from California dairies were used to monitor the survival and proliferation of *E.coli* O157:H7 and *Salmonella* marked with rifampicin and nalidix acid. Six liter proto-type re-circulating aerators were used. The pathogen fate was expressed as the rate of population decline per day based on the first day of incubation under both aerated and non-aerated conditions. Inoculated pathogens failed to survive in both aerated and non-aerated manure lagoons and *Salmonella* appear to decline faster from aerated manure waters. The mean D-value for *E.coli* O157:H7 in multiple trials for non-aerated manure waters was 3.15 days but not significantly different from the aerated treatments (P= 0.108). In addition to their rapid decline in manure waters, we also noticed variation in survival with different strains of *E.coli* O157:H7 under both aerated and non-aerated conditions. Furthermore, *E.coli* O157:H7 populations declined proportionately as the inoculum load of the pathogen increased from 10^3 to 10^7 cfu/mL in both aerated and settling pond manure waters. Although the initial rates of decline did not differ with or without aeration in microcosms, D-values based on population decline during the 13-day incubations indicate that the organism declined much more rapidly under non-aerated conditions. D-values for all inoculum loads under non-aerated and aerated conditions were 0.7 ± 0.1 and 6.1 ± 1.1 days, respectively.

Impact: The studies on pathogen survival in manure lagoons are critical in determining the potential for pathogen transmission through water and crops grown on-site by fertilization and irrigation with manure water. The inability of *E.coli* O157:H7 to establish in manure lagoons can be related to the absence of outbreaks of human health concerns despite the presence of large number of concentrated animal feeding operations. However, the factors responsible for pathogen re-growth leading to occasional outbreaks similar to the Walkerton, Canada incident require further research. These results also validate the use of laboratory microcosms as an alternative to the impractical field inoculations for monitoring the fate of pathogens.

Selected Publications:

Stanker, L.H. and S.V. Ravva. 2002. Survival of E. coli O157:H7 in aerated dairy manure lagoons. *In* Proceedings of the 31st United States-Japan Cooperative Program in Natural Resources (UJNR) Protein Resources Panel Meeting, December 1-7, 2002, Monterey, California.

Ravva, S.V., B.K. Duffy, L.H. Stanker, and R.E. Mandrell. 2001. Foodborne Pathogens in Dairy Environments. *In* Proceedings of the 30th United States-Japan Cooperative Program in Natural Resources (UJNR) Protein Resources Panel Meeting, October 15-19, 2001, p 64-71, Tsukuba, Ibaraki, Japan.

Pathogen re-growth potential of compost teas depend up on the amendments used in making the teas. Compost teas amended with molasses are gaining popularity among organic growers, largely because of their plant disease suppressive activity when applied to crops, but the re-growth potential of human pathogens of manure origin is unknown. The re-growth potential of outbreak strains of human pathogenic bacteria (*Salmonella enterica* serovar Thompson and *E.coli* O157:H7) marked with green fluorescent protein was monitored in compost teas amended with molasses. We found that molasses favor re-growth of human pathogens in compost teas, raising public health concerns about potential contamination of treated crops, particularly produce intended for fresh consumption.

Impact: This information on pathogen re-growth is critical to organic farmers and home gardeners using foliar or soil applications of compost teas as alternatives for agrochemicals for plant disease suppressive activity and plant nutritional improvement.

Selected Publication:

Duffy, B., C. Sarreal, R. Stevenson, S. Ravva, and L. Stanker. 2002. Regrowth of pathogenic bacteria in compost teas and risk of transmission to strawberry plants, p. 1142-1149. *In* F.C. Michel, Jr., R.F. Rynk and H.A.J. Hoitink (ed.), Proceedings of 2002 International Symposium: Composting and Compost Utilization, The JG Press, Inc., Emmaus, PA. *(http://www.composting2002.org)*

Potatoes grown in manure-amended soils were not contaminated by pathogens. Many producers use manure as their nutrient source in crop production; however, information is needed on the potential safety risk of eating vegetables grown in manure-amended soils. The presence and persistence of three major food related human pathogens in soil amended with liquid dairy manure was evaluated. *Listeria monocytogenes* and generic *E. coli* were found in soil for the first six weeks following manure application; however, potatoes collected at harvest were free of *E. coli, L. monocytogenes*, and *Salmonella*.

Impact: These preliminary results indicated potatoes grown in manure-amended soil are safe for human consumption.

Selected Publication:

Liao, C.H., C.W. Honeycutt, T.S. Griffin, and J.M. Jemison. 2003. Occurrence of gastrointestinal pathogens in soil of potato field treated with liquid dairy manure. J. Food, Agriculture & Environment 1:224-228.

***Cryptosporidium parvum* oocysts can persists for extended periods depending upon soil type, temperature and moisture**. Inactivation rates of *C. parvum* oocysts purified from calf feces and inoculated into different agricultural soil types from New York at different but constant temperatures and soil water potentials were determined. Based on these inactivation rates, days to reach 99.9% inactivation was estimated to range from 9 to much greater than 12 months, depending on temperature. Greatest survival was at 4 ºC and the greatest inactivation occurred at 30 ºC. Soil water potential between permanent wilting values (dry) and water holding capacity (wet) 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. Inactivation rates of *C. parvum* oocysts purified from calf feces and placed in surface soil in the field were also determined from a dairy farm in western New York. Days to reach 99% inactivation were estimated to be 163±30, yet after 120 days in the field, oocyst viability ranged between 10 and 30%. No statistically significant inactivation rate predictors were found by regression analysis. These results indicate soil type affects oocyst survival and that in the critical range of temperature in the temperate climates oocysts may survive for months in agricultural soils and pose a threat to surface water. These results indicate that *C. parvum* oocysts can survive for extended periods in agricultural soils under field conditions, and because of the heterogeneity of soil parameters, developing predictive models for *C. parvum* inactivation is problematical.

Impact: The inactivation studies demonstrated the long-term survival of *C. parvum* oocysts in soil where they can persist and from which they can be transported during rain events into surface and ground water.

Selected Publications:

Jenkins, M.B., D.D. Bowman, E.A. Fogarty, and W.C. Ghiorse. 2002. *Cryptosporidium parvum* oocyst inactivation in three soil types at various temperatures and water potentials. Soil Biol. Biochem. 34:1101-1109.

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. Sci. Total Environ. (in press).

Coliforms survived longer in irrigated than non irrigated systems, but soil was effective in filtering out coliforms. Total and fecal coliforms were measured in surface irrigation water moving across fields and in the underlying soil. Total coliforms in irrigation water moving across an orchard grass hay field were not affected by a liquid dairy waste application, however, fecal coliforms declined to background levels 28 days after waste application. Both total and fecal coliforms in the soil to 30 cm depth declined 10-fold after eight days and 100 fold after 64

days after liquid dairy waste application. Total and fecal coliform survival decreased as soil temperature increased and soils became dryer. Initial total coliform and fecal coliform die off rates in soil water and soil were 14- 28 day slower in non-irrigated systems compared to irrigated systems. Irrigation keeps the soil more moist during the growing season and therefore coliforms survive longer in soil and soil water. This study also found that total coliforms and fecal coliforms in irrigation water did not decline as the water moved downslope, yet there were few total coliforms and no fecal coliforms in water sampled 1 m below the soil regardless of waste application, indicating that the soil filtered these bacteria, preventing soil water contamination.

Impact: This research provides important information on the survival and control of enteric organisms from animal waste applications under irrigated systems, and will be used to develop recommendations for field applications of these materials in irrigated agriculture.

Selected Publications:

Entry, J. A. and N. Farmer. 2001. Movement of coliform bacteria and nutrients in groundwater flowing through basalt and sand aquifers. Journal of Environmental Quality. 30:1533-1539.

Spackman, R., J.A. Entry, R.E. Sojka, and J.W. Ellsworth. 2003. Polyacrylamide for coliform bacteria removal from agricultural waste water in irrigated forage production. Journal of Soil and Water Conservation. 58:276-283.

Bovine pathogens can survive for up to a year in feedlot playas in the southern High Plains and dried feedlot playas can be a source of endotoxins, but there is little movement of microbes and pathogens below the playas. Feedlot playas (shallow lakes in landscape depressions) in the in the southern High Plains are used as lagoons to store wastewater and runoff from cattle feedyards. Survival of bovine pathogens in water (parasites-*Cryptosporidium parvum;* viruses-infectious bovine rhinotracheaitis (IBR), bovine virus diarrhea (BVD), bovine respiratory syncytial virus (BRSV), and bovine parvovirus (BPV); bacteria-*Pasteurella haemolytica, Pasteurella multocidia, Staphylococcus aureus, Escherichia coli, Enterococcus faecalis, Actinomyces pyogenes, Salmonella enterica* serovar dublin, *Bacillus thuringiensis, Klebsiella pneumoniaae*, and *Pseudomonas aeruginosa;* fungi-*Aspergillus fumigatus* and *Aspergillus niger*) survived for 7 to 390 days in a feedyard shallow lake (playa). Two studies were conducted: one started in Sept. and one started in May. The *Pasteurella* isolates died within 7 to 35 days in both studies. *Actinomyces pyogenes* died within 84 days in one study and in 188 days in the second study. The remaining bacterial isolates survived for 390 days with low titers, except for *Pseudomonas aeruginosa*. Both fungal isolates died by 390 days. All bacteria and fungi survived for 188 days in the second study that was terminated at 188 days. The titer of the viruses decreased rapidly over 42 days except for BPV in the first study, and all viruses were inactivated by day 42 in the second study. Cryptosporidium parvum survived the winter of the first study but lost its ability to infect infant mice during the 9th month of the study. Endotoxins are pharmaceutically active chemicals produced primarily by fungi that are highly biologically reactive to the mucosal surface of animals and humans. Feedyard playas contained endotoxin concentrations that were 32 times higher (mean 8,640 ng/ml) than those found in non-feedyard playas (266 ng/ml). Concentrations in the bottom sediment of feedyard playa were significantly

greater than the respective water values (mean 17,700 ng/ml). However, microbes (bacteria and fungi) and endotoxin concentrations in dried parts of feedyard playas decreased with depth below the playas. The length of time that bovine pathogens can survive in feedyard playa water and the high concentrations of endotoxins make it imperative that cattle should be fenced off from feedyard playas and the use of this water should be very restricted. This water should not be sprayed on cattle to keep them cool or to abate dust in cattle pens. Fortunately, the infiltration of microbes and endotoxins below the playas was not a problem in the southern High Plains feedyard playas that are naturally lined with Randall clay, which is rather impervious to water. Therefore, the underlying aquifer should not be contaminated by microbes or endotoxins.

Impact: Feedyard owners and managers and regulatory and action agencies have critical information needed to better manage feedlot playas and to develop best management practices and effective regulations. Most importantly, water from playas should not be sprayed on cattle to keep them cool or to abate dust in cattle pens.

Selected Publications:

Purdy, C.W., D.C. Straus, J.A. Harp, et al. 2001. Microbial pathogen survival study in a High Plains feed yard playa. Texas J. Sci. 53:247-266.

Purdy, C.W., D.C. Straus, D.B. Parker, et al. 2001. Water quality in cattle feed yard playas in winter and summer. Am. J. Vet. Res. 62:1402-1407.

Rice, W. C., and C. W. Purdy. 2002. Microbial Ecology and Molecular Characterization of Pathogens in Feedyard Playa Air and Water Samples in the High Plains of Texas, American Society for Microbiology, Texas Branch, p 22 November 8, 2002, Austin, TX.

Purdy, W.W., D.C. Straus, and R.N. Clark. 2004. Diversity of *Salmonella* serovars in feed yard and non-feed yard playas (shallow lakes) of the Southern High Plains in the summer and winter. Am. J. Vet. Res. 65:45-52.

Pathogens Component

Problem Area 18: Research is needed to predict and control pathogen transport and dissemination.

Background: There are numerous modes of pathogen transport from manures to waters or food, depending on animal production practices, food production practices, and environmental variables. For example, direct contamination can occur via fecal deposition into surface waters or application of raw manure to food intended for fresh consumption. Indirect modes of contamination include: (i) leaching to potable groundwaters (e.g., karst groundwater) or runoff to rivers, streams, reservoirs, etc. from land-applied manures or from natural fecal deposition; (ii) use of contaminated waters for in-field processing of fresh produce; or (iii) aerial deposition, vectoring by wildlife (e.g., geese), or vectoring by plant pests.
In addition, an understanding of pathogen dissemination within the farm environment is critical to breaking cycles of reinfection within animal populations to prevent manure contamination. The goals of research in this problem area included:

- Developing functional relationships between vertical vs. surface pathogen transport and soil, topographic, vegetation, rainfall, and organism parameters.
- Integrating laboratory, field plot, and watershed scale data to describe pathogen transport in the context of hydrology.
- Assessing the importance of vectors and aerial transport.

Accomplishments:

***Cryptosporidium parvum* and fecal pathogens can move by preferential flow through soil to ground water.** Under conditions of simulated rain, *C. parvum* oocysts moved through an intact soil column and demonstrated that under conditions of unsaturated flow oocysts can move vertically through soil with preferential flow, i.e., water movement through cracks, channels, worm holes and root trails. The results of these column experiments suggest that transport of oocysts in the subsurface by preferential flow may create a significant risk to groundwater.

***Cryptosporidium parvum* oocyst and fecal coliform bacteria densities in a karst aquifer beneath beef grazing lands were substantial.** Areas dominated by karst topographies are especially susceptible to groundwater contamination because of direct connection between the land surface and groundwater. Although *Cryptosporidium parvum* oocyst and fecal coliform bacteria densities in a karst aquifer beneath beef grazing lands were substantial, mean storm densities of each were not correlated meaning that fecal coliform bacteria density is not a good indicator of *Cryptosporidium* contamination. Fecal coliform densities showed little seasonal variability and densities during storms were highly correlated with flow. The greatest coliform densities tended to coincide with peak flow and maximum sediment load. *C. parvum* oocyst densities during storms were not correlated with flow and the greatest densities tended to occur on the rising limb of the hydrograph, prior to peak flow. Seasonally, *C. parvum* oocyst densities were greatest in fall to early winter – six to nine months after calves were present in the pastures. It appears that *C. parvum* oocysts are being stored in the fractures and voids of the epikarst at the

soil/bedrock interface and are then being flushed out as the soil vadose zone saturates late in the year.

Impact: These results provide important information for the development of management and control strategies to protect groundwater quality in a region where groundwater is an important drinking water source. The results will also assist modelers in model development for predicting the fate and transport of pathogens in highly heterogeneous groundwater systems.

Selected Publications:

Boyer, D. G. and E. Kuczynska. 2003. Storm and seasonal distributions of fecal coliforms and *Cryptosporidium* in a spring. J. American Water Resources Association 39:1449-1456.

Boyer, D. G. and G. C. Pasquarell. 1999. Agricultural land use impacts on bacterial water quality in a karsts groundwater aquifer. J. American Water Resources Association, 35:291-300.

Kuczynska, E., D. G. Boyer, and D. R. Shelton. 2003. Comparison of immunofluorescence assay (IFA) and immunomagnetic electrochemiluminescence (IM-ECL) in detection of cryptosporidium parvum oocysts in karst water samples. J. Microbiological Methods, 53:17-26.

Darnault, C.J.G., P. Garnier, Y.-J. Kim, K. Oveson, T.S. Steenhuis, J.Y. Parlange, M. B. Jenkins, W.C. Ghiorse, and P.C. Baveye. 2003. Transport of *Cryptosporidium parvum* oocysts in the subsurface environment. Wat. Environ. Res. 75:113-120.

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 J. (in press).

Factors affecting *Giardia* and *Cryptosporidium* oocysts release from manure analyzed and modeled. Laboratory studies were initiated in California to determine release rates of naturally occurring *Giardia* and *Cryptosporidium* oocysts from Holstein dairy calf manure to flowing water. Experiments were conducted by sprinkling a particular aqueous solution over a manure disk and collecting the runoff water. The investigated factors included temperature (5 or 23 ^{o}C), manure type (calf manure, and various mixture of calf and cow manure), solution salinity, and water application method (mist or drip) and flow rate. Effluent oocyst concentrations were initially several orders of magnitude below the starting oocyst concentration in the manure, after continued application of water the oocyst concentration gradually decreased and then exhibited persistent concentration tailing. Higher oocysts release rates and effluent concentrations were observed for higher water application rates and intensity (drops compared to mist), low ionic strength solutions, and for calf manure (in comparison to cow manure). An effect of temperature on oocyst release was not observed. In these systems, a strong correlation between solution optical density and oocyst concentrations was observed. A conceptual model was developed to describe and predict the release of manure and protozoan parasite oocyst to flowing water. Manure release into water was characterized as diffusion controlled processes, and then the pathogen concentration was predicted from the dissolved manure concentration, the initial

pathogen concentration in the manure, and the release efficiency of the pathogens (relative to that of manure). The proposed model was successfully calibrated and applied to measured release data collected over a range of physical and chemical conditions. Additional studies have been conducted to examine the release behavior of bacteria and viruses from manure to water. Similarities and differences in the release behavior of the variously sized microorganisms are currently being investigated.

Impact: The pathogen release findings and models are providing a better description of pathogen loading to surface and groundwater. This information is needed to accurately evaluate the impact of hydrologic conditions and animal management practices on water quality, and to aid researchers to assess the vulnerability and minimize the potential of pathogen contamination to food and water supplies.

Selected Publications:

Schijven, J. F., S. A. Bradford, and S. Yang. 2002. Release of *Cryptosporidium* and *Giardia* from dairy calf manure. International Water Association, Health-Related Water Microbiology, April 6th-12th, Melbourne, Australia Symposium.

Bradford, S. A., and J. Schijvan. 2003. Release of *Cryptosporidium* and *Giardia* (oo)cysts from dairy calf manure: Impact of solution salinity. USGS/EPA STARS Grant Meeting on *Cryptosporidium* Removal by Bank Filtration, Reston, VA, September 9-10, 2003.

Bradford, S. A., and J. Schijven. 2002. Release of *Cryptosporidium* and *Giardia* from dairy calf manure: Impact of solution salinity. Environmental Science & Technology, 36, 3916-3923.

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. (in press).

Many domestic and wild animals can be contaminated by *C. parvum* oocysts and serve as vectors. For example, contamination of commercial oysters by water-borne is common as a result of accumulation of water-borne oocysts. Commercial oysters from 49 locations along the Atlantic and Gulf coast, near areas of agricultural runoff, were analyzed for *C. parvum* oocysts using immunofluorescent antibody (IFA) and polymerase chain reaction (PCR) techniques. Approximately, 90% of oysters were contaminated with *C. parvum* (bovine subtype). Geese can be vectors for "aerial" transport of *C. parvum* oocysts. Canada goose feces were collected from 9 sites in the Chesapeake Bay area and tested for *C. parvum* oocysts. Large numbers of infectious oocysts were found in 7 of the samples. Although geese cannot be infected with *C. parvum*, they are often observed in cattle pastures where they peck through the cattle feces in search of undigested grain and seeds. In this process the geese can ingest *C. parvum* oocysts, which simply pass through their digestive tract. These researchers have also shown that many other domestic and wild animals can harbor or be vectors for *C. parvum* oocysts.

Impact: Knowledge of animals that can serve as hosts or vectors is critical to devising effective control points and strategies for *C. parvum.*

Selected Publications:

Fayer, R., E. J. Lewis, J. M. Trout, T. K. Graczyk, M. C. Jenkins, J. Higgins, L. Xiao, and A. A. Lal. 1999. *Cryptosporidium parvum* in oysters from commercial harvesting sites in the Chesapeake Bay. Emerg. Inf. Dis. 5:706-710.

Graczyk, T.K., R. Fayer, J.M.Trout, M.C.,Jenkins, J. Higgins, E.J. Lewis, and A. Farley. 2000. Susceptibility of the Chesapeake Bay to contamination with *Cryptosporidium parvum*. Environmental Research (section A) 82:106-112.

Fayer, R., J. Trout, E.J.Lewis, L. Xiao, M. Jenkins, and T. Graczyk. 2002. Temporal variability of *Cryptosporidium* in the Chesapeake Bay. Parasitology Research. 88:998-1003.

Fayer, R., Trout, J., Lewis, Santin, M., Zhou, L., Lal, A., E.J., and Xiao, L. 2003. Contamination of Atlantic coast commercial shellfish with *Cryptosporidium*. Parasitology Research. 89:141-145.

Graczyk, T. K., R. Fayer, J. M. Trout, E. J. Lewis, C. A. Farley, I. Sulaiman, and A. A. Lal. 1998. *Giardia* sp. cysts and infectious *Cryptosporidium parvum* oocysts in the feces of migratory Canada geese (*Branta canadensis*). Appl. Environ. Microbiol. 64:2736-2738.

Runoff from manure-applied sites had significantly higher numbers of traditional and alternative fecal indicator microorganisms and protozoan parasites compared to areas lacking manure. Little data currently exists regarding microbial loads carried in rainfall runoff from manure applied to land. Runoff water was collected from manure-applied, no-till agricultural plots in Nebraska and analyzed for manure-borne microorganisms. Microbial load in runoff water from control plots, lacking manure, were also determined. Results from this research indicate that: a) Significantly higher numbers of traditional and alternative fecal indicator microorganisms (total coliforms, *Escherichia* coli, enterococci, coliphage and *Clostridium perfringens*) and protozoan parasites (*Giardia* cysts and *Cryptosporidium* oocysts) occurred in runoff water from manure-applied experimental plots compared to control (no manure) plots; b) for cattle manure-applied plots, corn residue had no significant effect on manure-borne microorganism concentration in runoff compared to plots without corn residue; c) concentrations of manure-borne microorganisms released from manure-applied plots varied according to manure type (swine versus cattle) and age (fresh versus aged); and d) *Clostridium perfringens* appears to be a better indicator of livestock manure dissemination from manure-applied land. The results of this study suggest that large microbial loads could be released in runoff water from manure-applied agricultural fields, of even modest size, and could significantly impact water bodies within the watershed.

Impact: Manure application, manure characteristics and agricultural practices all affect the concentrations and types of manure-borne microorganisms in runoff. This information is needed by those involved in conducting risk assessments relating to pathogens in manure, livestock producers, farmers who utilize manure as a crop nutrient source, policy makers, and other parties

(NRCS, EPA, extension personnel) concerned with manure-borne pathogen concentrations in manure and their potential for environmental dissemination.

Selected Publication:

Thurston-Enriquez, J. A., J. E. Gilley, and B. Eghball. 2004. Microbial quality of runoff from no-till agricultural plots treated with livestock manure. Journal of Water and Health. (in press)

Creek and irrigation return flow water contains native, human and cattle *E. coli*. Source tracking was used to identify the origin of fecal coliform counts in water obtained from Rock Creek, a perennial stream in southern Idaho that receives irrigation return flows during spring and summer. In spring and summer these counts have been several orders of magnitude above the recreational water quality standards. Targeted sampling was conducted on 23 July, 2002, when numbers of fecal coliform bacteria in the stream were highest for the year. At one site with persistent contamination, *Escherichia coli* numbers in the creek ranged from 72 to 1,200 colony-forming units per 100 ml. The two potential sources of contamination were cattle manure and nearby septic tanks (human source). Ribotyping was automated with a RoboPrinter using the restriction enzyme *Pvu*II. Ribotype patterns were matched at a 100% similarity index. Sixty-tree ribotypes were observed among the 111 *E. coli* isolates. Thirty-one ribotypes were associated with cattle only, 22 with humans only, and 10 ribotypes (16%) were shared, but shared ribotypes accounted for 49 isolates (44%). Either a large number of ribotypes were shared between these two sources or the restriction enzyme was unable to discriminate between the two sources. Regardless, the two potential sources were compared to isolates obtained from Rock Creek. Ninety-two ribotypes were observed among the 167 *E. coli* isolates. Thirty-one ribotypes were associated with cattle only, 20 with humans only, 28 with the creek only, and five with cattle and humans combined. The remaining eight ribotypes were shared with Rock Creek and either humans only (two ribotypes for four isolates), cattle only (one ribotype for two isolates), or both humans and cattle (four ribotypes for 47 isolates). Therefore, human and cattle manure accounted for 32% of the fecal contamination to Rock Creek. Irrigation return flow water was also studied. Human and cattle sources accounted for 33% of the fecal coliforms in this irrigated return flow water. The use of targeted sampling was used in this study to avoid many of the potential difficulties associated with source tracking.

Impact: Human and cattle were sources of contamination in creek and irrigation water. Knowing the sources of microorganisms in waters will enable control measures to be developed where they will be most effective.

Selected Publication:

Hartel, P.G., J.D. Summer, J.L. Hill, J. Collins, J.A. Entry and W.I. Segars. 2002. Biogeographic Variability of Escherichia coli Ribotypes from Idaho and Georgia. J. Environ.Qual. 31:1273-1278.

Entry, J. A. and Farmer, N. 2001. Movement of coliform bacteria and nutrients in groundwater flowing through basalt and sand aquifers. J. Environ. Qual. 30:1533-1539.

Cattle presence and cattle crossing increase microbial contamination in stream water. There is no information regarding the microbial water quality impact by cattle crossings, a new best management practice used to reduce stream bank erosion and limit livestock contamination of streams. A pasture stream and its sediment in Nebraska were surveyed for manure-borne microorganisms (fecal indicator microorganisms and protozoan parasites) to determine if cattle and a constructed cattle crossing had a significant impact on microbial water quality. Microbial concentrations, including flow-weighted microbial concentrations, in stream water collected upstream, immediately downstream, and at the outflow of the studied pasture were measured. A significant deterioration in microbial water quality, as determined by *E. coli* and enterococci concentrations, was observed when cattle were present in the studied pasture. *E. coli* concentrations exceeded EPA recommendations for secondary contact recreation in 63% and 44% of samples collected when cattle were present and absent from the pasture, respectively. The contamination in the absence of cattle indicates that agricultural and wildlife sources upstream are also major sources of microorganisms.

Impact: These initial studies demonstrated the use of the stream crossing by cattle and that upstream agricultural and wildlife sources can significantly threaten microbial water quality.

Selected Publication:

Henry, C. and J. A. Thurston-Enriquez. 2003. Impact of a constructed low water stream crossing, an innovative BMP, on microbial water quality of a rangeland pasture stream. American Society for Agricultural Engineers Annual Meeting Paper #032313.

Fecal bacteria in air samples were not affected by swine waste water, manure or biosiloid applications. Bioaerosol studies were conducted on emissions and transport during surface application of manure and biosolids. A multi-season study of passive transport of bioaerosols from inside swine houses to outdoors in Utah concluded this past fall. All studies were conducted in conjunction with other ARS researchers who measured emissions of ammonia, methane, and/or odorous volatile organic compounds. Meteorological measurements adequate to characterize existing site conditions and for transport model inputs were also made. At the 10 field sites, undetectable and trace concentrations of fecal bacteria were present in ambient background air collected prior to or upwind during application. Likewise, during application, undetectable and trace concentrations of fecal bacteria were present in air immediately downwind of the release points on the spreading and spraying equipment. Fecal bacteria concentrations at the property fence line downwind of the application fields were not

significantly different from those of the ambient air prior to or upwind during application, i.e., undetectable or trace.
The surface application studies involved two different application methods: a low solids (<12% solids) tank sprayer and a high solids (>22% solids) hopper spreader. The release point on the sprayer is about 4m above the land surface on the back of the tank; on the spreader, release is at approx. 0.6m above the land surface. Both pieces of equipment propel the material up to 20m from the release point and generate pulsed releases that last about 1.5-2.0 min depending on the hopper size and application rate. Releases are thus discontinuous with about 5-7 min downtime between 1.5-2.0 min releases because the tank or hopper must be refilled before the next pass across the field. The PM_{10} measurements in the fields do not reflect any significant increase over those obtained when the spreader or sprayer traverses the same field without releasing manure or biosolids.

Impact: Results so far indicate that particulates and bacterial bioaerosols (<10 um aerodynamic diameter), i.e. inhalable/respirable, are not significantly increased in the immediate vicinity or at the field fenceline (15- 300m) during manure or biosolids applications. Analysis of filters for endotoxin (gram-negative bacterial lipopolysaccharide) concentrations, lime particulates, heavy metals, clostridium spores, and coliphage is continuing.

Selected Publication:

Millner, P.D., L.L. McConnell, L.A. Harper, U. Walker, and R. Giani. 2004. Bioaerosol and VOC emissions measurements associated with land application of biosolids. *In* Proceedings from Sustainable Land Application Conference, Orlando, Florida. January 4-7, 2004.

Improved pathogen transport models developed. Knowledge of environmental transport processes is needed to accurately assess and minimize contamination potential of pathogens to food and water supplies. Laboratory and modeling studies were undertaken to explore the influence of various factors (colloid size, porous media grain size distribution, pathogen type, physical heterogeneity, colloid concentrations, and presence of dissolved manure) on the transport and fate of pathogens in saturated porous media. Column studies showed that increasing the pathogen size and/or decreasing the porous medium size lead to lower peak effluent concentrations, increased mass removal of pathogens near the column inlet, and an inability of conventional colloid filtration theory (models) to adequately describe or predict the experimental data. This transport behavior was consistent with straining, a process that is typically neglected in pathogen transport models. A novel conceptual model was developed that accounts for pathogen attachment and detachment using conventional first-order rate expressions, describes straining using a depth-dependent first-order rate expression, and models exclusions by employing the pathogen accessible pore space in transport parameters. The calibrated model yielded a significantly improved description of both the effluent concentration curves and the spatial distribution of variously sized colloids in four soils than conventional pathogen transport models. Similar results were obtained for *E. coli* O157:H7, a protozoan parasite (*Cryptosporidium*), and bacteriophages (MS2 and fX174).

Manure effects of pathogen transport in soil quantified and modeled. A new modeling-based method to estimate release rates of manure-borne microorganisms has been developed and successfully tested with data on leaching manure-born fecal coliforms and manure particulates from large undisturbed soil monoliths in Pennsylvania. The release rates and breakthrough of fecal coliforms coincided with those of manure particulates thus supporting the hypothesis that pathogen transport in soils has to be researched and mitigated as the colloid-facilitated transport. In a pioneer study, modeling was applied to discriminate between mechanisms of retention of manure-borne *Cryptosporidium parvum* oocysts in saturated and unsaturated soils. Parameter estimation indicated that straining and reversible attachment had dominated the retention in saturated and unsaturated soils, respectively. Research on selection of the most appropriate model to simulate attachment of manure-borne *E. coli*. and *Cryptosporidium parvum* oocysts to soils revealed qualitative changes in attachment isotherms caused by the presence of manure particulates and detrimental effects of manure concentrations on the attachment.

Pedotransfer functions developed to relate pathogen transport parameters to readily available data on soil and topography. New functional relationships have been developed to estimate hydrological parameters of water and bacteria transport to basic soil properties usually available from soil survey. Such relationships, or pedotransfer functions, were found using modern methods of artificial intelligence and data mining. The data on soil structure, organic matter content, and topographic attributes were shown to be reliable predictors of the soil's ability to retain and transmit water and solutes.

A model to account for soil infiltrability in grass buffers to mitigate microorganism transport. The first mechanistic model of coupled surface and subsurface microbial transport at the hillslope scale has been developed to account for soil infiltrability in evaluating the efficiency of grass buffers in retention of microorganisms released due to manure dissolution. A limited validation of the model was performed with data on fecal coliform transport from controlled studies at large soil lysimeters (described in another accomplishment). Simulation results show that the variable infiltrability may have substantial effects on the buffer strip efficiency, and has to be taken into account in evaluating management practices with respect to manure-borne pathogen transport.

Development of microbial transport submodel for the watershed-scale agricultural contaminant transport model SWAT. Process-based watershed scale hydrological non-point pollution model SWAT had an ability to simulate effect of agricultural practices on nitrate and phosphorus levels in water sources. Data from laboratory, field plot, and watershed scales were integrated to develop a microbial transport module for SWAT. The module considers fate and transport of bacteria as related to weather conditions, topography and soil properties, manure and soil management, and presence of vegetated buffer strips.

Impact: The pathogen transport findings and models have provided an improved characterization of and ability to predict the processes that control surface and subsurface pathogen transport at the pedon, field, farm and watershed scales. Continued incorporation of research findings into models will eventually provide more robust model predictions that will be

useful for assessing health risk and resource vulnerability, and for developing improved management and treatment options.

Selected Publications:

Bradford, S. A., S. R. Yates, M. Bettahar, and J. Simunek. 2002. Physical factors affecting the transport and fate of colloids in saturated porous media. *Water Resources Research*, 38:1327, doi:10.1029/2002WR001340.

Bradford, S. A., J. Simunek, M. Bettahar, M. Th. van Genuchten, and S. R. Yates. 2003. Modeling colloid attachment, straining, and exclusion in saturated porous media. *Environmental Science & Technology*, 37, 2242-2250.

Bradford, S. A., M. Bettahar, J. Simunek, and M. Th. Van Genuchten. 2004. Straining and attachment of colloids in physically heterogeneous porous media. *Vadose Zone Journal*, In Press.

Sadeghi, A.M. and Arnold, J.A. 2002. A Microbial Sub-Model for predicting pathogen loading in surface and groundwater at watershed and basin scales. Proceeding of the March 11-13, 2002 Conference on TMDL, Fort Worth, TX. An ASAE Paper Presentation. p. 56-63.

Roodsari, R., D. R. Shelton, Y. A. Pachepsky, A. Shirmohammadi, A. M. Sadeghi and J. L. Starr. 2002. Field-scale Monitoring and Simulation of the Overland Transport of Bromide and Pathogens. Agronomy Abstracts, 2002, CD-ROM

Pachepsky, Y. A., D. R. Shelton, A. M. Sadeghi, and W. L. Stout, USDA-ARS. Transport of manure-borne bacteria and colloids in a stony soil. Special symposium Reactivity and Transport of Organic Compounds and Colloids in Soils and Sediments: Colloid and Colloid-Facilitated Transport at the Joint Assembly of the European and American Geophysical Unions, Nice, France, 06 - 11 April 2003. CD-ROM.

Shelton, D., Pachepsky, Y. A., Sadeghi. A. M., Stout, W. L., Karns, J. S, Gburek, W. J. 2003. Release Rates of Manure-borne Coliform Bacteria from Data on Leaching through Stony Soil. Vadoze Zone Journal, 2: 34-39.

Roodsari, R., Pachepsky, Y., Shelton, D., Shirmohammadi, A., Sadeghi, A., Starr, J. 2003. Modeling manure-borne pathogen transport with runoff and infiltration. ASAE Paper No. 033101. p. 30-51.

Pachepsky, Y. A., Fayer, R., Perdue, M., Shelton, D. R., and van Kessel Jo Ann. 2003. Zoonotic Pathogens from Manure: Transport and Fate. Mid-Atlantic Crop Management School, 2003. CD-ROM. University of Delaware Extension Service, Newark, DE.

Kuczynska, E., Pachepsky, Y. A., Rouhi, S. A., and Shelton, D. R. 2004. Transport of Manure-borne *Cryptosporidium parvum* Oocysts Through Saturated and Unsaturated Soil Columns. Journal of Contaminant Hydrology (in review).

Kuczynska, E., D. R. Shelton, and Y. Pachepsky. 2004. Effect of Bovine Manure on *Cryptosporidium parvum* Oocyst Attachment to Soil. Journal of Environ. Quality (in review).

Representatives from government, agriculture, public health, and academia have shown significant interest in this research. For example, Dr. Barbara Williams (Biological and Agricultural Engineering, University of Idaho, Moscow, ID) has conferred with Dr. Bradford about the design and modeling of Anthrax spore transport experiments. Research findings have been presented to various audiences (American Geophysical Union, European Geophysical Union, Soil Science Society of America, Western Soil Science Society, USGS/EPA *Cryptosporidium* removal by bank filtration; International Workshop on Colloids and Colloid-Facilitated Transport of Contaminants in Soils and Sediments) and are currently being disseminated as reprints to various users in the scientific community. The research on pedotransfer functions has been presented by invitation in several universities and research centers in USA, France, United Kingdom, Spain, and Russia. Research results are annually presented by invitation at the Mid-Atlantic Crop Management School to crop consultants of seven states. The SWAT model with the microbial transport submodel is available on the WEB from the EPA and has become a model of choice in TMDL development.

Pathogens Component

Problem Area 19: Cost-effective treatment technologies to reduce the concentration of viable pathogens and parasites in manure and byproducts prior to land application are needed.

Background: An important part of manure and byproduct management is treatment prior to land application because it can reduce pathogens, manure volume, odor potential, and stabilize nutrients while improving the handling and spreading characteristics. Thus, effective treatments can contribute significantly to pollution prevention and hazard reduction. However, pathogen reduction aspects of treatment have often been a secondary consideration to nutrient stabilization, volume reduction, and temporary storage benefits. Consequently, little is known about pathogen reduction in many of the currently used treatments. Because composting, heat drying, digestion, and alkaline stabilization has been used to meet federal limits for pathogens in biosolids destined for land application, more is known about pathogen reduction with these technologies.

Treatment is particularly appropriate for confined animal production operations in contrast to grazing and free ranging animal systems. Treatments typically available include passive processes such as deep stacking, stockpiling, drying, storage lagoons, and direct land application with and without incorporation. Active treatment processes currently used include composting, heat drying, digestion, aerated lagoons, and constructed wetlands. Other treatment alternatives are under evaluation, adaptation, or demonstration trials and include: alkaline stabilization, fixed film digestion, algal scrubbing, and biomineral augmentation. There are also other approaches that are theoretically capable of reducing pathogens, but these have not been shown to be currently practical for manure because of cost and ease of incorporation into the overall animal production system. For all treatments there is a need to develop operational guidelines for existing and new manure treatments that, when followed, will result in quantifiable amounts of pathogen reduction. The goals of this problem area include:

- Determine rates of pathogen destruction for major existing treatments, i.e., deep stacks, compost (passive aerated, windrow, static piles, in-vessel), digestion, lagoon, air drying, heat drying, and new treatments, and include pathogens and parasites recently involved in the surge of food and waterborne illness outbreaks in the US.
- Determine what protectants in manures, composts, or soils affect survival of pathogens and parasites.
- Quantitatively relate rates of pathogen destruction to critical environmental factors associated with each of the various treatment processes; develop destruction functions for each of the major pathogens, manure types, and treatments.
- Develop process quality criteria to guide operators so that pathogen destruction is achieved to the extent possible for the treatment process selected and develop and validate appropriate quality control tests or measures for pathogen destruction for each major treatment process.
- Determine which indicator or surrogate organisms are appropriate for use in assessing reduction of particular pathogens in manure from various animal species; and use them in on-farm tests.
- Improve microbial growth, survival and thermal death models for manure and soil matrices, including species and strain differences, and nonlinear declines.

- Develop concepts and models of microbial exposure and risk analysis for treated manure products and link to more general microbial risk assessment models.
- Incorporate pathogen reduction data for major treatment methods into cost-benefit analysis models.
- Compare actual and predicted destruction in various on-farm treatment processes.
- Evaluate the use of industrial by-products to improve effectiveness of pathogen reduction treatments.
- Develop new methods to reduce or eliminate contaminants from establishing on plants before harvest.
- Develop new cost-effective disinfection methods and equipment and systems modifications for processing manure that are also consistent with air and water quality and nutrient management concerns.

Accomplishments:

Polyacrylamide (PAM) treatment is highly effective in removing fecal coliforms from wastewater and irrigation tailwater. Research conducted showed that polyacrylamide (PAM), PAM+alum, and PAM+hydrated lime reduced by 99% the total and fecal coliform released from cattle, fish or swine manure applications to irrigated soils in the Intermountain Western U.S. and Australia.

Impact: PAM is already being used to control sediment in irrigation water runoff. Its ability to also remove pathogens from wastewaters used for irrigation is another benefit of this treatment.

Selected Publications:

Sojka, R.E. and Entry. J.A. 2000. Influence of polyacrylamide on movement of microorganisms in irrigation water. Environmental Pollution 108:405-412.

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

Entry, J. A. and Farmer, N. 2001. Movement of coliform bacteria and nutrients in groundwater flowing through basalt and sand aquifers. Journal of Environmental Quality. 30:1533-1539.

Entry, J.A., R.E. Sojka, M.E. Watwood and C. Ross. 2002. Polyacrylamide preparations for protection of water quality threatened by agricultural runoff contaminants. Environmental Pollution. 120:191-200.

Entry, J.A., Phillips, I, Stratton, H. and Sojka.R.E. 2003. Polyacrylamide+$Al(SO_4)_3$ and polyacrylamide+CaO remove coliform bacteria and nutrients from swine wastewater. Environmental Pollution. 121:453-462.

Spackman, R. J.A. Entry, R.E. Sojka.R.E and J.W. Ellsworth. 2003. Polyacrylamide for coliform bacteria removal from agricultural waste water in irrigated forage production. Journal of Soil and Water Conservation. 58:276-283.

Wetlands may be effective means to treat wastewater from animal feeding operations. Dairy washwater is approximately three to five times higher in major constituents (e.g. nitrogen, phosphorus, BOD, etc.) than domestic raw sewage. Research was conducted in California on the efficiency of a sub-surface wetland system in the removal of chemical contaminants and pathogens from dairy washwater. The final effluent is to be used for irrigation. Samples were collected weekly for 11 months from two wetlands to determine the removal rate of chemical contaminants, total/fecal coliforms and *Escherichia coli*. Reduction by the treatment was greatest for biological oxygen demand (BOD), suspended solids, chemical oxygen demand (COD), nitrate, and coliforms. There was only moderate removal of total nitrogen and phosphorus. The removal of the main pollutants from the dairy washwater has had a beneficial impact on the surface and groundwater in the Chino Basin, and, in turn, has improved the quality of water leading into the Santa Ana River and the Orange County groundwater basin.
In Nebraska, an unvegetated constructed wetland is being evaluated as an alternative livestock manure management practice for the removal of fecal indicator microorganisms and bacterial and protozoan pathogens. Removal rates were more than 80 percent for coliforms, *E. coli* and enterococci, but only 64% for Giardia cysts and 31 % for Cryptosporidium oocysts. Removals in the studied unvegetated wetland are less than those reported for a vegetated constructed surface flow wetland receiving secondarily treated municipal wastewater. Removals for *E. coli* and total coliforms are, however, considerably higher than those observed in an aquatic pond receiving secondarily treated municipal wastewater. Information gained by this work will elucidate whether or not constructed wetlands are an effective alternative to traditional holding pond systems for the reduction of manure-borne microorganisms from livestock wastewater.

Impact: Wetlands may be an affordable means of waste management for the dairy industry and other confined animal facilities. They provide a cost-effective, low-maintenance process that can be independently built and managed. The project in California has already benefited the water district by reducing cost of contaminant removal down stream and the contamination of ground water with nitrate.

Selected Publications:

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

Ibekwe, A. M. and S. R. Lyon. 2003. Constructed wetlands for the removal of contaminants from dairy washwater. pp. 477-485. In Total Maximum Daily Load (TMDL). Environmental Regulations-II ed. A. Saleh. Proceedings of the 8-12 November 2003 conference (Albuquerque, NM, USA).

Thurston-Enriquez, J. A. 2004. Constructed wetlands for the reduction of manure-borne fecal indicator and pathogenic microorganisms from dairy cattle wastewater. 9th International Conference on Wetland Systems (Sept. 2004). Accepted.

Advanced alkaline stabilization effectively disinfects manure. Research on use of advanced alkaline stabilization with dairy, poultry, and steer manure has shown that disinfection can be achieved within a very short time. Select viable pathogens and indicators (coliforms, *E. coli*.) were not detected after 3 min. Further nutrient stabilization of the manure is achieved by co-composting the pre-treated manure with municipal yard trimmings, i.e. leaves, straw, grass clippings, wood chips. The product is an organically enhanced agricultural lime-type product with considerable buffering capacity because of the high Ca carbonate content.

Vegetated filter strips effective in removing fecal coliforms from runoff.
Numerous variables affect rates and extent of pathogen transport including slope, soil characteristics, vegetation and rainfall intensity/duration. Pathogens applied or deposited onto soil surfaces may infiltrate into the soil profile or, alternatively, may runoff to surface waters. Since both processes can occur simultaneously, a thorough understanding of the controlling factors is critical in predicting which process will predominate. A two-side lysimeter with 20% slope on both was instrumented to monitor the surface and vertical transport of manure-borne microbes. Each side of the lysimeter was divided into sub-plots (6.7 m x 7.3 m), one with grass and the other bare soil. Plots were instrumented to collect runoff samples along the 6.7 m slope at three equidistant transects. Samples of runoff were also collected in a gutter at the edge of each plot. All plots were equipped with multi-sensor moisture probes to monitor real-time water content through the soil profile. Bovine manure was applied at the top of the slope of each plot in one-foot strips. Rainfall was simulated at 61 mm/hr using a portable rainfall simulator. Surface flow was measured and sampled at five minute intervals at three different transects and in the gutter. Twenty-four hours after simulations, soil samples were taken at incremental depths (0-50 cm). Runoff and soil samples were analyzed for fecal coliform (FC) bacteria. FC data indicate that while 100% of the initial population could be lost to runoff from bare plots, less than 1% of the initial population was lost from vegetative plots. FC concentrations decreased with distance along the slope from the point of application. Results also show that bare plots offered no resistance to surface flow; FC were detected in total runoff at gutter within 10 minutes of rainfall initiation.

Impact: These data show that vegetative filter strips can dramatically reduce pathogen in runoff.

Selected Publications:

Roodsari, R., D. Shelton, A. Shirmohammadi, Y. Pachepsky, A. Sadeghi, and J. Starr. 2002. Pathogen Transport As Affected By Surface Conditions. American Society of Agricultural Engineers Annual International Meeting. July 28-July 31, Chicago, IL. *Paper Number: 022264*

Roodsari, R., Y. Pachepsky, D. Shelton, A. Shirmohammadi, A. Sadeghi, and J. Starr. 2003. Modeling Manure-Borne Pathogen Transport With Runoff and Infiltration. American Society of

Agricultural Engineers Annual International Meeting. July 27- July 30, , Las Vegas, NV. *Paper Number: 033101*

Shelton, D.R., Pachepsky, Y.A., Sadeghi, A.M., Stout, W.L., Karns, J.S., Gburek, W.L. 2003. Release rates of manure-borne coliform bacteria from data on leaching through stony soil. Vadose Zone Journal. 2003. v. 2. p. 34-39.

Salmonella bacteriophages (phages) have potential as biocontrol agents. Salmonella-specific phages were discovered in swine effluent lagoons. This research was based on the hypothesis that Salmonella phages occur naturally in manure and can be isolated for potential use as typing reagents, indicators and biocontrol agents. A protocol for isolation of lytic Salmonella phages from swine lagoons was developed. Swine lagoon effluent from commercial hog farms was a good source of Salmonella phages and the isolation and enrichment protocol produced high titers of phages for further characterization and research. Host range tests indicate that phages isolated by this protocol are specific for species of Salmonella and do not harm other species of bacteria found in swine effluent lagoons. With additional characterization these phages may be used to in studies of Salmonella strain typing and as indicators of Salmonella in animal waste-contaminated environments.

Impact: This discovery may benefit the concentrated animal feeding industry by providing a pathogen-specific, environmentally safe biological control treatment for animal wastes prior to land application or off-farm transport of the waste.

Selected Publication:

McLaughlin, M.R., Bal'a, M.F., Rowe, D.E., Doerner, K.C., King, R. and Andersland, J. 2003. Isolation of lytic Salmonella bacteriophages. International Poultry Scientific Forum.

A system of treatment technologies that capture nutrients, reduce emissions of ammonia and nuisance odors, and kills harmful pathogens has been developed. Aspects of this system have been also described in other parts of this report. The system greatly increases the efficiency of liquid-solid separation by injection of polymer to increase solids flocculation. Nitrogen management to reduce ammonia emissions is accomplished by passing the liquid through a module where immobilized bacteria transform nitrogen. Subsequent alkaline treatment of the wastewater in a phosphorus module precipitates recoverable phosphorus and kills pathogens. Treated wastewater can be recycled to clean hog houses or for crop irrigation. The system has been pilot tested and is going through full-scale demonstration and verification as part of the Smithfield Foods-Premium Standard Farms/North Carolina Attorney General agreement to replace current lagoons with Environmentally Superior Technology. The full-scale demonstration facility was installed at a 4,400-head finishing farm in Duplin County, NC. The system has been successfully stabilized and brought to steady-state operation with treatment performance that exceeded design expectations; it separated 97% of suspended solids, 99.9% of BOD, 98.9% of TKN and 94.8% of total P. Odorous compounds in the waste were reduced > 99% by treatment. Fecal coliforms, *E. coli., Salmonnella*, Enterococci, and *Clostridium perfringens* were reduced to non detectable levels. In less than one year, the anaerobic lagoon

that was replaced with the treatment system was converted into an oxic pond with ammonia concentration lower than 30 ppm.

Impact: The system has the potential for major positive impact as a functional advance in the treatment of animal waste.

Selected Publications:

Vanotti, M.B., Szogi, A.A., and Hunt, P.G. 2001 (inventors). Patent application entitled 'Wastewater Treatment System' filed 7/13/2001, Serial 09/903,620 US Patent and Trademark Office.

Vanotti, M. B., Millner, P.D., Hunt, P.G. , and Ellison, A.Q. 2004. Removal of pathogen and indicator microorganisms from liquid swine manure in multi-step biological and chemical treatment. Bioresource Technology (in press).

Vanotti, M.B. 2003. Evaluation of Environmental Superior Technology: Swine Waste Treatment System for Elimination of Lagoons, Reduced Environmental Impact, and Improved Water Quality. Year 3 Progress Report For the NC Attorney General – Smithfield Foods / Premium Standard Farms / Frontline Farmers Agreements.
http://www.cals.ncsu.edu/waste_mgt/3year%20Smithfield%20Report/pi%20report%20pdfs/super%20soil%20original.pdf

Pathogens Component

Problem Area 20: Risks associated with manure pathogens need to be assessed.

Background: Risk assessment is the process of using scientifically-supported relationships to delineate the impacts of specific actions, events or hazards on measurable, quantitative endpoints. Risk assessment encompasses a synthesis of sound scientific information on pathogen production, survival, and transport. Appropriate models are an effective means of integrating and organizing independent data sets for risk assessment. Models can assist with (i) assessing the relative impact of complex interactions among multiple variables, (ii) providing a framework to examine uncertainties in knowledge, (iii) ascertaining measurable endpoints, and/or (iv) highlighting potential monitoring strategies for further evaluation. However, there is often not adequate data to model the risks posed by pathogens in the environment. Where mathematical models are not adequate or yet possible to describe cause and effect relationships (e.g., potential for contamination of fresh produce), other qualitative methods will be explored. The goals for this problem area are to:

- Establish assessment endpoints.
- Evaluate manure management strategies in the context of risk assessment.

Accomplishments:

Poultry litter application increased the concentrations of estradiol, tesotosterone, *E. coli* and the enterococci in small watersheds. The potential for hormones as well as pathogens to contaminate water is a major concern that is not yet well informed by data. Elevated concentrations of estradiol, tesotosterone, *E. coli* and the enterococci from an agronomic application of poultry litter to four small (1.3 to 2.7 ha) instrumented watersheds in Georgia were measured when a significant rain event with surface runoff occurred three weeks after litter application, compared to concentrations in run off from rain events that occurred several months after litter application.

Estradiol and testosterone concentrations in drainage and runoff after poultry litter applications were not significant. The flow weighted concentrations of estradiol and testosterone in drainage and runoff from tilled or no-till plots that received a rate of litter commensurate with the N requirement of either rye or corn was not significantly different from the concentrations coming off plots that only received mineral fertilizer.
The major difference between the two studies is scale, catchments greater than one hectare compared to plots of 0.03 ha. Hydrologic differences are also significant, more infiltration drainage occurs in the smaller plots. However, because of the greater slope of the catchments runoff is much greater than drainage. The hydrographs of the two experimental sites can be different because of differences in storm characteristics. Depending on the concentration of the hormones in the litter (which can range between less than 1.5 to greater than 60 $\mu g\ kg^{-1}$) that is applied, these results indicate that poultry litter with lower concentrations of the hormones that are applied at agronomic levels may not have an impact on surface or ground water. However, litter applications in watershed greater than 1 ha may increase the load of *E. coli*, enterococci,

and the sex hormones when rain events occur within a few weeks of application, and thus impact surface water.

Impact: It appears that when concentrations of hormones in poultry litter are within normal ranges, they may not be observed in runoff, but if they are present in high concentrations and rainfall occurs shortly after land application elevated hormone concentrations may occur in runoff. More research is needed to determine if and when risks occur.

Selected Publications:

Jenkins, M.B., D.M. Endale, H.H. Schomberg, J.L. Steiner, M.L. Cabrera, and P.G. Hartel. 2002. Sex hormones from poultry litter–their fate and transport in runoff and drainage from cropped till- and no-till plots. Annual Meeting of the American Society of Agronomy, Agronomy Abstracts.

Jenkins, M.B. and D. Endale. 2001. Fecal bacteria and sex hormones in runoff from cropped watersheds amended with poultry litter. Annual Meeting of the American Society of Agronomy, Agronomy Abstracts.

Jenkins, M.B., D.M. Endale, H.H. Schomberg, H.A. Sangsupan, D.R. Radcliffe, P.G. Hartel, M.L. Cabrera, W.K. Vencill, and N.W. Shappell. 2004. Fate and transport of sex hormones from poultry litter applied to till and no-till cropping systems. National Water Quality Conference, Clearwater, FL.

Urban runoff contains more enteropathogenic *E. coli* than agricultural runoff and there appears to be greater diversity of *E. coli* O157, including pathogenic and nonpathogenic strains, than was previously suspected. Contamination of surface and ground water by pathogens represents a potentially serious public health threat. Although water-borne pathogens may derive from animal agriculture, wildlife and humans are also sources. Monitoring studies of pathogenic *E. coli* (including *E. coli* O157) were conducted in watersheds with various land-uses (animal agriculture, wildlife, urban/suburban) to assess the levels of contamination, and potential public health threat. The most extensive survey was conducted in the Baltimore County, MD watershed in collaboration with the US Forest Service. Surface water samples were analyzed for presumptive enteropathogenic (EPEC) and enterohemorrhagic *E. coli* (EHEC) using PCR methods and E. *coli* O157 using immunological methods. Essentially all water samples contained presumptive EPEC, while a substantial percentage of water samples contained *E. coli* O157. More enteropathogenic E. *coli* were detected in runoff from urban than agricultural sources. However, the concentrations of pathogenic *E. coli* were usually low, typically less than 10 cells per 100 mL. Immunological data are confounded by the observation that several *E. coli* O157 strains isolated from water samples were determined to be nonpathogenic. These results indicate that there is much greater diversity of *E. coli* O157, including pathogenic and nonpathogenic strains, than was previously suspected. Molecular analysis was conducted with selected water samples to determine relatedness of enteropathogenic *E. coli* strains and potential sources. These analyses indicated that there was a close genetic similarity with previously characterized enterohemorrhagic and enterotoxigenic strains of *E. coli*.

Impact: These results suggest that controlling runoff from agricultural sources may not decrease *E. coli* in water bodies. This information will be useful for public health departments, water utilities, regulators and home-land surveillance/security.

Selected Publication:

Higgins, J.A., Belt, K.T., Karns, J.S., and Shelton, D.R. 2003. Prevalence and molecular characterization of enteropathogenic *E. coli* in steams along an urban-rural gradient in the Baltimore, MD metropolitan area. Annual Society for Microbiology Meetings, May 20, Washington, D.C.

Endotoxins represent risk to animals and humans, even more than bovine Gram-positive culturable pathogens. Dusts in cattle feedlots were analyzed for microorganisms and endotoxins. Aerosolized feedyard endotoxin exposure in ruminants was found to be more biologically toxic than high concentration of bovine Gram-positive culturable pathogens. Aerosolized endotoxin from manure dust can induce a significant fever of 104 to 106°F within 4 hrs and an increase in total white blood cells (leukocytosis) within 12 to 24 hours of inhalation to cattle, sheep and goats. Increased doses of aerosolized endotoxin induced an increase in rectal temperature and leukocytes. A dose response was seen in goats aerosolized with endotoxin over increasing periods of time**.** A search for more dust/endotoxin biomarkers/markers in general is extremely important to understand dust/endotoxin effect on ruminants and to determine if dust/endotoxin has an effect on sickness and production. The feeder calf industry has been proactive in dust control for employees and because neighbors frequently complain. If a dollar cost could be associated with feedyard dust events related to sickness and production cost, feedyard owners and managers, veterinarians and nutritionist, could more afford dust abatements programs, and more attention would be devoted to dust abatement.

Impact: Aerosolized endotoxin is the most biologically active part of feedyard dust, even more than the viable culturable Gram-positive bovine pathogens. Dust in a feedyard is a common happening and may precipitate illness especially on market stressed feeder calves and it may have a negative impact on production, thus increasing the price of beef. Endotoxin in feedyard air can have a similar effect on human employees, or downwind neighbors.

Common fungi spores and mycotoxins present risks at cattle feedyards. Bioaerosols from 7 feedyards were analyzed for the concentration of bacteria, fungi in the winter and summer. The following bacterial cultures were determined: anaerobic mesophilic, aerobic mesophilic, and theromophilic; and mesophilic and thermophilic fungal cultures. Differences were noted in different feedyards, which may mean that some management practices are better than others. Common fungi spores (*Mucor ramosissimus, Chaetomium globosum*, and T*richoderma viride*) can cause pathological changes in the lungs of non-immunosuppressed ruminants. Mycotoxins of certain common feedyard fungi are toxic in the respiratory tract of ruminants. Mycotoxins extracted from *Mucor ramosissimus, Chaetomium globosum*, and T*richoderma viride* were toxic on transthoracic injections of non-immunosuppressed ruminants. Common feedyard fungi in addition to endotoxin may cause inflammation of the respiratory tract of ruminants.

Impact: For the first time bacterial, fungal, and endotoxin aerosols concentrations were identified and many of the fungal and bacterial isolates were identified. Some common feedyard fungal spores are very toxic when they gain entrance to the respiratory system. Potentially other toxins could reside in manure organic dust and should be determined to protect animal and human well-being.

Selected Publications:

Purdy, C.W., Rice, W.C., Straus, D.C., et al. 2002. Air quality and its microbial component is important to rural areas. Great Plains Foundation Symposium, April 1-3.

Purdy, C.W., Straus, D.C., Parker, D.B., et al. 2002. Treatment of feed yard dust containing endotoxin and its effect on weanling goats. Small Ruminant Research. 46:123-132.

Rice, W. C., and C. W. Purdy. 2002. Microbial Ecology and Molecular Characterization of Pathogens in Feedyard Playa Air and Water Samples in the High Plains of Texas, American Society for Microbiology, Texas Branch, p 22 November 8, 2002, Austin, TX.

Purdy, C.W., Straus, D.C., Chirase, N., et al. 2003. Effects of aerosolized dust in goats on lung clearance if Oasteyrekka abd Nabbgeunua soecues, Current Microbiology. 45:174-179.

Chirase, N.K., Purdy, C.W., Avampato, J.M. 2004. Effect of simulated ambient particulate matter exposure on performance, reactal temperature and leukocytosis of young Spanish goats with or without tilmicosin phosphate. J. Animal Science (in press).

Chirase, N.K., Greene, L.W., Purdy, C.W., et al. 2004. The effect of transport stress on respiratory disease, serum antioxidant status and lipoperoxidation levels in beef cattle. Am J. Vet. Res. (Accepted, 28 August 2003).

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

A watershed scale models for assessing pathogen loadings in surface and groundwater from agriculture was developed. Existing pathogen fate and transport models are either designed for small-scale applications (i.e., MWASTE, COLI, etc.) or applicable to large-scale watershed assessment, and they are mostly spread-sheet type model such as HSPF. No continuous, process-based simulation model exists that can provide simultaneous estimates of nutrients, sediment, and pathogen loadings into surface and groundwater resources at watershed or basin levels. We have recently included a new microbial component into SWAT (Soil & Water Assessment Tool) model. SWAT is a watershed-scale model and has been extensively tested for nutrient and sediment at different geographical locations and under various climatic conditions. SWAT is also used by U.S. EPA (within the framework of the BASIN modeling platform) for watershed assessment. This new SWAT/Microbial model will allow for the

assessment of pathogen release and loadings into water resources along with the nutrients and sediment evaluations. It has recently been successfully applied to the Shoal Creek Watershed in Southwest Missouri by FAPRI (Food and Agricultural Policy Research Institute) scientists. In a 30-year scenario, the model predicted the variations of fecal coliform measured in the stream for 70% of the years within one standard deviation (Baffaut and Benson, 2003).

Impact: This model can be used NRCS for the EQIP (Environmental Quality Incentive Program), since nearly 50% of the EQIP budget has been devoted to reducing the environmental impacts of animal unit operations. It can also be used by other agencies (FSA, EPA, etc.) that do risk assessments. The SWAT/Pathogen model is also a useful tool for TMDL assessment of pathogen contributions.

Selected Publications:

Sadeghi, A.M. and Arnold, J.A. 2002. A Microbial Sub-Model for predicting pathogen loading in surface and groundwater at watershed and basin scales. Proceeding of the March 11-13, 2002 Conference on TMDL, Fort Worth, TX. An ASAE Paper Presentation. p. 56-63.

Sadeghi, A., Pachepsky, Y., Shelton, D., Stout, W. 2002. Modeling coliform bacteria and bromide transport in large in-situ columns of a fractured soil. ASA, Agronomy Abstract, CD-ROM..

Roodsari, R., Pachepsky, Y., Shelton, D., Shirmohammadi, A., Sadeghi, A., Starr, J. 2003. Modeling manure-borne pathogen transport with runoff and infiltration. An ASAE Meeting Presentation. Paper No. 033101. p. 30-51.

Shelton, D.R., Pachepsky, Y.A., Sadeghi, A.M., Stout, W.L., Karns, J.S., Gburek, W.L. 2003. Release rates of manure-borne coliform bacteria from data on leaching through stony soil. Vadose Zone Journal. 2003. v. 2. p. 34-39.

Planning Activities

ARS researchers studying pathogens have held two internal workshops in the last two years. The workshop purposes were to share information (since so many of the scientists were only recently hired or are new to this research topic), to investigate opportunities for collaboration and to increase coordination. Other meetings have also been held with other agencies and organizations with similar objectives. The ARS workshops have resulted in the initial formation of teams to address the following topics across multiple locations: (1) methods development and cross lab testing, (2) source tracking, (3) indicator selection and testing coordinated with fate and transport studies using common protocols, and (4) model development in concert with experimentalists for testing and validating the models . These are not meant to be ARS only teams and others are most welcome to participate. We think more formal coordination and collaboration on these and other topics will enable quicker progress and greater impact to be made. Are there other or better topics for increased coordination and collaboration?