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National Program 214
AGRICULTURAL & INDUSTRIAL BYPRODUCTS

ACCOMPLISHMENT REPORT 2009-2013

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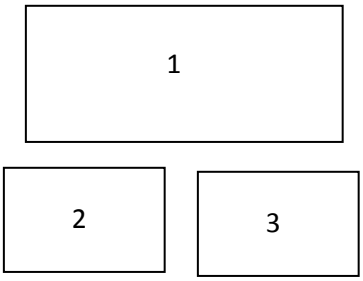

1. Aerial view of second-generation wastewater treatment system in a swine farm in Duplin Co., North Carolina. *Photo by Matias Vanotti*

2. Manure collection tank at the Beltsville (Maryland) Agricultural Research Center. *Photo by Keith Weller*

3. Collection of airborne microorganisms (via glass impingers) at a 10,000 cow open-lot dairy in southern Idaho. Results from this study will be published in ARS magazine next month.

National Program 214
Agricultural & Industrial Byproducts

ACCOMPLISHMENT REPORT 2009-2013

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National Program 214
Agricultural & Industrial Byproducts

Accomplishment Report 2009-2013

Introduction

Purpose of this Report
This report summarizes selected accomplishments of the Agricultural Research Service (ARS) national program that focuses on agricultural and industrial byproducts. A key purpose of the report is to provide information for an external assessment of the program's performance over the past 5 years. This assessment will also provide recommendations for the future direction of the program. Because of space limitations not every accomplishment can be presented. Emphasis is placed on reporting accomplishments that when taken as a whole will provide the greatest benefits to the public and scientific community.

Overview of the ARS Mission, Structure, and Research Planning

Role of ARS. ARS is the principal in-house research agency of the U.S. Department of Agriculture (USDA). It is one of the four component agencies of the Research, Education, and Economics (REE) mission area. Congress first authorized Federally-supported agricultural research in the Organic Act of 1862, which established what is now the USDA. That statute directed the Commissioner of Agriculture "...To acquire and preserve in his Department all information he can obtain by means of books and correspondence and by practical and scientific experiments...." The scope of USDA's agricultural research programs has been expanded and extended many times since the Department was first created.

Interaction with National Institute of Food and Agriculture (NIFA). NIFA is also in the REE mission area and has responsibility for advancing scientific knowledge to help sustain the U.S. agricultural sector through a research, education, and outreach system external to USDA by working with eligible partner institutions and organizations. The interrelated and complementary programs of ARS and NIFA requires the agencies to be visionary and forward thinking in effectively utilizing limited public resources through collaborative partnerships. Therefore, the two agencies regularly seek opportunities to increase the efficiencies of cooperative strategies and activities involving partnerships with the land-grant colleges and universities, other non-land-grant universities, Federal and State agencies, and customers.

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ARS size and budget. Today, the ARS workforce is approximately 8,400 employees, including 2,200 scientists and postdoctoral researchers who represent a wide range of disciplines. ARS has approximately 800 research projects spread over 90 locations across the country and at 4 overseas laboratories. The National Agricultural Library and the National Arboretum are also part of ARS. The annual budget is just over $1 billion. **Mission objectives entering the 21st century**. ARS conducts research to develop and transfer solutions to agricultural problems of high national priority and provides information access and dissemination to

- Ensure high-quality, safe food and other agricultural products,
- Assess the nutritional needs of Americans,
- Sustain a competitive agricultural economy,
- Enhance the natural resource base and the environment, and
- Provide economic opportunities for rural citizens, communities, and society as a whole.

A problem-solving organization. To achieve these broad objectives, ARS identifies critical problems affecting American agriculture, develops strategies to mobilize resources (both human and financial), writes and reviews research plans to efficiently solve these problems, performs multidisciplinary research, and reports the results to customers. Each step of the process involves communicating and interacting with the scientific community, customers, stakeholders, partners, and beneficiaries to ensure program relevancy, quality, and impact.

National programs. ARS research currently organized into 18 national programs. These programs are managed by the Office of National Programs through 24 National Program Leaders (NPLs) to bring coordination, communication, and empowerment to the approximately 800 research projects carried out by ARS. The national programs focus on ensuring the relevance, impact, and quality of ARS research. The national programs as currently structured are as follows:

Animal Production & Protection
Food Animal Production
Animal Health
Veterinary, Medical, and Urban Entomology
Aquaculture

Natural Resources & Sustainable Agricultural Systems
Water Availability & Watershed Management
Climate Change, Soils, and Emissions
Biorefining
Agricultural & Industrial Byproducts
Pasture, Forage, & Rangeland Systems
Agricultural System Competitiveness & Sustainability

Crop Production & Protection
Plant Genetic Resources, Genomics and Genetic Improvement
Plant Biological and Molecular Processes
Plant Diseases
Crop Protection & Quarantine
Crop Production
Methyl Bromide Alternatives

Nutrition and Food Safety
Human Nutrition
Food Safety (Animal & Plant Products)
Quality & Utilization of Agricultural Products

Teamwork between national programs. Ideally, the entire ARS research portfolio would go through an integrated programming cycle, but this is not possible because of the diversity, size, and geographic distribution of ARS activities. The national program structure is an administrative construct dividing a complex research program into manageable parts. There are clearly overlaps between national programs and this is addressed by managing each program with a team of NPLs who provide the appropriate mix of skills and experience.

Introduction to national program management and cycle. The management of all ARS research programs is organized around a 5-year national program cycle consisting of four sequential phases (Input, Planning, Implementation, and Assessment) designed to ensure the relevance, quality, and impact of every ARS national program. NPLs who work through multidisciplinary teams define and articulate the scope of each program with input from customers; stakeholders; partners; and ARS scientists, managers, and leaders. A prime mechanism used by the national program team to seek input is the national program workshop, conducted at the start of each program cycle. NPLs define the ARS program and provide broad scientific direction to ARS scientists through the development of the national program strategic vision and an action plan. Action plans serve as the central reference for defining a program‘s relevance and performance expectations, and as the basis for NPLs to assign research objectives, personnel, and dollars to research units. After programs are planned, research is implemented at more than 90 locations across the Nation and the world. NPLs monitor and demonstrate performance at the program level through program annual reports, and have an ongoing coordination role. ARS continually monitors the quality of its work to meet Federal requirements and ensure public accountability. ARS regularly identifies accomplishments and major technology transfers in project annual reports and national program annual reports. Also, toward the completion of every 5-year program cycle, each national program's performance is evaluated by an external panel of customers and stakeholders against the goals and outcomes of the national program action plan.

The reporting of accomplishments for this review does not precisely correspond to the actual 5-year cycle dates of the corresponding projects. This is so that the feedback from this review can be utilized in the planning for the next cycle. As a result, however, some accomplishments may have occurred at the end of the preceding national program cycle and not have been reported in that cycle’s review. And some accomplishments in this cycle will occur between the date of this review and the actual end of the project. Therefore, readers will be presented with accomplishments and citations in this report that cover the 5-year period 2008–2013.

Overview: Agricultural and Industrial Byproducts (NP 214)

Mission. The goal of the Utilization of Manure and Other Agricultural and Industrial Byproducts national program (NP 214) is to effectively and safely manage and use manure and other agricultural and industrial byproducts in ways that maximize their potential benefits while protecting the environment and human and animal health.

Background. The total amount of manure, biosolids (treated sewage sludge), and industrial and municipal wastes generated annually in the United States exceeds 1 billion tons. The majority of all animal manure and biosolids and significant amounts of other byproducts are spread, sprayed, or otherwise applied to agricultural land because of the benefits they can provide. These benefits include

nutrients for crop production and organic matter to improve soil properties. Improperly managed manure and other byproducts, however, can pose a threat to soil, water, and air quality, and to human and animal health.

Animal production and associated animal product sales in the United States in 2007 was valued at more than $150 billion annually. New technological innovations and the economic advantage of size have driven a structural shift from small to large operations where animals are grown in houses, feedlots, and other confinement facilities. These production facilities are referred to as animal feeding operations (AFOs). Large AFOs meeting specific criteria are called concentrated animal feeding operations (CAFOs). According to the U.S. Environmental Protection Agency (EPA) about 15 percent of all AFOs are now CAFOs.

The development of AFOs and CAFOs has separated animal production from crop production. Consequently, less land is often available for on-farm recycling of manure-derived nutrients to crops, although nationwide there is more than enough agricultural land available to readily utilize all the nutrients in manure. Transportation costs inhibit distribution of manure at sites distant from where it is generated. Most manure, therefore, is usually land-applied within about 10 miles of beef cattle feedlots, dairy barns, poultry houses, or swine facilities. The amount of manure generated in the United States is estimated to exceed 335 million tons of dry matter per year. The volume of animal waste produced at CAFOs or AFOs often exceeds local demand for use as fertilizer. Because of this imbalance and other concerns (e.g., water quality, air quality, pathogens), CAFOs are currently subject to regulations designed to prevent water quality impairment. The EPA is also gathering data on atmospheric emissions from CAFOs in advance of potential future rule making (ARS scientists submitted their findings for use by the EPA). These developments have increased the challenge of using manure on agricultural lands while protecting the environment. In addition, a great demand exists for scientific information about effective management of manure to guide policy and regulatory decisions.

Each year millions of tons of industrial and municipal byproducts are produced. They are often considered to have little value and are frequently disposed in landfills or incinerated at considerable expense. However, many of these byproducts are potentially useful on agricultural land or in horticulture either individually or through blending, mixing, or treatment with other byproducts. Byproducts have many characteristics that may make them useful for direct land application, soil reclamation and remediation, as components of manufactured soils and composts, or as feedstuffs. Research and development is needed, however, to determine the composition and bioactivity of these products and to determine potential hazards and appropriate uses. At this time, State regulatory agencies lack analytical tools to make reasonable policy decisions regarding the beneficial use of these byproducts in agriculture or horticulture. Protocols and methodology standards are needed to enable regulatory authorities to examine and approve byproducts for agricultural use. Treatment technologies and management practices to make these products usable will reduce potential environmental hazards, reduce disposal costs, and increase the cost-effectiveness of agriculture.

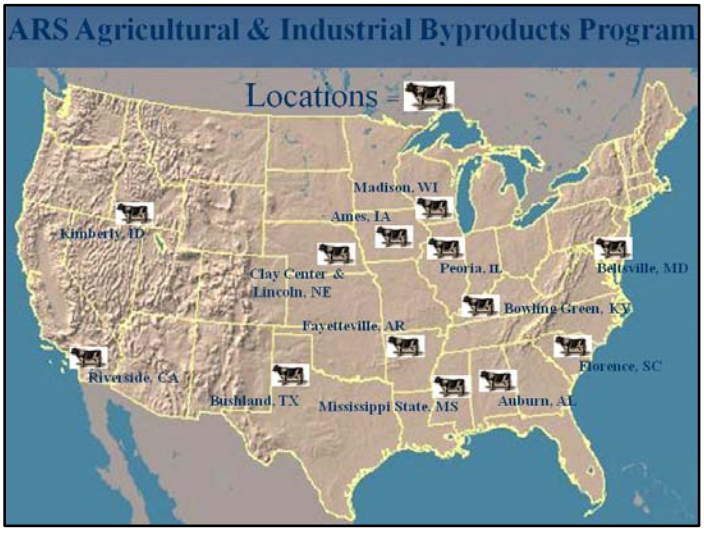
Contribution to ARS strategic goals. Outputs of NP 214 research support the “Strategies and Means” associated with the performance measures and targets in the ARS strategic plan for FY 2012–2017, Strategic Goal 2.4 ("effectively and safely manage and use manure and other agricultural and industrial byproducts in ways that maximize their potential benefits while protecting the environment and human and animal health").

Approach. ARS and NIFA jointly hosted a customer/stakeholder workshop on agricultural and industrial byproducts in Denver, Colorado, in November 2008. Over the course of a day the stakeholders and ARS scientists cycled through several focus groups to learn about the customers’ perceived research needs. Subsequently, the ARS scientists and the ARS and NIFA NPLs refined the focus group reports into four

primary topic areas that became the components of the new 2009–2014 ARS NP 214 Action Plan. Those components are as follows:

1. Management, Enhancement, and Utilization of Manure Nutrients and Resources
2. Manure Pathogens and Pharmaceutically Active Compounds (PACs)
3. Atmospheric Emissions
4. Developing Beneficial Uses of Agricultural, Industrial, and Municipal Byproducts

In many cases research overlaps two or more of these component areas and related accomplishments are included under the component that seems most fitting.



Research conducted under NP 214 occurs at locations and scales ranging from a laboratory bench top or growth chamber to 10,000-head dairies. The following ARS locations have participated in research projects conducted under NP 214: Ames, Iowa; Auburn, Alabama; Beltsville, Maryland; Bowling Green, Kentucky; Bushland, Texas; Clay Center, Nebraska; Fayetteville, Arkansas; Florence, South Carolina; Kimberly, Idaho; Lincoln, Nebraska; Madison, Wisconsin; Mississippi State, Mississippi; Peoria, Illinois; and Riverside, California. More detail on specific project titles and locations is present in Appendix A.

Cooperation within ARS. In addition to NP 214, other ARS national programs are making significant contributions to improving the productivity, profitability, and environmental sustainability of the Nation's croplands. These programs include Agricultural Systems Competiveness and Sustainability; Water Availability & Watershed Management; Biorefining; Pasture, Rangeland, & Forage Systems; Crop Protection & Quarantine; Crop Production; Climate Change, Soils & Emissions; Animal Production Systems; Food Safety; and Plant Genetic Resources, Genomics and Genetic Improvement.

Use of references in the report. The accomplishments summarized in this report are supported mainly by references in peer-reviewed scientific publications. In some cases, references to scientific presentations and abstracts are used when accomplishments are recent and there has not been sufficient time to publish. A nearly complete listing of peer-reviewed publications arising from NP 214 research projects is included as Appendix B (by project) and Appendix C (by author).

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COMPONENT 1. Management, Enhancement, and Utilization of Manure Nutrients and Resources

Manure, biosolids, and other agricultural and industrial byproducts often contain components (e.g., nitrogen, phosphorus, potassium, and carbon) that can be used to improve plant growth or as a potential bioenergy source. The quantity of nutrients and energy in manure is primarily determined by the animal species and diet, and the postexcretion management and treatment of the manure. Because the quantity of readily available fertilizer nutrients is frequently limited or high in cost, recycling these nutrients in manure and byproducts back into production agriculture is highly desirable.

Strategies to take advantage of the opportunities and resources identified above involve managing animal diets, manure, and other byproducts to maximize the quantity of nutrients that are beneficial in agriculture. These strategies are the basis for the four problem areas identified for this component. The problem areas identified are: 1) animal nutrition and management; 2) collection, storage, treatment, and utilization of manure; 3) utilization of manure in integrated farming systems; and 4) energy recovery from manure and other agricultural byproducts.

Some of the significant ARS research accomplishments that address these Problem Statements follow.

Problem Statement 1A: *Improving the Usability of Manure Nutrients through More Effective Animal Nutrition and Management*
Major factors controlling the type, quantity, and form of nutrients in animal manures are composition and quantity of diet consumed, nutrient retention in the animal or in animal products, and, in some cases, the route of excretion by the animal. Retention of nutrients in livestock or their marketable products is typically less than 30 percent of total dietary intake. As a consequence, excretion of nutrients into urine and feces (manure) can be relatively high. Thus, it may be possible through diet modification to improve nutrient utilization efficiency within the animal, decrease nutrient excretion, and alter the phytoavailability of nutrients in the manure, thereby reducing the impact of animal production on the environment.

Nitrogen use efficiency in dairy production. The more efficient dairy farmers are in managing nitrogen, the less nitrogen will be wasted in manure. ARS researchers in Madison, Wisconsin, and University Park, Pennsylvania, along with Australian colleagues, calculated nitrogen-use efficiency ratings to guide dairy farmers. These ratings can help dairy farmers make better use of their nitrogen in the face of escalating costs and increasing nutrient regulation. The researchers found that only about 20–35 percent of the nitrogen fed to dairy cows is converted into milk. They also discovered that 16–77 percent of the nitrogen in manure or fertilizer is taken up by crops and pasture plants. In addition, the study showed that between 8 and 64 percent of all nitrogen applied to typical commercial dairy farms is converted into farm products. The wide ranges in nitrogen-use efficiency point to the fact that there is significant room for improvement of nitrogen use, profits, and the environment. Nitrogen-use efficiency formulas can be used as tools to promote practices that maximize nitrogen use so that nitrogen does not leave farms to pollute waterways and ground water and negatively impact air quality. These tools are available

in a fact sheet and a video for dairy farmers, consultants, and policy makers at the Web site of Livestock and Poultry Environmental Learning Center sponsored by the Cooperative Extension Service (www.extension.org/pages/19855/livestock-and-poultry-environmental-learning-center-newsletter).

Powell, J.M., Gourley, C.P., Rotz, C.A., and Weaver, D.A. 2010. Nitrogen use efficiency: a performance indicator for dairy farms. Environmental Science and Policy 13:217-228.

Supplementation of phosphorus for developing replacement heifers. When phosphorus is fed to cattle in amounts greater than what they can utilize, the excess is excreted in the manure, which if spread on farm fields may cause an excess of phosphorus in runoff that can promote the undesirable growth of algae in lakes. While phosphorus is essential for dairy heifer bone growth and development, dietary phosphorus requirements are very similar to that found naturally in many forages. ARS scientists in Marshfield, Wisconsin, in collaboration with researchers at the University of Wisconsin, evaluated the phosphorus intake of dairy heifers ranging in age from 4 to 22 months. The scientists determined that phosphorus supplementation had minimal effect on the extent of frame development, bone density, or bone metabolism. This provides dairy producers and nutritionists with the information they need to formulate heifer rations so that they contain adequate, but not excessive, amounts of phosphorus to meet heifer growth needs without releasing excess phosphorus into the environment.

Esser, N.M., Hoffman, P.C., Coblentz, W.K., Orth, M.W., and Weigel, K.A. 2009. The effect of dietary phosphorus on bone development in dairy heifers. Journal of Dairy Science 92:1741-1749.

Hedtcke, J.L., Posner, J.L., Coblentz, W.K., Hall, J., Walgenbach, R.P., and Davidson, J. 2011. Orchardgrass ley for improved manure management in Wisconsin: II. Nutritive value and voluntary intake by dairy heifers. Agronomy Journal 103:1106-1114.

Managing dairy diet and manure to reduce runoff phosphorus losses. Manure application to cropland can contribute to runoff losses of phosphorus, which can lead to excessive algae growth in lakes and streams. ARS researchers in Marshfield, Wisconsin, conducted a series of rainfall simulation experiments to assess how the amount of dissolved phosphorus in runoff would be affected by: 1) phosphorus supplementation of dairy heifer diets; 2) manure application method and rate; and 3) the amount of available phosphorus already in the soil. The researchers determined that phosphorus supplementation in the diet resulted in more phosphorus in manure, which led to 2 to 3 times more dissolved phosphorus in runoff. By incorporating manure into the soil, the researchers determined that phosphorus runoff concentrations were reduced 85 to 90 percent compared with surface application. These results show that large reductions in manure phosphorus runoff losses can be achieved by avoiding unnecessary dietary phosphorus supplementation, incorporation of manure into the soil, limiting application rate when applying to cropland, and avoiding soils with excessive phosphorus. By adopting these practices, farmers can greatly reduce the amount of phosphorus leaving their farms.

Hanrahan, L.P., Jokela, W.E., and Knapp, J.R. 2009. Dairy diet phosphorus and rainfall timing effects on runoff P from land-applied manure and eutrophication in surface waters. Journal of Environmental Quality 38:212-217.

Nitrogen losses from beef cattle feedyards. Nitrogen losses as ammonia gas from beef cattle feedyards is a loss of valuable fertilizer nitrogen and can negatively impact the environment. But the quantity of nitrogen lost from feedyards, and the factors controlling those losses, is not clear. ARS researchers in Bushland, Texas, in collaboration with researchers at West Texas A&M University and Texas AgriLife Research, assessed this nitrogen loss by continuously measuring ammonia emissions from two feedyards over a 2-year period. They discovered that the major factors affecting ammonia losses were ambient temperature and dietary crude protein concentration. The researchers determined that averaged over the 2 years of the study, 52 to 59 percent of the nitrogen in the cattle feed was lost as ammonia at the two feedyards. These results are the most extensive data available of ammonia losses from feedlots. This study provides scientists with a database to validate and verify process models of emissions and both the cattle industry and regulatory agencies with accurate science-based ammonia emissions data to meet regulatory requirements.

Rhoades, M.B., Parker, D.B., Cole, N.A., Todd, R.W., Caraway, E.A., Auvermann, B.W., Topliff, D.R., and Schuster, G.L. 2010. Continuous ammonia emission measurements from a commercial beef feedyard in Texas. Transactions of the ASABE 53(6):1823-1831.

Todd, R.W., Cole, N.A., Rhoades, M.B., Parker, D.B., and Casey, K. 2011. Daily, monthly, seasonal, and annual ammonia emissions from Southern High Plains cattle feedyards. Journal of Environmental Quality 40:1-6.

Utilization of crude glycerin from the biodiesel industry in swine and poultry diets. Livestock and poultry producers are looking for new sources of feed supplements. ARS researchers in Ames, Iowa, investigated the use of crude glycerin as a source of calories in diets for nonruminants. Experiments conducted by the scientists and their university collaborators demonstrated that crude glycerin, a byproduct of biodiesel production, contains an energy concentration similar to corn and can be utilized as an ingredient in swine and poultry rations. In general, feeding levels of up to 10 percent crude glycerin do not have harming effects on growth performance, carcass composition, lactation performance, or egg and meat quality. This research provides information on the energy value of crude glycerin and recommendations for its use in non-ruminant diets to nutritionists and the swine and poultry industry. In addition, this research has provided the biodiesel industry another marketing outlet for a byproduct of their production.

Dozier III, W.A., Kerr, B.J., and Branton, S.L. 2011. Apparent metabolizable energy of crude glycerin originating from different sources in broiler chickens. Poultry Science 90:2528-2534.

Kerr, B.J. 2011. Utilization of crude glycerin in nonruminants. Brazilian Animal Science Society 40:344-351.

Kerr, B.J., Shurson, G.C., Johnston, L.J., and Dozier III, W.A. 2011. Utilization of crude glycerin in nonruminants. In: Montero, G., Stoytcheva, M., editors. Biodiesel-Quality, Emissions and By-Products. Rijeka, Croatia: Intech Publishers pp. 365-380. Available: www.intechopen.com/articles/show/title/utilization-of-crude-glycerin-in-nonruminants

Kerr, B.J., Weber, T.E., Dozier III, W.A., and Kidd, M.T. 2009. Digestible and metabolizable energy content of crude glycerin originating from different sources in growing pigs. Journal of Animal Science 87:4042-4049.

Lammers, P.J., Kerr, B.J., Weber, T.E., Bregendahl, K., Lonergan, S.M., Prusa, K.J., Ahn, D.U., Stoffregen, W.C., Dozier III, W.A., and Honeyman, M. 2008. Growth performance, carcass characteristics, meat quality, and tissue histology of growing pigs fed crude glycerin-supplemented diets. Journal of Animal Science 86:2962-2970.

Schieck, S.J., Johnston, L.J., Kerr, B.J., Baidoo, S.K., and Shurson, G.C. 2010. Use of crude glycerol, a biodiesel co-product, in diets for lactating sows. Journal of Animal Science 88:2648-2656.

Reducing phosphorus excretion from monogastric animals. Livestock producers are looking for ways to reduce phosphorus excretion from production animals to decrease potential phosphorus loss after land application of manures. The use of low phytate grains and phytase additions to grain-based diets has the potential to reduce phosphorus excretion from monogastric animals (i.e. swine and poultry). However, these diet modifications can lead to enhanced solubility of phosphorus in manures, which are then a threat to water quality when applied to land. ARS researchers in Kimberly, Idaho, and Ames, Iowa, demonstrated that utilization of low-phytate grains or cereal-based diets with phytase supplementation in monogastric animals can reduce phosphorus excretion by 33 to 46 percent. Additionally, the soluble phosphorus fraction of manures generated from these diets are not greater than that from traditional diets, and therefore do not pose a greater environmental risk when land applied. In poultry, the researchers demonstrated that changes in manure soluble phosphorus in phytase-amended diets was due to the effect of dietary calcium levels, and that manure soluble phosphorus could be reduced by as much as 73 percent irrespective of phytase amendment by increasing dietary calcium levels. The use of low phytate feeds and phytase in the swine and poultry industry could reduce phosphorus excretion by over 31,000 metric tons per year and reduce the numbers of hectares needed for sustainable manure application by over 400,000, thereby reducing producers' costs and the risk of phosphorus transfer to water bodies.

Kerr, B.J., Weber, T.E., Miller, P.S., and Southern, L.L. 2009. Effect of phytase on apparent total tract digestibility of phosphorus in corn-soybean meal diets fed to 100 kg pigs. Journal of Animal Science 88:238-247.

Leytem, A.B., Plumstead, P.W., Maguire, R.O., Kwanyuen, P., and Brake, J. 2008. Interaction of calcium and phytate in broiler diets: 2. Effects on total and soluble phosphorus excretion. Poultry Science 87:459-467.

Leytem, A.B. and Thacker, P.A. 2010. Phosphorus utilization and characterization of excreta from swine fed diets containing a variety of cereal grains balanced for total phosphorus. Journal of Animal Science 88:1860-1867.

Leytem, A.B., Widyaratne, G.P., and Thacker, P.A. 2008. Phosphorus utilization and characterization of ileal digesta and excreta from broiler chickens fed diets varying in cereal grain, phosphorus level, and phytase addition. Poultry Science 87(12):2466-2476.

Leytem, A.B., Willing, B.P., and Thacker, P.A. 2008. Phytate utilization and phosphorus excretion by broiler chickens fed diets containing cereal grains varying in phytate and phytase content. Animal Feed Science and Technology 146:160-168.

Plumstead, P.W., Leytem, A.B., Spears, J.W., Maguire, R.O., Kwanyuen, P., and Brake, J. 2008. Interaction of calcium and phytate in broiler diets: 1. Effects on apparent prececal digestibility and retention of phosphorus. Poultry Science 87:449-458.

Protecting the environment through more efficient use of nutrients in poultry and livestock feeds including distillers grains. The rapid growth of the biofuel industry has led to an abundance of ethanol co-products, such as distillers grains, which can be used as substitute cereal grains in poultry and livestock diets. Although feeding distillers grains to poultry, swine, and cattle may lower feed costs, the quantity of nutrients excreted in manure and the subsequent loss of these nutrients into the environment may increase. ARS scientists in Kimberly, Idaho; Ames, Iowa; Lincoln and Clay Center, Nebraska; and Bushland, Texas, have conducted extensive research on animal diets, including that on distillers grains, subsequent nutrient retention and excretion, and reducing effects of animal production on the environment. The researchers determined that inclusion of distillers grains in livestock and poultry diets can affect both nitrogen and phosphorus excretion and the solubility of excreted phosphorus, resulting in increased odors and excess nutrient losses to the environment. This research provides industry with recommendations for diet formulation and feed processing, and dietary management strategies that improve nutrient capture by cattle, swine, and poultry and can decrease manure nutrient loads that reduces the effects of animal production on the environment.

Cole, N.A., McCuistion, K.C., Greene, L., and McCollum, F. 2011. Effects of concentration and source of wet distiller's grains on digestibility of steam-flaked corn-based diet fed to finishing steers. Professional Animal Scientist 27:302-311.

Gilley, J.E., Berry, E.D., Eigenberg, R.A., Marx, D.B., and Woodbury, B.L. 2010. Nutrient transport in runoff from feedlots as affected by wet distiller's grain diet. Transactions of the ASABE 53(2):545-552.

Hales, K.E., Parker, D.B., and Cole, N.A. 2012. Potential odorous volatile organic compound emissions from feces and urine from cattle fed corn-based diets with wet distillers grains with solubles. Atmospheric Environment 60:292-297.

Lubbe, M.K., Patterson, J.M., Jenkins, K.H., Buttrey, E.K., Davis, T.C., McCollum, F., Cole, N.A., and MacDonald, J.C. 2011. Wet distillers grains plus solubles concentration in steam-flaked corn-based diets: Effects on feedlot cattle performance, carcass characteristics, nutrient digestibility, and ruminal fermentation characteristics. Journal of Animal Science 90:1589-1602.

Rice, W.C, Galyean, M., Cox, S., Dowd, S.E., and Cole, N.A. 2012. Influence of wet distillers grains diets on beef cattle fecal bacterial community structure. BMC Microbiology 12:25.

May, M.L., Quinn, M.J., Depenbusch, B.E., Reinhardt, C.D., Gibson, M.L., Karges, K.K., Cole, N.A., and Drouillard, J.S. 2010. Dried distiller’s grains with solubles with reduced corn silage levels in beef finishing diets. Journal of Animal Science 88:2456-2463.

Spiehs, M.J., Miller, D.N., Woodbury, B.L., Eigenberg, R.A., Varel, V.H., and Parker, D.B. 2012. Effect of feeding wet distillers grains with solubles to beef cattle on air and manure quality. Applied Engineering in Agriculture 28(3):423-430.

Spiehs, M.J. and Varel, V.H. 2009. Nutrient excretion and odorant production in manure from cattle fed corn wet distillers grains with solubles. Journal of Animal Science 87:2977-2984. DOI:10.2527/jas.2008-1584.

Spiehs, M.J., Whitney, M.H., Shurson, G.C., Nicolai, R.E., Renteria-Flores, J., and Parker, D.B. 2012. Odor and gas emissions and nutrient excretion from pigs fed diets containing dried distillers grains with solubles. Applied Engineering in Agriculture 28(3):431-437.

Weber, T.E. and Kerr, B.J. 2011. Effect of dietary distillers dried grains with solubles on indicators of oxidative stress and immune function in growing pigs. Livestock Science 142:85-91.

Woodbury, B.L., Eigenberg, R.A., Varel, V., Lesch, S., and Spiehs, M.J. 2011. Using electromagnetic induction technology to predict volatile fatty acid, source area differences. Journal of Environmental Quality 40:1416-1422.

Leytem, A.B., Kwanyuen, P., and Thacker, P. 2008. Nutrient excretion, phosphorus characterization, and phosphorus solubility in excreta from broiler chicks fed diets containing graded levels of wheat distillers grains with solubles. Poultry Science 87(12):2505-2511.

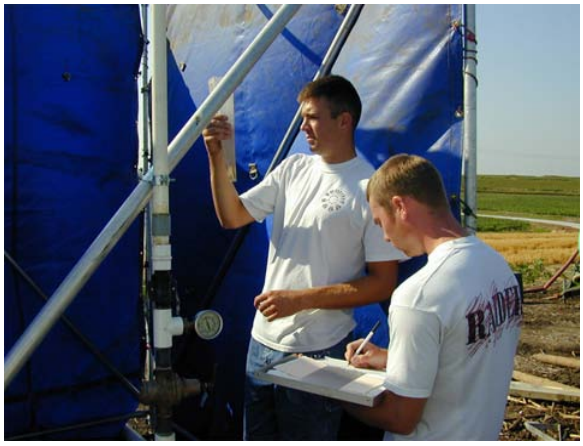
Varel, V.H., Wells, J.E. Berry, E.D., Spiehs, M.J., Miller, D.N., Ferrell, C.L., Shackelford, S.D., and Koohmaraie, M. 2008. Odorant production and persistence of *Escherichia coli* in manure slurries from cattle fed zero, twenty, forty, or sixty percent wet distillers grains with solubles. Journal of Animal Science. 86:3617-3627.

Problem Statement 1B: *Maximizing the Value of Manure through Improved Collection, Storage, and Treatment Options.*

Significant losses of nutrients can occur from manure in animal facilities or on pastures, during collection or storage, or soon after land application. For example, nitrogen in manure is especially susceptible to loss through ammonia volatilization, denitrification, leaching, and runoff. The ratio of nitrogen to phosphorus in manure often differs from that required by many crops. Thus, applying manure based on meeting crop nitrogen needs generally results in over-application of phosphorus; whereas, applying manure to meet crop phosphorus needs significantly decreases manure application rate, increases land requirements and manure transportation costs, and may require application of supplemental commercial nitrogen fertilizer to meet plant needs. Ratios of other nutrients in manure also frequently do not match the needs of plants. In addition, many nutrients such as carbon, nitrogen, and phosphorus are subject to chemical and biological transformations that alter their chemistry, plant availability, and environmental behavior following land application.

Most livestock and poultry feeding operations are required to control and capture animal manure and runoff to prevent manure from entering surface waters, such as lakes and streams. The design and form of runoff containment facilities and methods of manure treatment and handling vary with location, climate, animal species, and other factors.

Manure nutrient losses are reduced by stiff-stemmed grass hedges. Most livestock feeding operations are required to control and capture manure and runoff to prevent manure nutrients from entering surface waters such as lakes and streams. Narrow stiff-grass hedges planted on the contour across areas of concentrated flow are an alternative method for using vegetated barriers



to slow runoff and to reduce soil loss and nutrients. ARS scientists in Lincoln, Nebraska, measured the effectiveness of narrow grass hedges for reducing runoff nutrient transport from sites on which beef cattle manure was applied to meet 0-, 1-, 2- or 4-year corn phosphorus requirements. Manure application rate significantly increased the transport of phosphorus in runoff on treatment plots without a grass hedge. However, phosphorus transport on the treatments where manure was applied to plots containing a grass hedge was similar to the treatments that did not receive manure. This research indicates that stiff-stemmed grass hedges reduce the transport of nutrients in runoff occurring soon after manure application. Adoption of stiff-stem grass hedges for crop production helps to decrease manure phosphorous runoff into streams and enhance water quality.

Gilley, J.E., Durso, L.M., Eigenberg, R.A., Marx, D.B., and Woodbury, B.L. 2011. Narrow grass hedge control of nutrient loads following variable manure application. Transactions of the American Society of Agricultural and Biological Engineering 54(3):847-855.

Precision harvesting of feedlot manure for nutrients or energy. Manure accumulation on pen surfaces is not uniform in nutrient or energy content. ARS scientists in Clay Center, Nebraska, adapted an electronic system for determining the accumulated manure depth on feedlot surfaces. This system, combined with other spatial technologies makes possible precision harvesting of manure. Use of this technology by beef producers allows direct harvesting of manure that is best suited for land application or as a fuel for energy recovery.

Eigenberg, R.A., Woodbury, B.L., Auvermann, B., Parker, D.B., and Spiehs, M.J. 2012. Energy and nutrient recovery from cattle feedlots. Scholarly Research Exchange 2012:1-5.

Eigenberg, R.A., Woodbury, B.L., Nienaber, J.A., Spiehs, M.J., Parker, D., and Varel, V.H. 2010. Soil conductivity and multiple linear regression for precision monitoring of beef feedlot manure and runoff. Journal of Environmental and Engineering Geophysics 15:175-183.

Woodbury, B.L., Lesch, S.M., Eigenberg, R.A., Miller, D.N., and Spiehs, M.J. 2009. Electromagnetic induction sensor data to identify areas of manure accumulation on a feedlot surface. Soil Science Society of America Journal 73(6):2068-2077.

Riparian buffers to minimize off-site impacts of manure application to crops and pastures. Riparian buffers within the South Atlantic Coastal Plain perform the important ecosystem function of filtering nutrient runoff. Relative to nitrogen, the removal of nitrate via denitrification improves surface and groundwater quality. Yet, when denitrification is incomplete, there is the potential for emission of the greenhouse gas nitrous oxide. ARS researchers in Florence, South Carolina, are sampling nitrous oxide emissions along manure impacted riparian buffers of the South Atlantic Coastal Plain that includes crop production and pasture fields receiving poultry, swine, or beef manure. Five points are sampled along a topographic gradient (riparian wetland to field) on each buffer. Nitrous oxide emissions are sampled using static gas chambers with subsequent gas chromatographic analyses. Soil samples from the surface (upper 10 cm) were also being analyzed for denitrification enzyme activity. Analyses of the first year results show

that riparian buffers release some nitrous oxide into the atmosphere. Nitrous oxide emission values are consistent with denitrification without extraordinarily high nitrous oxide emission. These findings are providing important data to producers and their consultants (university extension and the USDA Natural Resources Conservation Service [NRCS]) on recommendations for the use of riparian buffers to protect water quality from nutrients in poultry and livestock manure without significant releases of greenhouse gases. A reference publication is being reported in 2013.

Development of a green and profitable manure treatment technology. New and expanding swine production facilities in North Carolina are required to use manure management systems that meet the strictest environmental performance standards in the nation. ARS scientists in Florence, South Carolina, and their cooperators developed a second-generation manure management system that is an alternative to open lagoons and that meets State environmental standards. The design innovations of this system significantly reduced costs by two-thirds to build and operate than the first-generation system, which was tested in 2003. The new on-farm treatment system uses solid-liquid separation and nitrogen and phosphorus removal processes. It removed high levels of several pollutants from manure wastewater, including almost all of the pathogens, odor-causing constituents, and ammonia. Replacing anaerobic lagoon-based systems with the new technology also reduced greenhouse gas emissions by 97 percent. Animal health and production also benefited. Swine daily weight gain increased, feed conversion improved, animal mortality decreased, and 5.6 percent more hogs were sold per growing cycle. Separated manure solids were converted in a centralized facility into composted materials and used for organic plant fertilizer, soil amendments, and plant growth media. The new system allows producers to profit by selling greenhouse gas emission reduction credits and water quality credits. A U.S. Patent was issued for the system and international patent rights have been filed. This new manure treatment technology was recognized with an ARS Technology Transfer Award and an Excellence in Technology Transfer Award from the National Federal Laboratory Consortium.

Garcia, M.C., Vanotti, M.B., and Szogi, A.A. 2008. Simultaneous separation of phosphorus sludge and manure solids with polymers. Transactions of the ASABE 50(6):2205-2215.

Loughrin, J.H., Vanotti, M.B., Szogi, A.A., and Lovanh, N. 2009. Evaluation of second-generation multistage wastewater treatment system for the removal of malodorous compounds from liquid swine waste. Journal of Environmental Quality 38:1739-1748.

Vanotti, M.B., Szogi, A.A., and Fetterman, L. 2010. Wastewater treatment system with simultaneous separation of phosphorus sludge and manure solids. U.S. Patent and Trademark Office, Patent No. 7,674,379 B2.

Vanotti, M.B., Szogi, A.A., Millner, P.D., and Loughrin, J.H. 2009. Development of second-generation environmentally superior technology for treatment of swine manure in the USA. Bioresource Technology 100:5406-5416.

Novel bacteria for wastewater treatment. The use of the anaerobic ammonium oxidation (anammox) as a new pathway to biologically remove ammonia has created great expectations in the field of wastewater treatment because it can significantly reduce aeration needs and cost of treatment. ARS scientists in Florence, South Carolina, have discovered a novel anammox bacterium strain *Candidatus* Brocadia caroliniensis that oxidizes ammonia and releases di-

nitrogen gas under anaerobic conditions. The novel anammox bacterium was isolated from livestock manure sludge. The bacterium isolate can be used for the treatment of wastewater contaminated with animal waste and/or having undesirable levels of ammonia, including agricultural, industrial, or municipal wastewaters. Compared to conventional biological nitrogen removal methods, the anammox process can save more than 50 percent of the oxygen supply and 100 percent of the external carbon source for denitrification. This could lead to the development of new-generation, anammox-based treatment for livestock wastewater with a significant decrease in operational costs. A patent application has been filed with the U.S. Patent and Trademark Office for a novel anammox bacterium isolate *Candidatus* Brocadia caroliniensis, having Accession Deposit Number NRRL B-50286 and the characteristics of oxidizing ammonia and releasing di-nitrogen.

Magri, A., Vanotti, M.B., and Szogi, A.A. 2012. Anammox sludge immobilized in polyvinyl alcohol (PVA) cryogel carriers. Bioresource Technology 114:231-240.

Rothrock Jr, M.J., Vanotti, M.B., Szogi, A.A., Gonzalez, M.G., and Fujii, T. 2011. Long-term preservation of Anammox bacteria. Applied Microbiology and Biotechnology 92:147-157.

Vanotti, M.B., Szogi, A.A., and Rothrock, M.J. 2011. Novel anammox bacterium isolate. U.S. Patent and Trademark Office, Patent Application no. US2001/0180476 A1.

Recovering phosphorus from solid manure. Although animal manure is typically used by farmers to fertilize their field crops, it usually contains more phosphorus than the crops need. The excess phosphorus has the potential to wash away and pollute nearby rivers and lakes. ARS scientists in Florence, South Carolina, developed a process called ‘quick wash’ to recover phosphorus and reduce the environmental impact of phosphorus in poultry litter and solid manure. This technology provides alternative poultry litter management when application onto land is not an option in Georgia, North Carolina, and land near the Chesapeake Bay. The quick wash technology is a process for selectively removing phosphorus from solid poultry or animal manure. The technology forms a concentrated phosphorus solid material and leaves a washed poultry litter or manure solids residue containing low phosphorus and most of the original organic carbon and nitrogen. This innovation provides an environmentally sound phosphorus recovery system that livestock producers can use to manage the excess phosphorus in manure. It can facilitate economic phosphorus transport in concentrated form from areas where it is in excess to areas where it is needed for its effective utilization as plant fertilizer. A patent application for this invention is currently pending with the U.S. Patent and Trademark Office. The USDA has granted an exclusive license for commercialization of this invention in the United States.

Szogi, A.A., Bauer, P.J., and Vanotti, M.B. 2010. Fertilizer effectiveness of phosphorus recovered from broiler litter. Agronomy Journal 102:723-727.

Szogi, A.A. and Vanotti, M.B. 2009. Prospects for phosphorus recovery from poultry litter. Bioresource Technology 100:5461-5465.

Szogi, A.A., Vanotti, M.B., and Hunt, P.G. 2008. Phosphorus recovery from poultry litter. Transactions of the American Society of Agricultural and Biological Engineers 51:1727-1734.

New microbial composition for effective low-temperature nitrification. Low nitrification rates during cold weather are often a problem for adoption of biological treatment ammonia in livestock effluents. ARS scientists in Florence, South Carolina, discovered and patented a high performance nitrifying sludge (HPNS) with excellent ammonia removal performance during cold weather conditions. The unique microbial community composition that contained ammonia oxidizers and cold tolerant and floc-forming microorganisms provided a nitrifying sludge capable of very high rates of nitrification at cold temperatures as low as 5°C. These nitrification rates are the highest reported for nitrification treatment of high-ammonia wastewater at low temperatures. The HPNS is used for rapid start-up of full-scale plants for swine wastewater treatment. The biological process removes more than 95 percent of the ammonia from wastewater containing 1,000-2,000 parts-per-million ammonia. This technology is well suited for economical nitrification of high-ammonia livestock wastewater under cold weather conditions. A U.S. patent has been issued on this technology.

Ducey, T.F., Vanotti, M.B., Shriner, A.D., Szogi, A.A., and Ellison, A.Q. 2010. Characterization of a microbial community capable of nitrification at cold temperature. Bioresource Technology 101:491-500.

Vanotti, M.B., Szogi, A.A., and Ducey, T.F. 2013. High performance nitrifying sludge for high ammonium concentration and low temperature wastewater treatment. U.S. Patent 8,445,253 B2. U.S. Patent and Trademark Office.

Systems and methods for reducing ammonia emissions from liquid effluents and recovery of ammonia using gas-permeable membranes. There is a major interest from producers, industry, and the general public in implementing best control technologies that will abate ammonia emissions from confined livestock operations by capturing and recovering nitrogen. In addition, recovery of nitrogen is important in agriculture because of the high cost of commercial nitrogen fertilizers. ARS researchers in Florence, South Carolina, invented a new system and methods that use gas-permeable membranes to capture and recover ammonia from liquid manure, reducing ammonia emissions from livestock operations and recovering concentrated liquid nitrogen that could be sold as fertilizer. The new process includes the passage of gaseous ammonia contained in the liquid manure through a microporous hydrophobic membrane and the capture and concentration with circulating diluted acid on the other side of the membrane. The membranes can be assembled in modules or manifolds. For liquid manure applications, the membrane manifolds are submerged in the liquid and the ammonia is removed from the liquid in barn pits or storage tanks and lagoons before it goes into the air. A patent application for this invention is currently pending with the U.S. Patent and Trademark Office. On-farm demonstration studies are being pursued in cooperation with university researchers and swine industry funded by a NRCS Conservation Innovation Grant.

Vanotti, M.B. and Szogi, A.A. 2011. Systems and Methods for Reducing Ammonia Emissions form Liquid Effluents and for Recovering Ammonia. U.S. Patent and Trademark Office, Patent Application no. 13/164,363.

Removal and recovery of ammonia gas from animal production systems. Volatilization of ammonia inside poultry housing often results in an excessive accumulation of ammonia in the air, which can negatively affect the health of both workers and birds. A new technology was developed by ARS scientists in Florence, South Carolina, that has the potential to reduce

ventilation and energy needs to lower ammonia in the air in poultry barns and composting systems. The scientists investigated the potential use of gas-permeable membranes as components of a new process to capture and recover ammonia in poultry houses. This new process includes the passage of gaseous ammonia through a micro-porous hydrophobic membrane, the capture with a circulating dilute acid on the other side of the membrane, and the production of a concentrated ammonium salt. Results are cleaner air inside the barns with benefits to animal health and reduced environmental emissions and re-use of the recovered ammonia as concentrated plant fertilizer. A patent application for this invention is currently pending with the U.S. Patent and Trademark Office.

Rothrock Jr, M.J., Szogi, A.A., and Vanotti, M.B. 2010. Recovery of ammonia from poultry litter using gas-permeable membranes. Transactions of the American Society of Agricultural and Biological Engineers 53:1267-1275.

Szögi, A.A., Vanotti, M.B., and Rothrock Jr., M.J. 2011. Gaseous ammonia removal system. U.S. Patent and Trademark Office, Patent Application no. 61/314,683.

Problem Statement 1C: *Utilizing Manure in Integrated Farming Systems to Improve Profitability and Protect Soil, Water, and Air Quality.*
Sustainable agricultural production systems will likely require some degree of reintegration of crop and animal production systems. In most cases, this integration will occur via beneficial utilization of the carbon and nutrients contained in the collected manures. Increased complexity in agricultural production systems requires development of integrated farming systems to efficiently utilize manure resources and protect soil, water, and air quality. Manure and other byproducts must be carefully managed if they are to be used beneficially in production agriculture. These materials are frequently bulky and their nutrients are usually less concentrated and released more slowly and less predictably than those in commercial fertilizers so a greater quantity must be applied to meet plant nutrient requirements. Over-application or mismanagement of manure can potentially result in excess leaching or runoff of nitrogen and/or phosphorus, which can lead to degradation of ground or surface water quality. The risk of over-application of manures can be especially great in areas with high concentrations of animal production or when high phosphorus byproducts constitute a significant portion of the diet. Trace elements (e.g., copper, selenium, etc.) and salts are also potential environmental contaminants in many manures and byproducts.

Process-based numerical models are efficient tools for integrating site-specific data with current knowledge of the physical, chemical, and biological processes governing nutrient dynamics. Model results can expand assessment of the environmental impacts of wastewater pollutants and improve understanding of watershed-scale nutrient and manure-borne contaminant transport.

Liquid manure injection improves ammonia retention, but increases other nitrogen losses.
Incorporation of liquid manure into the soil is often recommended to reduce ammonia losses, odor, and nutrient runoff in surface water. However, incorporation with tillage is not compatible with high-residue conservation practices, such as no-till, and is not possible with pasture or perennial forages. Manure injection technologies allow incorporation with limited disruption of the soil surface or plant residue cover. ARS scientists in Beltsville, Maryland, and University Park, Pennsylvania, conducted a critical review and analysis of the literature and found

publications that show injection of liquid manures can reduce ammonia nitrogen emissions by 40-90 percent, compared to surface application. However, the studies surveyed indicated that injection can create anaerobic soil conditions leading to losses of other gaseous forms of nitrogen. Up to half of the nitrogen conserved by reducing ammonia emissions can later be lost as nitrogen gas (a chemically inert gas that makes up 78 percent of earth's atmosphere) or as nitrous oxide (a potent greenhouse gas). The survey indicated that improved crop utilization of the nitrogen conserved by reducing ammonia emissions is the most common observation following injection, but this benefit can be minimal. The result of this literature survey provides scientists, nutrient managers, and policy makers with improved estimates of the effects of manure injection on the fate and transport of nitrogen that can be used to improve economic return and minimize adverse effects of manure nitrogen.

Dell, C.J., Meisinger, J.J., and Beegle, D.B. 2011. Subsurface application of manure slurries for conservation tillage and pasture soils and their impact on the nitrogen balance. Journal of Environmental Quality 40:352-361.

Management recommendations for temporary storage of poultry litter. Temporary in-field storage piles of poultry litter are commonly used in the mid-Atlantic region because of a shortage of on-farm litter storage and the desire to transport and disperse the litter to more distant areas. A 10-member technical expert panel of ARS, NRCS, and university scientists (Poultry Litter Science Forum) reviewed the literature on temporary storage piles of litter and developed a set of recommendations for using this in-field storage technique. The findings and recommendations include: 1.) Minimizing the need for using in-field storage by increasing on-farm storage; 2.) Using an "A" shaped pile to minimize the pile footprint and runoff; 3.) Locating piles on well-drained level land distant from surface waters with site location changed each year; 4.) Allowing piles to remain intact until just before spreading because the greatest nutrient losses occur after land application; 5.) Develop soil and agronomic practices for stockpile management; and 6.) Encourage land application that includes shallow incorporation of poultry manure. These recommended management practices to conserve nutrients for the producer and minimize nutrient losses to the Chesapeake Bay were incorporated in the 2010 U.S. EPA Report Guidance for Federal Land Management in the Chesapeake Bay Watershed, Chapter Agriculture 2. Nonpoint Source Pollution Office of Wetlands, Oceans, and Watersheds (EPA841-R-10-002).

Poultry Litter Experts Science Forum. 2008. Can we reach consensus on storage times for chicken litter? Summary of Chesapeake Research Consortium-Maryland Environmental Finance Center Science Forum. CRC Publication 08-165. Available at: http://ag.udel.edu/plsc/faculty/documents/LitterForumFactshtFNL.pdf.

Subsurface application technology to reduce poultry litter nutrient losses in runoff. Poultry production is the primary source of income for many small family farms throughout the southeastern and Middle Atlantic states. While poultry litter is an excellent source of crop nutrients, the common practice of spreading it on the soil surface promotes odor emissions,

exacerbates nutrient runoff to nearby waterways (most notably the Chesapeake Bay), and allows ammonia nitrogen releases into the atmosphere. Surface broadcasting has remained the only option available for producers applying poultry litter in perennial pastures and other no-till systems because existing farm implements cannot apply bulky, low moisture, solid materials such as poultry litter subsurface without seriously damaging the crop.

A collaborative team of ARS scientists at multiple locations in Alabama, Arkansas, Kentucky, and Mississippi, and an ARS-university coalition across five Chesapeake Bay states, developed and evaluated subsurface application options that allow no-till farmers and grassland operations to place poultry litter in the crop root zone with only minimal disturbance of the soil structure and plant cover. This research was initiated at the request of poultry producers, crop growers, and the NRCS.

ARS scientists in Auburn, Alabama, developed equipment that places poultry litter in subsurface soil bands. The tool digs shallow trenches about two to three inches deep in the soil. Then the machine places the poultry litter in the trenches and covers it with soil. Designed to attach to a tractor, the litter applicator can dig four trenches as it is pulled through the field. When the poultry litter was applied in subsurface bands with this tool, phosphorus and nitrogen concentrations in water running off field plots were not significantly different from control plots that received no litter. However, this method reduced nutrient losses by 80 to 95 percent compared to traditional broadcast surface litter application.

Another recent advance for subsurface application of poultry litter is the development of the "poultry litter subsurfer" by ARS researchers in Boonville, Arkansas. This machine consists of a patented internal auger system to distribute a steady controlled flow of litter to eight trench openers simultaneously that then cover the shallow parallel trenches with soil. It allows the subsurface application of poultry litter to pasture, hay fields, and pre-plant applications of litter to row crops. Subsurface application of litter with the subsurfer was effective in lowering nutrient runoff and ammonia emissions at least 90 percent in Arkansas pastures, while increasing forage yields.

Adeli, A., Tewolde, H., and Jenkins, J.N. 2012. Broiler litter type and placement effects on corn growth, nitrogen utilization and residual soil nitrate-nitrogen in a no-till field. Agronomy Journal 104:43-48.

Kibet, L.C., Allen, A.L., Kleinman, P.J.A., Feyereisen, G.W., Church, C., Saporito, L.S., and Way, T.R. 2011. Phosphorus runoff losses from a no-till coastal plain soil with surface and subsurface-applied poultry litter. Journal of Environmental Quality 40:412-420.

Pote, D.H, Way, T.R., Kleinman, P.J.A., Moore Jr., P.A., Meisinger, J.J., Sistani, K.R., Saporito, L.S., Allen, A.L., and Feyereisen, G.W. 2011. Subsurface application of poultry litter in pasture and no-till soils. Journal of Environmental Quality 40:402-411.

Pote, D.H., Way, T.R., Sistani, K.R., and Moore Jr., P.A. 2009. Water-quality effects of a mechanized subsurface-banding technique for applying poultry litter to perennial grassland. Journal of Environmental Management 90:3534-3539.

Sistani, K.R., Bolster, C.H., Way, T.R., Torbert III, H.A., Pote, D.H., and Watts, D.B. 2010. Influence of poultry litter application methods on the longevity of nutrient and E. coli in runoff from tall fescue pasture. Water, Air, and Soil Pollution 206:3-12.

Sistani, K.R., Torbert III, H.A., Way, T.R., Bolster, C.H., Pote, D.H., and Warren, J.G. 2009. Broiler litter application method and runoff timing effects on nutrient and Escherichia coli losses from tall fescue pasture. Journal of Environmental Quality 38:1-8.

Tewolde, H., Armstrong, S., Way, T.R., Sistani, K.R., and Rowe, D. 2009. Cotton response to poultry litter applied by subsurface banding relative to surface broadcasting. Soil Science Society of America Journal vol.73:384-389.

Watts, D.B., Way, T.R., and Torbert III, H.A. 2011. Subsurface application of poultry litter and its influence on nutrient losses in runoff water from permanent pastures. Journal of Environmental Quality 40:421-430.

Poultry litter is better cotton fertilizer than commercial fertilizers. The local availability of poultry litter in abundance in the southern and southeastern U.S. presents cotton farmers with an opportunity to reduce cost of production by substituting expensive conventional fertilizer with poultry litter. ARS scientists in Mississippi State, Mississippi, found poultry litter to be superior to conventional inorganic fertilizers for cotton production in certain marginally productive upland soils. On soils that historically have low productivity, cotton fertilized with raw litter produced up to 26 percent more lint than cotton fertilized with conventional inorganic fertilizers. In soils that are considered more productive, cotton fertilized with poultry litter had comparable lint production as cotton fertilized with conventional fertilizers. Thus poultry litter has the potential to replace many of the commonly used and more expensive cotton fertilizers in all soils and increase the profitability of cotton production in the southern and southeastern United States.

Adeli, A., Shankle, M.W., Tewolde, H., Sistani, K.R., and Rowe, D.E. 2008. Nutrient dynamics and availability from broiler litter applied to no-till cotton in an Upland soil. Agronomy Journal 100:564-570.

Tewolde, H., Adeli, A., Rowe, D.E., and Sistani, K.R. 2011. Cotton lint yield improvement attributed to residual effect of repeated poultry litter application. Agronomy Journal 103:107-112.

Tewolde, H., Adeli, A., Sistani, K.R., Rowe, D.E., and Johnson, J.R. 2010. Equivalency of broiler litter to ammonium nitrate as a cotton fertilizer in an upland soil. Agronomy Journal 102:251-257.

Tewolde, H., Armstrong, S., Way, T.R., Rowe, D.E., and Sistani, K.R. 2009. Cotton response to poultry litter applied by subsurface banding relative to surface broadcasting. Soil Science Society of America Journal 73:384-389.

Tewolde, H., Buehring, N., Adeli, A., Sistani, K.R., Rowe, D.E., and Pratt, R.G. 2009. Cotton response to chicken litter in a rotation with corn in clayey soil. Agronomy Journal 101:626-634.

Cover crop use for managing fall-applied broiler litter. Spring is the best time to apply broiler litter as row crop fertilizer in the southern and southeastern United States, but wet springs in the region often force producers to apply broiler litter in the fall, a timing that may result in substantial leaching losses of nitrogen and in the reduction of the fertilizer value of the litter. ARS scientists in Mississippi State, Mississippi, determined that fall-applied litter can be managed with a cover crop of winter rye. They found that overseeding a cover crop with fall-applied broiler litter synchronized available nitrogen with crop needs, increased nitrogen use efficiency, and minimized the risks of leaching losses. These results fill critical gaps in understanding whether detrimental effect of fall-applied broiler litter can be mitigated using cover cropping strategies. This row crop management practice is currently being implemented in some areas in the region. A module based on this work was selected and written into a Continued Education (CEU) article for *Crops & Soils* magazine and has been sent out to approximately 14,000 certified crop advisers and soil scientists.

Adeli, A., Tewolde, H., Jenkins, J.N., and Rowe, D.E. 2011. Cover crop use for managing broiler litter applied to cotton in the fall. Agronomy Journal 103:200-210.

User-friendly phosphorus loss model improves predictions of surface water contamination. In response to concerns over phosphorus loss from agricultural fields and the impact on water quality, the NRCS revised its 590 Nutrient Management Standard to restrict phosphorus application to fields based on their risk of phosphorus loss. Most states use a Phosphorus Index (estimate of potential phosphorus loss in water runoff) to assess a field's risk of phosphorus loss, so producers stay in compliance with NRCS policy. NRCS is now requiring states to demonstrate the accuracy of their Phosphorus Indexes and modify them if needed. ARS researchers in Madison, Wisconsin, developed and validated a user-friendly spreadsheet model (Annual Phosphorus Loss Estimator - APLE) to predict long-term changes in soil phosphorus and phosphorus loss in runoff for a wide variety of agricultural conditions. APLE provides an easy, straightforward way to evaluate and improve Phosphorus Indexes, which can help states comply with NRCS policies quickly and economically. APLE is available at: www.ars.usda.gov/services/software/download.htm?softwareid=304#downloadForm. Since 2011, the software has been downloaded by more than 400 farmers, consultants, extension personnel, policy makers, and researchers in 48 U.S. states and 33 countries. APLE equations have been incorporated into Phosphorus Indexes in Wisconsin and Arkansas. APLE has formed the basis for new Phosphorus Indexes in Kentucky, Oregon, and Washington, and is being used to evaluate indexes in Maryland and Delaware. APLE also is being used in three new NRCS Conservation and Innovation Grants representing 20 states to evaluate and update Phosphorus Indexes.

Bolster, C., Vadas, P.A., Sharpley, A.N., and Lory, J.L. 2012. Using a phosphorus loss model to evaluate and improve phosphorus indices. Journal of Environmental Quality 41:1758-1766.

Good, L.W., Vadas, P.A., Panuska, J.C., Bonilla, C.A., and Jokela, W.E. 2012. Testing the Wisconsin P Index with year-round, field-scale runoff monitoring. Journal of Environmental Quality 41:1730-1740.

Vadas, P.A., Good, L.W., Moore Jr., P.A., and Widman, N. 2009. Estimating phosphorus loss in runoff from manure and fertilizer for a phosphorus loss quantification tool. Journal of Environmental Quality 38:1645-1653.

Vadas, P.A., Joern, B.C., and Moore, Jr., P.A. 2012. Simulating soil phosphorus dynamics for a phosphorus loss quantification tool. Journal of Environmental Quality 41:1750-1757.

Vadas, P.A., Owens, L.B., and Sharpley, A.N. 2008. An empirical model for dissolved phosphorus in runoff from surface-applied fertilizers. Agriculture Ecosystems and the Environment 127:59-65.

Vadas, P.A. and White, M.J. 2010. Validating soil phosphorus routines in the SWAT Model. Transactions of the ASABE 53:1469-1476.

Problem Statement 1D: *Using Manure and Other Agricultural Byproducts as a Renewable Energy Resource.*

U.S. and world citizenry face a fundamental challenge in meeting future energy needs in an environmentally sustainable way, especially as world energy consumption is projected to increase by 71 percent by 2030. These issues are compounded by the increased release of carbon dioxide and other combustion byproducts that can potentially affect local air quality and global climate. In addition, energy generation must be balanced against the loss of nitrogen and organic matter, which can be used in other manure utilization systems.

Animal feeding operations generate large quantities of nutrients in manure that can potentially strain the nutrient utilization capacity of adjacent farm and pasture lands. Frequently, because of these environmental limitations associated with high livestock densities, sufficient land is not available near feeding operations to economically use animal manure as a soil amendment for on-farm nutrient recycling. Thus, alternative uses for manure and other byproducts are of interest.

Development of renewable energy from manure and other byproducts has received much attention due to diminishing availability and higher costs of conventional fossil fuels, especially transportation fuels. Because agriculture may be uniquely positioned to address some of these renewable energy issues, there has been increased interest in developing waste treatment technologies to produce energy from manure and other agricultural byproducts. Some energy recovery methods have the added environmental benefits of decreasing pathogens, controlling odor, and mitigating the introduction of pharmacologically active compounds into the environment.

Development of thermochemical technologies for manure-to-energy conversion. Livestock operations in the United States currently face issues with both manure management and energy. Both issues can be advanced by implementing innovative manure-to-energy conversion technologies that can contribute to renewable energy solutions,

improve crop yields, and sustain natural resources. Thermochemical conversion technologies such as pyrolysis (heating without oxygen) require much smaller physical footprints compared to biological processes (such as anaerobic digestion), destroy pathogens, and yield multiple byproducts. ARS scientists in Florence, South Carolina, extensively reviewed the potential use of various thermochemical conversion technologies for managing manures and other biomass residuals. They concluded that successful implementation of thermochemical conversion technologies as a manure management option would not only reduce associated disposal costs, but it could also produce both renewable energy and value-added byproducts. Conducting pyrolysis experiments with industrial cooperators, the scientists reported that high temperature pyrolysis of swine manure blended with rye grass produced energy co-products similar to natural gas and a solid char similar to low-grade coals, also known as biochar. Manure-based biochars without the nuisance manure odor are reasonably transportable and rich in nutrients such as phosphorous and potassium. Furthermore, biochar can be used as a soil amendment to build up soil quality.

Cantrell, K.B., Ducey, T.F., Ro, K.S., and Hunt, P.G. 2008. Livestock waste-to-bioenergy generation opportunities. Bioresource Technology 99:7941-7953.

Cantrell, K.B., Hunt, P.G., Ro, K.S., Stone, K.C., Vanotti, M.B., and Burns, J.C. 2010. Thermogravimetric characterization of irrigated bermudagrass as a combustion feedstock. Transactions of the American Society of Agricultural and Biological Engineers 53:413-420.

Cantrell, K.B., Ro, K.S., Szogi, A.A., Vanotti, M.B., Smith, M.C. and Hunt, P.G. 2012. Green farming systems for the Southeast USA using manure-to-energy conversion platforms. Journal of Renewable and Sustainable Energy 4(041401):1-12. http://dx.doi.org/10.1063/1.3663846

Ro, K.S., Cantrell, K.B., and Hunt, P.G. 2010. High-temperature pyrolysis of blended animal manures for producing renewable energy and value-added biochar. Industrial and Engineering Chemistry Research 49:10125-10131.

Ro, K.S., Cantrell, K.B., Hunt, P.G., Ducey, T.F., Vanotti, M.B., and Szogi, A.A. 2009. Thermochemical conversion of livestock wastes: Carbonization of swine solids. Bioresource Technology 100:5466-5471.

Biochars produced from manure feedstocks as effective bioenergy sources and other value added products. Biochar made from renewable biomass such as animal manures can provide environmental and economical benefits to livestock farmers. ARS scientists in Florence, South Carolina, with university and industrial collaborators developed innovative and efficient ways of producing biochar and improving its characteristics. Using a highly accurate temperature control furnace-retort pyrolysis system, they were able to produce both manure and plant based biochars with consistent characteristics. The manure-based biochars had moderate energy content and were alkaline and nutrient-rich, especially in phosphorus. However, they also contained substantial amounts of chlorine and sulfur that may promote equipment corrosion in downstream combustion equipment. Plant-based biochars had better energy content and lower ash concentrations implying better fuel quality compared to manure biochars. Blending these two types of materials can provide a manure-based energy product suitable for conversion processes. The scientists also evaluated the potential of wet pyrolytic technology in converting wet manures, such as swine manure, into biochar without drying prior to pyrolysis. This avoidance in

water evaporation step would substantially reduce energy requirements for pyrolyzing wet manures. They also found that the manure-based biochar from wet pyrolysis had excellent sorption capacity of environmental contaminants such as endocrine disrupting chemicals, herbicides, and polyaromatic hydrocarbons.

Cantrell, K.B., Hunt, P.G., Uchimiya, S.M., Novak, J.M., and Ro, K.S. 2012. Impact of pyrolysis temperature and manure source on physicochemical characteristics of biochar. Bioresource Technology 107:419- 428.

Cantrell, K.B., Martin, J.H., and Ro, K.S. 2010. Application of thermogravimetric analysis for the proximate analysis of livestock wastes. Journal of American Society for Testing and Materials International 7(3):Paper ID JAI102583 (available online at www.astm.org). DOI: 10.1520/JAI102583.

Cao, X., Ro, K.S., Chappell, M., Li, Y., and Mao, J. 2011. Chemical structures of swine-manure chars produced under different carbonization conditions investigated by advanced solid-state ^{13}C nuclear magnetic resonance (NMR) spectroscopy. Energy and Fuels 25:388-397.

Libra, J.A., Ro, K.S., Kammann, C., Funke, A., Berge, N.D., Neubauer, Y., Titirici, M., Fuhner, C., Bens, O., Kern, J., and Emmerich, K. 2011. Hydrothermal carbonization of biomass residual: A comparative review of the chemistry, processes and applications of wet and dry pyrolysis. Biofuels 2:89-124.

Novak, J.M., Cantrell, K.B., and Watts, D.W. 2012. Compositional and thermal evaluation of lignocellulosic and poultry litter chars via high and low temperature pyrolysis. BioEnergy Research 6:114-130.

Novak, J.M., Cantrell, K.B., Watts, D.W., Busscher, W.J., and Johnson, M. 2013. Designing relevant biochars as soil amendments using lignocellulosic and manure-based feedstocks. Journal of Soils and Sediments DOI:10.1007/S11368-013-0680-8.

Increasing biogas production by dry anaerobic digestion of manure and switchgrass mixtures. Anaerobic digestion is a biological method used to convert organic wastes into a stable product for land application without adverse environmental effects. The biogas produced can be used as an alternative renewable energy source. Dry anaerobic digestion (> 15 percent total solids) has an advantage over wet digestion (<10 percent total solids) because it allows for the use of a smaller volume of reactor and because it reduces wastewater production. In addition, it produces a fertilizer that is easier to transport. ARS scientists in Beltsville, Maryland, evaluated the performance of anaerobic digestion of animal manure-switchgrass mixture under dry (85 percent moisture content) and thermophilic conditions (55° C). Three different mixtures of animal manure (swine, poultry, and dairy) and switchgrass were digested using batch-operated 1-L reactors. Considering the overall results of anaerobic digestion of animal manure- switch grass mixtures, the swine manure test units maintained well balanced conditions, while the dairy and poultry manure test units showed poor performances. The swine manure test units proved to have the high biogas production potential (0.337 L methane/g Volatile solids). Although dairy and poultry manure performed poorly during this study, they may still have high potential as biomass for dry anaerobic digestion if appropriate designs are developed to prevent significant volatile fatty acids accumulation and pH drop. Future research is necessary into feasible operational conditions to improve biogas production of dairy and poultry manure. In addition, a suitable design needs to be developed to minimize the energy required to maintain reactor temperature.

The energy required for heating may be reduced by lowering the digestion temperature or by linking the digester to an economical complementary heat source, such as a composting system.

Ahn, H., Smith, M.C., Ingram, S.K., and White, J.W. 2010. Evaluation of biogas production by dry anaerobic digestion of switchgrass-animal manure mixtures. Applied Biochemistry and Biotechnology 160:965-975.

Component 2. Manure Pathogens and Pharmaceutically Active Compounds

Animal and zoonotic pathogens, antibiotic-resistant bacteria (ARB), and pharmaceutically active compounds (PACs) may be found in manure, waste storage systems, soils where manure slurries are applied, or contaminated waters. Pathogens, ARB, and PACs are a public health concern because they may be transmitted to animals and humans via contact with contaminated manure, soil, air, or water, or from other colonized or infected animals. Data are needed to better understand mechanisms for the shedding (deposition), survival, and transport of potentially harmful microorganisms and PACs in livestock wastes; the adequacy of manure management techniques for reducing their levels in agricultural wastes; and to determine the fate of these contaminants in the environment after land application of livestock manure and wastewater. Therefore, the focus of this component was to evaluate the occurrence, fate, and transport of manure pathogens, ARB, and PACs in agricultural systems.

Problem Statement 2A: *Identifying Factors That Control the Fate and Transport of Pathogens from Animal Agriculture.*
Research currently being conducted at ARS units has resulted in data sets that describe the inactivation and transport of pathogens and indicators under environmentally relevant conditions. These data are being used to create more accurate mathematical models and to validate the use of new and existing indicators to predict the fate and transport of pathogens. The application of modern molecular methodologies has enabled ARS researchers to evaluate the duration and level of contamination of air, plants, and soils with pathogens and indicator organisms following application and/or storage of livestock manures. Molecular analyses, including high-throughput sequence analysis, have revealed new information about how microbial communities in the livestock gastrointestinal (GI) tract respond to different diets and provided insight into methods used by pathogens (i.e. *Salmonella enterica*) to colonize the swine intestine.

Selected Accomplishments

Colonization of swine by Salmonella. The gastrointestinal microbiota influences *Salmonella* shedding in pigs. *Salmonella* causes the most bacterial foodborne disease and death in the United States. Controlling *Salmonella* in our food chain is difficult because the bacterium can live in food-producing animals without causing disease. This lack of noticeable clinical symptoms results in *Salmonella*-shedding animals contaminating other animals, meat products during processing, and crops when *Salmonella*-containing manure is used as a soil fertilizer. ARS researchers in Ames, Iowa, examined the influence of the bacteria residing in the intestinal tract of pigs (GI microbiota) on *Salmonella* shedding. Three discoveries of interest were made. First, prior to inoculating the pigs with *Salmonella enterica* serovar *Typhimurium*, the “will-be” low *Salmonella*-shedder pigs (LS pigs) and “will-be” high *Salmonella*-shedder pigs (HS pigs) had significantly different microbiotas, suggesting that the bacterial members of the swine GI tract may affect subsequent *Salmonella* shedding status. Second, following inoculation with *Salmonella*, HS pigs showed dramatic changes in their microbial communities compared with LS pigs; in fact, the microbiota of LS pigs did not appear to be different during the first week of acute infection from the control group of pigs that were not inoculated with *Salmonella* (NI

pigs). Third, after 3 weeks, the GI microbiota of HS and LS pigs were no longer significantly different from one another, but both were significantly different from that of NI pigs, suggesting that *Salmonella* caused comparable changes in the swine GI microbiota regardless of shedding status. The results of the study indicate that a reciprocal interaction exists between the swine GI microbiota and *Salmonella* for intestinal colonization. Depending on its composition, the microbial community in the swine GI tract may either reduce or enhance *Salmonella* colonization. Conversely, *Salmonella* colonization of the swine GI tract can alter the microbial composition. The interactions between *Salmonella* and the swine GI microbiota may affect swine health, growth performance, production profits, and food safety. Furthermore, *Salmonella*-shedding pigs are at risk for environmental dissemination of the pathogen following application of *Salmonella*-containing manure onto the agricultural landscape. A goal for this research is to develop prebiotic and probiotic interventions to reduce *Salmonella* carriage in swine.

Bearson, S.M.D., Allen, H.K., Bearson, B.L., Looft, T., Brunelle, B.W., Kich, J.D., Tuggle, C.K., Bayles, D.O., Alt, D., Levine, U.Y., and Stanton, T.B. 2013. Profiling the gastrointestinal microbiota in response to *Salmonella*: low versus high *Salmonella* shedding in the natural porcine host. Infection, Genetics and Evolution 16:330-340.

Bearson, B.L., and Bearson, S.M.D. 2011. Host specific differences alter the requirement for certain *Salmonella* genes during swine colonization. Veterinary Microbiology 150:215-219.

Bearson, S.M.D., Bearson, B.L., Brunelle, B.W., Sharma, V.K., and Lee, I.S. 2011. A mutation in the poxA gene of *Salmonella enterica* serovar *Typhimurium* alters protein production, elevates susceptibility to environmental challenges, and decreases swine colonization. Foodborne Pathogens and Disease 8(6):725-732.

Bearson, B.L., Bearson, S.M.D., Lee, I.S., and Brunelle, B.W. 2010. The *Salmonella enterica* serovar *Typhimurium* QseB response regulator negatively regulates bacterial motility and swine colonization in the absence of the QseC sensor kinase. Microbial Pathogenesis 48(6):214-219.

Transport of pathogens and indicators. Research has shown that retention and transport of microorganisms is a complex process that depends on forces associated with hydrological, chemical, and biological factors. Current models and watershed management plans are limited by the lack of robust, science-based data sets on microbial transport under environmentally relevant conditions. Researchers at ARS units in Riverside, California, and Bowling Green, Kentucky, are working in association with scientists at the University of California at Riverside to determine factors that affect the transport of pathogens and indicators by 1) optimizing models used to predict transport, 2) correlating adhesion and transport to microbiological cell surface properties, and 3) comparing pathogen and indicator transport. Their studies have provided data that improve the ability to predict attachment and transport on heterogeneous surfaces for a variety of soil particle sizes and for different cells types and strains grown under environmentally relevant conditions. Data comparing transport of multiple strains of the same species and those comparing the transport of pathogens to that of indicators provide data sets important for validating U.S.

Environmental Protection Agency standards. These data are useful to producers, managers of watersheds, decision makers, and developers of predictive models.

Bolster, C.H., Cook, K.L., Haznedaroglu, B.Z., and Walker, S.L. 2009. The transport of *Mycobacterium avium* subsp. *paratuberculosis* through saturated aquifer materials. Letters in Applied Microbiology 48:307-312.

Bolster, C.H., Cook, K.L., Marcus, I.M., Haznedaroglu, B.Z., and Walker, S.L. 2010. Correlating transport behavior with cell properties for eight porcine *Escherichia coli* isolates. Environmental Science and Technology 44:5008–5014.

Bolster, C.H., Haznedaroglu, B.Z., and Walker, S.L. 2009. Diversity of cell properties and transport behavior among 12 environmental *Escherichia coli* isolates. Journal of Environmental Quality 38:465-472.

Bradford, S.A., and Kim, H. 2012. Causes and implications of colloid and microorganism retention hysteresis. Journal of Contaminant Hydrology 138-139:83-92.

Bradford, S.A., Torkzaban, S., and Simunek, J. 2011. Modeling colloid transport and retention in saturated porous media under unfavorable attachment conditions. Water Resources Research 47:W10503. DOI:10.1029/2011WR010812.

Haznedaruglu, B.Z., Bolster, C.H., and Walker, S.L. 2008. The role of starvation on *Escherichia coli* adhesion and transport in saturated porous media. Water Research 42:1547-1554.

Haznedaroglu, B.Z., Kim, H.N., Bradford, S.A., and Walker, S.L. 2009. Relative transport behavior of *Escherichia coli* O157:H7 and *Salmonella enterica* serovar *Pullorum* in packed bed column systems: influence of solution chemistry and cell concentration. Environmental Science and Technology 43(6):1838-1844.

Kim, H., Walker, S., and Bradford, S.A. 2010. Macromolecule mediated transport and retention of *Escherichia coli* O157:H7 in saturated porous media. Water Research 44(4):1082-1093.

Kim, H., Walker, S., and Bradford, S.A. 2010. Coupled factors influencing the transport and retention of *Cryptosporidium parvum* oocysts in saturated porous media. Water Research 44(4):1213-1223.

Airborne transport of endotxoins and microorganisms. Airborne microorganisms (e.g., endotoxins, fungi, bacteria) could be a human health concern near dairy farms. Animal feeding operations apply large quantities of manure that produce airborne particles and that can be a source of potentially harmful bioaerosols. To evaluate the potential for adverse health effects to humans and livestock, ARS researchers at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho, collected air samples from upwind and downwind locations at a

large open-lot dairy over the course of a year. They found that culturable bacteria and fungi as well as endotoxin concentrations were less than concentrations known to induce acute lung dysfunction and generally close to background concentrations at 500 to 4,000 feet downwind from the dairy, depending on wind speed. The scientists determined that the primary factors affecting airborne endotoxin emissions were wind speed, lot management, and animal activity. Overall, the concentrated dairy operation does not appear to increase the risk of exposure to bioaerosols and the exposure risk to offsite individuals is expected to decrease with distance from the facility. The results from this study are particularly useful to researchers and regulatory agencies performing microbial risk assessments and for the congressionally mandated air quality task force established to address air quality issues.

Dungan, R.S., Bjorneberg, D.L., and Leytem, A.B. 2011. Effect of sprinkler pressure and spray plate on culturable microorganism concentrations during simulated irrigation of dairy wastewater. Transactions of the ASABE. 54(5):1669-1673.

Dungan, R.S. and Leytem, A.B. 2009. Airborne endotoxin concentrations at a large open-lot dairy in southern Idaho. Journal of Environmental Quality 38:1919-1923.

Dungan, R.S., and Leytem, A.B. 2011. Ambient endotoxin concentrations and assessment of transport at an open-lot and open-freestall dairy. Journal of Environmental Quality 40:462-467.

Dungan, R.S., Leytem, A.B., and Bjorneberg, D.L. 2011. Concentrations of airborne endotoxin and microorganisms at a 10,000 cow open-freestall dairy. Journal of Animal Science 89:3300-3309.

Dungan, R.S., Leytem, A.B., Verwey, S.A., and Bjorneberg, D.L. 2010. Assessment of bioaerosols at a concentrated dairy operation. Aerobiologia 26:171-184.

Bacterial communities in beef cattle with diets containing corn and wet distillers grains. Beef cattle may be fed with diets containing corn and wet distillers grains, a byproduct of the ethanol industry. There is concern that use of wet distillers grains in cattle feed may create a GI environment that allows the growth of bacterial pathogens such as *Escherichia coli* O157:H7 that can affect human health. Because all *E. coli* must compete for resources with other fecal community members, ARS researchers in Lincoln, Nebraska, determined what other kinds of bacteria are present with *E. coli* in the cattle gut. Results indicate that *E. coli* experiences fundamentally different microbial communities in animals fed distillers grain compared with animals fed corn. Competition within different communities may reduce O157:H7 in the gut and thus, management of animal diet could be a legitimate practice in reducing the potential for O157:H7 food contamination. The same group determined that diet significantly affects transport of parasitic bacterial viruses, but not bacteria from manure-amended fields. The researchers are using this information to develop land application practices that incorporate the use of manure as a nutrient source for crop production while minimizing potential adverse environmental impacts.

Durso, L.M., Gilley, J.E., Marx, D.B., and Woodbury, B.L. 2011. Effects of animal diet, manure application rate, and tillage on transport of microorganisms from manure-amended fields. Applied and Environmental Microbiology 77:6715-6717.

Durso, L.M., Harhay, G.P., Smith, T.P., Bono, J.L., Desantis, T.Z., and Clawson, M.L. 2011. Bacterial community analysis of beef cattle feedlots reveals that pen surface is distinct from feces. Foodborne Pathogens and Disease 8(5):647-649. DOI:10.1089/fpd.2010.0774.

Durso, L.M., Wells, J., Harhay, G.P., Rice, W.C., Kuehn, L.A., Bono, J.L., Shackelford, S.D., Wheeler, T.L., and Smith, T.P. 2012. Comparison of bacterial communities in faeces of beef cattle fed diets containing corn and wet distillers grain with solubles. Letters in Applied Microbiology 55(2):109-114. DOI:10.1111/J.1472-765X.2012.03265.X.

Spiehs, M.J., Miller, D.N., Woodbury, B.L., Eigenberg, R.A., Varel, V.H., and Parker, D.B. 2012. Effect of feeding wet distillers grains with solubles to beef cattle on air and manure quality. Applied Engineering in Agriculture 28(3):423-430.

Pathogen survival after land application of manure. Enteric pathogens on soils and plants fertilized with manure can pose risks to grazing animals and humans if the pathogens survive or grow in the soil or plant environments. ARS scientists at the Genetics and Precision Agriculture Research Unit in Mississippi State, Mississippi, studied the survival of naturally occurring bacterial pathogens and fecal indicator bacteria in swine manure lagoon effluent during and immediately following land application in a commercial farming operation. Bacteria were monitored in aerosols, soil, and on grass leaves. Survival of most indicator bacteria and pathogens was intermittent and most bacteria were either inactivated within 72 hours of land application or were diluted in the application process to levels below cultural detection limits in the soil and grass environments. Aerosolized pathogens were rarely detected and then only within the immediate (less than 10 miles) downwind vicinity. This study established that bacterial pathogens known to be present in swine manure were rarely detected in environmental samples after land application of lagoon effluent, suggesting that 1) land application of lagoon effluents dilutes bacterial pathogens and mitigates potential risks; and 2) efforts to track pathogens, such as from an outbreak of enteric illness, back to manure-contaminated plants or soil will require development of more sensitive detection techniques than those currently available.

Brooks, J.P., and McLaughlin, M.R. 2009. Antibiotic resistant bacterial profiles of anaerobic swine lagoon effluent. Journal of Environmental Quality 38:2431-2437.

McLaughlin, M.R., Brooks, J.P., and Adeli, A. 2009. Characterization of selected nutrients and bacteria from anaerobic swine manure lagoons on sow, nursery, and finisher farms in the mid-south US. Journal of Environmental Quality 38:2422-2430.

McLaughlin, M.R., Brooks, J.P., Adeli, A., and Read, J.J. 2010. Comparison of selected nutrients and bacteria from common contiguous soils inside and outside swine lagoon effluent spray fields after long-term use. Journal of Environmental Quality 39:1829-1840.

Problem Statement 2B: *Minimizing the Release of Veterinary Pharmaceuticals and Hormones.* Animal drugs and feed additives are routinely used in concentrated animal feeding operations to improve health and production. Many of these compounds are excreted by the animals along with several natural hormones. Evidence is available that several of these compounds, including natural hormones, can persist in the environment and may affect the ecology of downstream areas and perhaps even humans. It is documented that large volumes of hormones and veterinary pharmaceuticals are present in animal wastes (wastewater and manure). The potential public health and environmental effects from environmental exposures to veterinary PACs are largely unknown.

Research is being conducted by ARS scientists to identify the fate of these compounds in run-off from agricultural sites to surface and subsurface waters and to determine processes controlling their transport. The occurrence, transport, and degradation of these compounds in dairy, swine, and poultry wastes and waste treatment systems are being evaluated. Also being evaluated is how these compounds interact with other important bacterial populations in soils and water. Ongoing work is being conducted to evaluate the suitability of treatment systems for breaking down veterinary pharmaceutical compounds before they can reach environmental ecosystems and to determine the environmental persistence and degradation byproducts associated with these compounds.

Selected Accomplishments

Estradiol and testosterone concentrations in run-off associated with poultry litter application. Because poultry litter contains fecal bacteria, sex hormones, and low levels of antibiotics it is important to determine whether poultry litter poses a risk to public health. One particular concern is that poultry litter contains the reproductive hormones estradiol and testosterone. These are endocrine disruptors that have been detected in surface waters worldwide. ARS researchers evaluated the potential impact of poultry litter applications on estradiol and testosterone concentrations in subsurface drainage and surface runoff in irrigated crop land. Controlled rainfall simulations on long-term no-till and conventional tillage fields with poultry litter applications at rates recommended for crop production did not contribute to the loads of fecal bacteria, hormones, or antibiotics in runoff to surface waters. Rainfall following application of poultry litter at recommended agronomic levels, and depending on the concentrations of fecal bacteria and hormones, appears to have little potential of contaminating surface waters with pathogens or hormones. This is important information for the poultry industry and environmental protection agencies because surface waters contaminated with pathogens or hormones from

poultry litter are likely an indication of inappropriate or mismanagement of litter applications. Data sets will also provide a scientific basis for establishing total maximum daily loads for these compounds.

Jenkins, M., Endale, D.M., Schomberg, H.H., Hartel, P., and Cabrera, M. 2009. 17B-Estradiol and testosterone in drainage and runoff from poultry litter applications to tilled and no-till crop land under irrigation. Journal of Environmental Management 90:2659-2664.

Jenkins, M., Truman, C.C., Siragusa, G.R., Line, J.E., Bailey, J.S., Frye, J.G., Endale, D.M., Franklin, D.H., Schomberg, H.H., Fisher, D.S., and Sharpe, R.R. 2008. Rainfall and tillage effects on transport of fecal bacteria and sex hormones 17ß-estradiol and testosterone from broiler litter applications to a Georgia Piedmont Ultisol. Science of the Total Environment 403(1-3):154-163.

Occurrence, transport, and degradation of veterinary pharmaceuticals. ARS researchers at units in Beltsville, Maryland, working with others in Clay Center, Nebraska, and Bowling Green, Kentucky, are conducting studies to quantify the occurrence of pharmaceutically active compounds (PACs) in livestock manures and to evaluate methods to reduce their occurrence. They found that concentrations of veterinary pharmaceuticals in a beef cattle feedlot were highest in livestock feeding areas where manure was concentrated, but compounds were not transported down-gradient through grass filter strips. Other research showed that concentrations of PACs (17β-estradiol and chlorotetracycline) in dairy lagoon sludge, or swine or cattle manure, were reduced by anaerobic digestion or by treatment with differing levels of ferrate (VI) or ferric chloride. Enhanced knowledge of the concentration, persistence, and fate of PACs during collection, storage, and treatment can be used by producers, regulators, and researchers to develop recommendations and optimize management practices to control manure-borne contaminants. Research demonstrated that composting reduced the concentrations of antibiotics in beef manure. ARS researchers at the Environmental Management and By-Product Utilization Laboratory in Beltsville, Maryland, are part of an interagency task force commissioned by the Committee on the Environment and Natural Resources, Office of Science and Technology Policy, that was tasked with summarizing federal research in this area and developing an integrated interagency strategy.

Arikan, O., Mulbry III, W.W., and Rice, C. 2008. Management of antibiotic residues from agricultural sources: use of composting to reduce chlortetracycline residues in beef manure from treated animals. Journal of Hazardous Materials 164:483-489.

Arikan, O.A., Rice, C., and Codling, E. 2008. Occurrence of antibiotics and hormones in a major agricultural watershed. Desalination 226(1-3):121-133.

Bevacqua, C. E., Rice, C. P., Torrents, A., and Ramirez, M. 2011. Steroid hormones in biosolids and poultry litter: a comparison of potential environmental inputs. Science of the Total Environment 409:2120-2126.

Netthisinghe, A.M.P., Cook, K.L., Rice, C., Gilfillen, R.A., and Sistani, K.R. 2013. Soil nutrients, bacteria populations, and veterinary pharmaceuticals across a backgrounding beef feedlot. Journal of Environmental Quality 42(2):532-544.

Varel, V.H., Wells, J.E., Shelver, W.L., Rice, C.P., Armstrong, D.L., and Parker, D.B. 2012. Effect of anaerobic digestion temperature on odour, coliforms and chlortetracycline in swine manure or monensin in cattle manure. Journal of Applied Microbiology 112(4):705-715.

Problem Statement 2C: *Reducing Antibiotic Resistant Bacteria in Agricultural Manures and Wastes.*
Public health can be compromised by overuse of antibiotics, as has been recently demonstrated with outbreaks of community-acquired methicillin-resistant *Staphylococcus aureus* (MRSA) and *Clostridium dificile* in the United States and Europe. U.S. industries such as the poultry industry have made strong commitments to reducing antibiotic use, although the length of time required for these mitigation approaches to become effective is unknown. The issue is particularly complex due to the realization that any bacterium exposed to antibiotics can potentially harbor resistance—not just the pathogens targeted by the compound. Very little information is available on the types or concentration of antibiotic-resistant bacteria in manure or manure-impacted environments. Thus, little is known about the fate and transport of pathogenic and nonpathogenic antibiotic-resistant bacteria or the occurrence of resistance genes in soil, water, crops, and agronomic systems.

Accordingly, research is occurring to determine concentrations of antibiotic-resistant bacteria and associated genes in manures and manure treatment systems, and soil and water sources. Ongoing work is providing needed data sets on risk factors associated with antibiotic-resistant bacteria and genes in water, air, and soils. Studies include those to measure antibiotic resistance factors in urban and agriculturally affected watersheds; in bioaerosols released in animal production systems; and in soils with dairy, swine, or poultry manure applied to food and forage crops over successive years.

Selected Accomplishments

Antibiotic resistance genes identified in swine feces and manure. Bacteria commonly present in swine feces and stored manure may provide reservoirs of antibiotic resistance genes that may possibly be transferred to bacteria and thus affect human health. However, relatively little is known about such genes in these ecosystems. ARS scientists in Peoria, Illinois, demonstrated that a variety of antibiotic resistance genes are present in both swine feces and stored swine manure. These results will guide the development of methods to quantitatively measure each of these genes in these ecosystems and assess the impact of varying management practices on reducing the concentration of such genes. Such reductions

will aid swine producers, environmental protection agencies, health officials, and local residents who live near swine facilities.

Whitehead, T.R., and Cotta, M.A. 2013. Stored swine manure and swine faeces as reservoirs of antibiotic resistance genes. Letters in Applied Microbiology 56(4):264-267.

Aerosolized antibiotic-resistant poultry bacteria. Antibiotic-resistant bacteria may shuttle in a resurgence of long-controlled diseases. The presence of resistant bacteria in concentrated poultry feeding operations has long been known and can be a nuisance not only to human workers but to poultry as well. The presence of these bacteria in poultry litter has been documented; however, their presence in poultry house aerosols has not been demonstrated. ARS scientists at the Genetics and Precision Agriculture Research Unit in Mississippi State, Mississippi, have completed a study in a commercial broiler house in which they measured the antibiotic resistance patterns of aerosolized *Staphylococcus*, *E. coli*, and *Enterococcus*. Resistance increased in the litter and aerosols as the flock cycle progressed through the sell-off period. Resistance in aerosols dropped to baseline levels between flocks; however, litter levels remained elevated. These data demonstrate there may be a need for worker protection and better control of aerosols to limit potential house-to-house contamination by resistant bacteria. Data sets also provide environmentally based scientific data to aid decision makers in evaluating risk factors associated with antibiotic resistance and bioaerosols.

Brooks, J.P., McLaughlin, M.R., Scheffler, B.E., and Miles, D.M. 2010. Microbial and antibiotic resistant constituents associated with biological aerosols and poultry litter within a commercial poultry house. Science of the Total Environment 408:4770-4777.

McLaughlin, M.R., Brooks, J.P., and Adeli, A. 2009. Characterization of selected nutrients and bacteria from anerobic swine manure lagoons on sow, nursery, and finisher farms in the mid-south US. Journal of Environmental Quality 38:2422-2430.

Multiple antibiotic resistance associated with E. coli and enterococci in waterways. *E. coli* and Enterococci are widely used as indicators of fecal contamination of waterways in most urban areas throughout the United States, and exposure of these bacteria to excessive antibiotics may become a serious public threat. This research was conducted at the U.S. Salinity Laboratory in Riverside, California, to investigate the prevalence, genetic diversity, and antimicrobial susceptibility of *E. coli* and *Enterococcus* populations and to determine the influence of pollutant sources associated with the Santa Ana River watershed of southern California. *Enterococcu*s species showed multiple resistance to ciprofloxacin, erythromycin, and

tetracycline, and resistance to tetracycline was prevalent in samples collected from sediments that were affected by agricultural activities, whereas ciprofloxacin and erythromycin were prevalent from samples affected by urban runoff. The occurrence of greater numbers of *E. coli* with resistance to multiple antibiotics from urban runoff sources than from agricultural sources in this watershed provides useful evidence in planning strategies for water quality management and public health protection.

Ibekwe, A.M., Murinda, S.E., and Graves, A.K. 2011. Genetic diversity and antimicrobial resistance of *Escherichia coli* from human and animal sources uncovers multiple resistances from human sources. PLoS One 6(6):1-12.

Ibekwe, A.M., Murinda, S.E., and Graves, A.K. 2011. Microbiological evaluation of water quality from urban watersheds for domestic water supply improvement. International Journal of Environmental Research and Public Health 8:4460-4476.

Problem Statement 2D: *Minimizing Risk with Best Management Practices and Treatment Technologies.*
Traditional and alternative livestock manure, runoff, and wastewater treatment systems are primarily designed for the control of nutrients. Best management practices (BMPs) focusing on comprehensive nutrient management plan development; and precision nutrition and waste handling, storage, and recycling are supported by the EPA and other regulatory agencies, however, few data are available to determine how these policies affect fecal contaminants such as pathogens, ARB, and PACs. The fate of manure-borne contaminants in treatment systems optimized for manure reduction or nutrient control has not been fully characterized. Because these contaminants pose a risk to human, animal, and environmental health, the reduction of pathogens, ARB, and PACs should be considered as a part of any sanctioned BMP or treatment technology.

ARS scientists are evaluating the effect of diet, growth promoters, and management systems on existing microbial communities and their ability to inhibit pathogen persistence or colonization. The interdisciplinary, multifactorial nature of these studies provides data needed to incorporate the fate of pathogens, ARB, and PACs into current waste treatment and nutrient management plans. These studies provide farmers, regulators, and researchers with information for production of risk management models and for application of new or improved BMPs and treatment technologies that are optimized for control of nutrient, emissions, and pathogen contamination.

Selected Accomplishments

Effect of diet and management practices on microbial communities in manures. It is known that manures are a major source of pathogens, ARB, and PACs. However, only limited research has occurred to determine how dietary composition, including the use of antibiotics, influences the microbial community and subsequent deposition and/or transport of contaminants to the environment. ARS researchers in Clay Center and Lincoln, Nebraska, have conducted studies to show that 1) diet affects transport of parasitic bacterial viruses but not bacterial transport from manure-amended fields; 2) bacterial communities in feedlot pens are distinct from those of the fecal source material; and 3) the use of growth-promoting antibiotics in feed materials does not

affect odor production but does result in deposition of antibiotic residuals that were not degraded at temperatures encountered during anaerobic digestion. It suggests that a temperature for anaerobic digestion be evaluated that is greater than what might be common in deep pits where swine manure slurries are stored and anaerobic digestion occurs. These findings resulted in information that is being used to develop land application practices and treatment technologies that optimize the use of manure as a nutrient source for crop production while minimizing potential adverse environmental impacts.

Durso, L.M., Gilley, J.E., Marx, D.B., and Woodbury, B.L. 2011. Effects of animal diet, manure application rate, and tillage on transport of microorganisms from manure-amended fields. Applied and Environmental Microbiology 77:6715-6717.

Durso, L.M., Harhay, G.P., Smith, T.P., Bono, J.L., Desantis, T.Z., and Clawson, M.L. 2011. Bacterial community analysis of beef cattle feedlots reveals that pen surface is distinct from feces. Foodborne Pathogens and Disease 8(5):647-649. DOI: 10.1089/fpd.2010.0774.

Varel, V.H., Wells, J., Berry, E.D., Spiehs, M.J., Miller, D.N., Ferrell, C.L., Shackelford, S.D., and Koohmaraie, M. 2008. Odorant production and persistence of *Escherichia coli* in manure slurries from cattle fed zero, twenty, forty, or sixty percent wet distillers grains with solubles. Journal of Animal Science 86:3617-3627.

Varel, V.H., Wells, J.E., Shelver, W.L., Rice, C.P., Armstrong, D.L., and Parker, D.B. 2012. Effect of anaerobic digestion temperature on odour, coliforms and chlortetracycline in swine manure or monensin in cattle manure. Journal of Applied Microbiology 112(4):705-715.

Pathogen presence in broiler houses is dependent on flock age. Targeting foodborne (e.g., *Salmonella*) and nuisance (e.g., *Clostridium*) pathogens in broiler houses could reduce broiler house microbial treatment costs. According to two recent studies by ARS scientists at the Genetics and Precision Agriculture Research Unit in Mississippi State, Mississippi, pathogen presence in broiler house litter is not necessarily based on intrahouse specific site variations. These studies showed and confirmed that foodborne and nuisance pathogens were linked to flock age. In-house pathogen variability was associated with the brood end of the house, but not with high moisture or high-traffic locations. Pathogen presence appeared to be cyclical, and to be reintroduced with baby chicks in successive flocks, suggesting egg and chick production as the probable source. Interhouse traffic and management operations likely contributed to transfer of pathogens from contaminated to uncontaminated sites within and between houses.

Roberts, B., Bailey, R., McLaughlin, M, Miles, D., and Brooks, J. 2013. Spatial and temporal analysis of microbial populations in production broiler house litter in the southeastern U.S. Journal of Applied Poultry Research. In Press.

Troughs as a hidden source of Johne's Disease. *Mycobacterium avium* subsp. *paratuberculosis* (*M. paratuberculosis*) causes Johne's disease, a chronic intestinal infection that affects ruminants

such as dairy cows. This disease can cause losses of as much as $200,000 per year in a herd of 1,000 dairy cows. A continued increase in the number of cases of Johne's disease among dairy cattle suggests that there may be uncharacterized sources of contamination on farms. Scientists with the ARS laboratory in Bowling Green, Kentucky, evaluated differences in the ability of the bacteria to adhere to and persist on the surfaces of different livestock watering trough materials. Researchers found high concentrations of *M. paratuberculosis* on all trough materials within 3 days of inoculating trough water with the bacteria and they persisted for more than 149 days. Persistence of *M. paratuberculosis* was lowest on stainless steel, followed by plastic, galvanized steel, and concrete. To reduce exposure of susceptible animals to *M. paratuberculosis* on infested farms, best management practices aimed at reducing slime build-up on trough surfaces should be included in any Johne's control plan. This research has been featured in industry publications and has generated inquires from trough manufacturers interested in alternative materials.

Cook, K.L. 2010. Survival of the causative agent of Johne's Disease (*Mycobacterium avium* subsp. *paratuberculosis*) in biofilms on trough materials. Natural Resources Research Update. Beltsville, MD: Agricultural Research Service; technical update number 252974.

Cook, K.L., Bolster, C.H., Britt, J., and Rothrock Jr., M.J. 2010. Effect of watering trough chlorination on persistence of *Mycobacterium avium* subsp. *paratuberculosis*. Bovine Practitioner Journal 44(1):69-76.

Cook, K.L., Britt, J., and Bolster, C.H. 2010. Survival of *Mycobacterium avium* subsp. *paratuberculosis* in biofilms on livestock watering trough materials. Veterinary Microbiology 141:103-109.

Use of biochar to increase E. coli retention in soils. The incorporation of biochar into soils has been proposed as a means to sequester carbon from the atmosphere. Recent studies have shown added environmental benefits to biochar amendments to soil such as increased soil retention of nutrients, heavy metals, and pesticides, yet no studies have examined the role biochar plays on microbial transport in soils. ARS scientists at the Animal Waste Management Research Unit in Bowling Green, Kentucky, have conducted studies to evaluate whether biochar amendments can reduce the transport of *E. coli* through soils. Results from this research show that the addition of biochar to soil can indeed affect the retention and transport of *E. coli*—a commonly used indicator of fecal contamination in groundwater. Results indicate that the amount of *E. coli* retention in biochar-amended soils depends on biochar application rate, temperature at which the biochar was produced, and surface characteristics of the bacteria. If biochar is to be widely used as a soil amendment, it is important that its effect on microbial transport through the soil be understood, especially in fields where animal manure is applied. This research is the first to investigate this important environmental topic and results from this research provide important information on the factors controlling bacterial transport through biochar-amended soils. Results suggest that biochar has the potential for being used as a management practice for protecting shallow groundwater supplies from contamination by pathogenic microorganisms.

Abit, S.M., Bolster, C.H., Cai, P., and Walker, S.L. 2012. Influence of feedstock and pyrolysis temperature of biochar amendments on transport of *Escherichia coli* in

saturated and unsaturated soil. Environmental Science and Technology 46: 8097-8105.

Bolster, C.H., and Abit Jr., S.M. 2012. Biochar pyrolyzed at two temperatures impacts *E. coli* transport through a sandy soil. Journal of Environmental Quality 41(1):124-133.

Component 3. Atmospheric Emissions

Concentrated animal production systems and the manure they produce are sources for ammonia, hydrogen sulfide, volatile organic compounds, odor, greenhouse gases, particulates, and bioaerosols. Emissions may come from multiple sources, including the site of animal production, manure storage, and the fields where manure is applied. Understanding the production, emission, and transport of gases and particulates from livestock production systems is critical to identifying and implementing management practices that will reduce these emissions.

ARS emissions research has three major themes: scientifically sound assessment of emission rates and emission factors for air quality constituents; understanding the physical, chemical, and biological processes that control emissions and using that understanding to develop process-based models to describe the emission of gases, particulates, and bioaerosols; and development and assessment of technologies to reduce emissions from agricultural operations.

Practices implemented to control a single type of atmospheric emission can also affect other types of atmospheric emissions and manure-related environmental issues (nutrients, pathogens, or phamaceutically active compounds [PACs]) when the production system is viewed as a whole. Air quality has many constituents, and the variation among these constituents in the overall scope of emission, nutrient, and pathogen control associated with animal production increases the complexity in addressing these problems.

ARS scientists are studying these issues at multiple locations across the country in laboratories and full-scale commercial operations encompassing beef, dairy, swine, and broiler production practices. The scientists have also come together to form a working group known as Livestock GRACEnet, building upon the success and name recognitions of ARS' GRACEnet (Greenhouse gas Reduction through Agricultural Carbon Enhancement network) project. The mission of Livestock GRACEnet is to lead the development of livestock management practices to reduce greenhouse gas, ammonia, and other emissions and provide a sound scientific basis for accurate measurement and modeling of emissions. The Livestock GRACEnet group consists of 24 ARS scientists from 13 locations working on the effects of livestock production on emissions and air quality. The Livestock GRACEnet group has produced several fact sheets related to management practices aimed at reducing on-farm emissions. Additionally, the Livestock GRACEnet group is working closely with the Livestock Research Group of the Global Research Alliance on Agricultural Greenhouse Gases. Plans are underway for international participation in Livestock GRACEnet and collaboration on a methods manual for greenhouse gas measurement.

Problem Statement 3A: *Quantifying the Extent of Agricultural Emissions of Air Pollutants.* Ammonia emissions from livestock production systems constitute a loss of valuable fertilizer nitrogen and can negatively impact sensitive ecosystems and degrade air quality. In confined housing systems such as those for poultry and swine, high NH_3 concentrations can also result in poor animal performance and health risks to workers. Emissions of greenhouse gasses (CH_4 and N_2O) that originate from either enteric methane production in ruminants or manure storage systems are a concern from a climate change perspective. There is only limited on-farm emissions data from livestock production facilities covering the range of trace gases that are important from regulatory and environmental standpoints. The implementation of air quality

regulations in livestock producing States increases the need for accurate on-farm determination of emission rates that reflect the range of animal production facilities and climatic conditions that exist in the United States. ARS researchers determined the quantity and factors controlling losses of trace gases from poultry, beef, and dairy production systems.

Ammonia emission factors for broiler production. ARS researchers from the Poultry Production and Product Safety Research Laboratory and the Dale Bumpers Small Farms Research Center in Fayetteville and Boonville, Arkansas, respectively, measured ammonia emissions from litter in four commercial broiler houses during storage and after land application. In addition, a mass balance for nitrogen was conducted to verify the quantity of nitrogen lost from the system. Total ammonia losses (housing, manure storage, land application) from broiler production were 45.6 grams of NH_3 per bird marketed. This value is less than half of the value currently used by the EPA (100 g NH_3 per bird). The percent of nitrogen recovery for the nitrogen mass balance study was 98.8 percent, indicating that this emission factor appears to be appropriate. This research provided industry and regulatory agencies with better estimates of atmospheric nitrogen losses associated with poultry production.

Moore Jr., P.A., Miles, D., Burns, R., Pote, D., Berg, K., and Choi, I.H. 2011. Ammonia emission factors from broiler litter in barns, in storage and after land application. Journal of Environmental Quality 40:1395-1404.

Ammonia emission factors from southern high plains beef cattle feedyards. ARS researchers with the Conservation and Production Research Laboratory in Bushland, Texas, in collaboration with researchers at West Texas A&M University and Texas AgriLife Research, measured NH_3 emissions from two feedyards over a 2-year period to identify the sources and fate of NH_3 gas losses. Average annual NH_3-N emissions were 52–59 percent of fed nitrogen. Annual patterns of NH_3 fluxes correlated with air temperature, with greatest fluxes during the summer and the fewest fluxes during the winter. Mean per capita NH_3-N emission rates were 72 g per head per day in year 1 when crude protein in feed was similar. The use of distillers grains on one of the feedyards in year 2 increased the crude protein in feed from 13 percent to 19 percent, resulting in increased monthly NH_3 emissions of 44 percent to 144 percent relative to feeding corn-based rations. Over a 2-year period, the annual emission rate was 80 g NH_3-N per head per day on the feedyard using corn-based rations and 115 g NH_3-N per head per day on the feedyard where distillers grains had been fed. These results are the most extensive measures available of NH_3 emission from feedlots and provide an important database that can be used by scientists to validate and verify process models of emissions, provide the cattle industry accurate science-based information to meet regulatory requirements, and give regulators more comprehensive real-world data to build NH_3 emissions inventories.

Rhoades, M.B., Parker, D.B., Cole, N.A., Todd, R.W., Caraway, E.A., Auvermann, B.W., Topliff, D.R., and Shuster, G.L. 2010. Continuous ammonia emission measurements from a commercial beef feedyard in Texas. Transactions of the American Society of Agricultural and Biological Engineers 53:1823-1831.

Todd, R.W., Cole, N.A., Rhodes, M.B., Parker, D.B., and Casey, K.D. 2011. Daily, monthly, seasonal and annual ammonia emissions from southern high plains cattle feedyards. Journal of Environmental Quality 40:1090-1095.

Todd. R.W., Cole, N.A., Clark, R.N., Flesch, T.K., Harper, L.A., and Baek, B.H. 2008. Ammonia emissions from a beef cattle feedyard on the southern high plains. Atmospheric Environment 42:6797-6805.

Ammonia and greenhouse gas emission factors from western dairy production. ARS researchers at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho, determined emission rates of NH_3, CH_4, and N_2O from three commercial dairies in southern Idaho that varied in size, animal housing, and manure handling systems. Both housing and manure management systems were monitored to determine whole-farm emissions and the effects of manure handling practices on emissions from the different farm sectors. Average ranges for whole-farm emissions per cow per day for the three farms were 150–200 g NH_3, 325–1,400 g CH_4, and 10–20 g N_2O. This equates to an 18–24 percent loss of total nitrogen fed. It was demonstrated that emissions can vary by a factor of 10 over a 24-hour period and can also vary seasonally, thus it is important to capture both the diurnal and seasonal variations in emissions when determining emission factors. These results provide a comprehensive measurement of trace gases from western dairy production systems and can be used to develop emission factors from these systems as well as improve process-based models aimed at estimating emissions from dairy production systems.

Bjorneberg, D.L., Leytem, A.B., Westermann, D.T., Griffiths, P.R., Shao, L., and Pollard, M.J. 2009. Measurement of atmospheric ammonia, methane, and nitrous oxide at a concentrated dairy production facility in southern Idaho suing open-path FTIR spectrometry. Transactions of the American Society of Agricultural and Biological Engineers 52:1749-1756.

Leytem, A.B., Dungan, R.S., Bjorneberg, D.L., and Koehn, A.C. 2011. Emissions of ammonia, methane, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. Journal of Environmental Quality 40:1383-1394.

Leytem, A.B., Dungan, R.S., Bjorneberg, D.L., and Koehn, A.C. 2013. Greenhouse gas and ammonia emissions from an open-freestall dairy in southern Idaho. Journal of Environmental Quality 42:10-20.

Ammonia emission factors from Wisconsin dairy farms. ARS researchers at the Dairy Forage Research Center in Madison, Wisconsin, in collaboration with University of Georgia and University of Alberta researchers measured NH_3 emissions from housing and manure storage areas over three seasons on three commercial dairy farms. Total farm emissions varied from 15 to 330 kg NH_3 per day depending on the farm and season, with interfarm variability largely explained by farm size. Whole-farm emissions were affected by temperature (i.e., summer and autumn emission were significantly higher than winter emissions. The average yearly per animal emission rate for the three farms was 20 kg NH_3, which equates to a loss of 7.6 percent of fed nitrogen. These results were some of the first published NH_3 emissions data from dairy housing and manure storage areas in the Midwest and provide valuable data for industry and regulators regarding emissions factors from these production facilities.

Flesch, T.K., Harper, L.A., Powell, J.M., and Wilson, J.D. 2009. Inverse-dispersion calculation of ammonia emissions from Wisconsin dairy farms. Transactions of the American Society of Agricultural and Biological Engineers 52:253-265.

Harper, L.A., Flesch, T.K., Powell, J.M., Coblentz, W.K., Jokela, W.E., and Martin, N.P. 2009. Ammonia emissions from dairy production in Wisconsin. Dairy Science 92:2326-2337.

In addition to trace gas emissions, livestock production facilities can also produce elevated bioaerosol concentrations that may cause adverse health effects such as allergy and toxicosis in animals, workers, and residents in nearby communities. Bioaerosols are airborne viable and nonviable particles (e.g., bacteria, fungi, virus) and their byproducts and fragments (e.g., endotoxins). Only limited data are available that describe the diurnal and seasonal effects on bioaerosol emissions from livestock production facilities and the potential for transport away from livestock production sites.

Emissions of bioaerosols from western dairy production. ARS researchers at the Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho, measured airborne endotoxin and microorganisms seasonally at two commercial dairies in southern Idaho. Compared with background ambient concentrations, both endotoxin and culturable heterotrophic bacteria were as high as several hundred-fold greater at 50 meters downwind from the facility, and then decreased to near background concentrations at 200 meters. At 0–50 meters downwind the average inhalable endotoxin concentrations ranged from 5 to 4,243 endotoxin units/m^3, whereas bacteria concentrations ranged from 10^2 to 10^5 cfu/m^3. Bioaearosol concentrations were positively correlated with temperature, wind speed, and cattle activity. These results are the most extensive measures available of bioaerosol emissions from dairy production facilities, and provide an important database that can be used to assess the potential for offsite transport of bioaerosols from western dairy production systems.

Dungan, R.S., and Leytem, A.B. 2011. Ambient endotoxin concentrations and assessment of offsite transport at open-lot and open-freestall dairies. Journal of Environmental Quality 40:462-467.

Dungan, R.S., Leytem, A.B., and Bjorneberg, D.L. 2011. Concentrations of airborne endotoxin and microorganisms at a 10,000 cow open-freestall dairy. Journal of Animal Science 89:3300-3309.

Dungan, R.S., Leytem, A.B., Verwey, S.A., and Bjorneberg, D.L. 2010. Assessment of bioaerosols at a concentrated dairy operation. Aerobiologia 26:171-184.

Dungan, R.S., Leytem A.B., and Bjorneberg, D.L. 2010. Year long assessment of airborne endotoxin at a concentrated dairy operation. Aerobiologia 26:141-148.

Problem Statement 3B: *Characterize the Physical, Chemical, and Biological Processes Essential for the Development and Evaluation of Emissions Models.*
There is a need for improved understanding of the basic physical, chemical, and biological processes that contribute to the range of emissions from animal production systems. Emission factors are currently used to develop emissions inventories or assess emissions for regulatory purposes, although they are limited by the relatively small number of measurements from limited examples out of a great diversity of animal production systems. A better approach is to employ

process models. Process models are mathematical representations with mass balance constraints of the physical, chemical, and biological processes that contribute to the emission of a constituent of interest.

Selected Accomplishments

Processes affecting broiler litter gas fluxes. Ammonia losses from broiler litter are influenced by both the chemical and physical properties of the litters. Identification of the factors that affect emissions is valuable for estimating and modeling NH_3 losses from broiler houses. ARS researchers with the Genetics and Precision Agriculture Research Laboratory in Mississippi State, Mississippi, used intensive sampling in commercial broiler houses to demonstrate that 1) pooled single point measurements do not adequately characterize complex, nonuniform processes of gas evolution and its relationship to litter physical properties or changes in those parameters throughout the flock; 2) from middle to late flock, the birds insulate the litter, maintaining its temperature, which may negate some seasonal and management effects; and 3) caked surfaces that form over litter in high-traffic areas differ depending on location (near feeder or fan), but both limit NH_3 flux. Growers, integrators, and researchers can use this information to understand how bird activities influence emissions, manage NH_3 flux from the litter, and develop mitigation strategies for in-house control (i.e., zone litter treatment). This data set enhances knowledge of the chemical and physical mechanisms that contribute to NH_3 emissions, provides a foundation for recommending prospective changes in house design for feed and water delivery, and is a resource for process-based modeling required for mitigation.

Miles, D.M., Brooks J.P., McLaughlin, M.R., and Rowe, D.E. 2013. Broiler litter ammonia emissions near sidewalls, feeders, and waterers. Poultry Science 92:1693-1698.

Miles, D.M., Brooks, J.P., and K. Sistani. 2011. Spatial contrasts of seasonal and intraflock broiler litter trace gas emissions, physical and chemical properties. Journal of Environmental Quality 40:176-187.

Miles, D.M., Rowe, D.E., and Cathcart, T.C. 2011. Litter ammonia generation: moisture content and organic versus inorganic bedding material. Poultry Science 90:1162-1169.

Models to predict ammonia loss from feedyards. Ammonia emissions from feedyards are closely related to dietary nitrogen intake and climatic variables such as temperature. Feedyard managers need ways to predict NH_3 losses to meet reporting requirements and to make management decisions that affect NH_3 loss. Researchers at the Conservation and Production Research Laboratory in Bushland, Texas, used a unique, comprehensive, 2-year database of NH_3 emissions from two west Texas beef feedyards to describe the relationship between NH_3 loss, temperature, and dietary crude protein. They found a strong relationship between temperature and NH_3 loss, because many chemical processes that lead to NH_3 loss are controlled by temperature. This relationship was described with a simple equation that can be used to predict NH_3 losses in southern High Plains feedyards. Ammonia loss is predicted even more accurately if dietary crude protein concentrations are included in the equation. Managers and consultants of southern High Plains feedyards can use these equations to predict NH_3 loss and meet regulatory requirements until more widely applicable models of NH_3 loss are available.

Todd, R.W., Cole, N.A., Waldrip, H.M., and Aiken, R.M. 2013. Arrhenius equation for modeling feedyard ammonia emissions using temperature and diet crude protein. Journal of Environmental Quality 42:666-671.

Statistical and process-based models have been developed to estimate NH_3 emissions from dairy barns and other enclosed livestock production systems. Little research has occurred to determine their accuracy for large, open-lot beef cattle feedyards, which are inherently more vulnerable to changing environmental conditions than enclosed barns. Researchers at the ARS Pasture Systems Management and Watershed Research Unit in University Park, Pennsylvania, and the Conservation and Production Research Laboratory in Bushland, Texas, with collaborators from the University of New Hampshire validated two process-based models for predicting NH_3 emissions from open-lot feedyards. This was achieved by comparing 2 years of measured NH_3 emissions taken from commercial feedyards in the Texas Panhandle with predictions made by Manure-DNDC and the Integrated Farm System Model (IFSM). Both models slightly overestimated NH_3 emissions; however, their prediction accuracy was a significant improvement over estimates currently being used for beef cattle by regulatory agencies in the United States. Predictions made by Manure-DNDC and the modified IFSM were sensitive to variations in air temperature and dietary protein concentration, similar to the measured NH_3 emissions. Results indicate that both Manure-DNDC and IFSM can assist with NH_3 emissions reporting for commercial beef cattle feedyards and provide accurate information for legislators and policy-makers. Process-based models can also help evaluate how specific management practices influence feedyard nutrient balances.

Waldrip, H.M., Todd, R.W., Li, C., Cole, N.A., and Salas, W. 2013. Estimation of ammonia emissions from beef cattle feedyards using the process-based model Manure-DNDC. Transactions of the American Society of Agricultural and Biological Engineers 56(3):1103-1114.

Problem Statement 3C: *Develop and Test Technologies and Improved Management Practices to Reduce Emissions.*

Reduction of atmospheric emissions from animal agriculture is necessary because of concerns over global air quality, climate change, and human health. The use of control technologies and improved manure management practices will protect the air quality for animals, farm workers, and neighboring communities, and mitigate the negative effect of emissions on climate. Stakeholders will benefit from the development of cost-effective emission control technologies with the potential to generate additional income through production of valuable manure byproducts and environmental offset credits.

Selected Accomplishments

Capturing ammonia from animal production facilities. Livestock production is the largest source of NH_3 emissions in the United States. ARS researchers at the Coastal Plains Soil, Water and Plant Research Center in Florence, South Carolina, invented a system that uses gas-permeable membranes to capture and recycle NH_3 from livestock wastewater and housing before the NH_3 goes into the air. The NH_3 is captured and concentrated as a nonvolatile ammonium salt that can be used as a fertilizer. The potential benefits are reduced NH_3 emissions from liquid manure, cleaner air inside the barns with benefits to animal health, and recovery of NH_3 as a concentrated liquid nitrogen that is reusable as a plant fertilizer.

Rothrock Jr., M.J., Szogi, A.A., and Vanotti, M.B. 2013. Recovery of ammonia from poultry litter using flat gas permeable membranes. Waste Management 33:1531-1538.

Rothrock Jr., M.J., Szogi, A.A., and Vanotti, M.B. 2010. Recovery of ammonia from poultry litter using gas permeable membranes. Transactions of the American Society of Agricultural and Biological Engineers 53:413-420.

Ammonia scrubbers to reduce ammonia emissions from poultry rearing facilities. Approximately 0.1 pound of ammonia is lost into the atmosphere for each broiler grown. In 2009, 8.9 billion broilers were produced in the United States, representing a potential loss of 445,000 tons of NH_3. Because nitrogen fertilizer is currently selling for $0.64 per pound of actual nitrogen, this represents a loss of $469,000,000 worth of nitrogen. ARS researchers at the Poultry Production and Products Safety Research Laboratory in Fayetteville, Arkansas, designed and patented an ammonia scrubber designed to strip dust and NH_3 out of exhaust air from mechanically ventilated poultry houses. This technology will reduce NH_3 concentrations emitted from poultry houses by 75 percent or more and could recover a large amount of that nitrogen, making poultry production more sustainable.

Moore Jr., P.A.,, Maguire, R., Ogejo, J., Burns, R., Li, H., Miles, D., and Buser, M.. 2013. Development of an acid scrubber for reducing ammonia emissions from animal rearing facilities. Proceedings of the Waste to Worth Conference held in Denver, CO. http://www.extension.org/pages/67663/development-of-an-acid-scrubber-for-reducing-ammonia-emissions-from-animal-rearing-facilities#.UieofX8o7EY. Accessed September 25, 2013.

Treatment technology to reduce ammonia and odor from swine manure. New swine waste management systems need to meet high performance standards in NH_3 and odor reduction, and remain affordable and simple to operate. ARS researchers at the Coastal Plains Soil, Water and Plant Research Center in Florence, South Carolina, developed a second-generation treatment technology for swine waste that consists of three modules: solids separation, biological nitrogen removal, and phosphorus recovery/wastewater disinfection. An on-farm demonstration project showed a 97 percent reduction in NH_3 and a 99.9 percent reduction in odors. Animal health and therefore productivity were enhanced with an increase of 5.6 percent in live weight per cycle. This also shows that cleaner treatment technologies can have significantly positive effects not only on the environment but also on livestock productivity, thereby enhancing the sustainability of swine production.

Vanotti, M.B., Szogi, A.A., Milner, P.D., and Loughrin, J.H. 2009. Development of a second generation environmentally superior technology for treatment of swine manure in the USA. Bioresearch Technology 100:5406-5416.

Removal of ammonia in wastewater using a novel anammox bacteria. Anammox (anaerobic ammonium oxidation) converts nitrate and ammonium directly into dinitrogen gas and can be used to reduce ammonia levels in waste waters. ARS researchers at the Coastal Plains Soil, Water and Plant Research Center in Florence, South Carolina, discovered novel anammox bacteria having the characteristics of oxidizing NH_3 and releasing dinitrogen gas under anaerobic conditions. The novel bacterial strain may be used for the treatment of wastewater having

undesirable levels of NH_3. Compared with conventional biological nitrogen removal methods this anammox microbial method reduces 60 percent of the energy for aeration and does not require external carbon addition. In addition, byproducts do not include greenhouse gases. This leads to a significant decrease in operation costs and provides environmental credit benefit for the users of this new technology.

Magri, A., Vanotti, M.B., Szogi, A.A., and Cantrell, K.B. 2012. Partial nitritation of swine wastewater in view of its coupling with the anammox process. Journal of Environmental Quality 41(6):1989-2000.

Using cover crops to reduce nitrous oxide emissions from manure-amended fields. Nitrous oxide is a greenhouse gas that is many times more potent than carbon dioxide in terms of global warming potential. Agriculture is the largest human-related source of nitrous oxide emissions. ARS scientists at the National Laboratory for Agriculture and the Environment in Ames, Iowa, studied the temporal patterns of N_2O emissions following addition of swine manure slurry under fluctuating soil moisture regimes, assessed the potential of a rye cover crop to decrease N_2O emissions under these conditions, and quantified field N_2O emissions in response to either spring-applied conventional nitrogen fertilizer or different rates of fall-applied liquid swine manure in the presence or absence of a rye/oat winter cover crop. Results showed a significant reduction in N_2O emissions in the presence of the rye cover crop. Nitrous oxide emissions were evaluated at three swine manure application rates and with spring-applied fertilizer, in the presence or absence of an oat/rye cover crop. The primary factor influencing N_2O emission was nitrogen application rate, regardless of form or timing. The response of N_2O emission to nitrogen additions was nonlinear, with progressively more N_2O emitted with increasing nitrogen application. These results indicate that although cover crops have the potential to reduce N_2O emissions, nitrogen application rate may be the overriding factor thus emphasizing the need for careful nitrogen application management practices.

Jarecki, M.K., Parkin, T.B., Chan, A.S.K, Kaspar, T.C., Moorman, T.B., Singer, J.W., Kerr, B.J., Hatfield, J.L., and Jones, R. 2009. Cover crop effects on nitrous oxide emission from a manure-treated mollisol. Agriculture, Ecosysystems and the Environment 134:29-35.

Feeding practices to mitigate emissions from cattle. One of the management strategies that can be used to mitigate emissions from cattle production is to alter feed composition. Researchers at the Conservation and Production Research Laboratory in Bushland, Texas, investigated the effects of feeding distillers grains and corn processed using different techniques (steam flaked or dry rolled) on emissions of NH_3, CH_4, and odor (volatile organic compounds and H_2S). When wet distillers grains with soluble (WDGS) are fed to cattle in place of corn, crude protein and minerals often exceed dietary needs. A feeding trial with steers fed a finishing diet demonstrated that increasing levels of WDGS in the diet increased odor, NH_3, and H_2S emissions. Feeding WDGS in a steam-flaked corn-based diet increased CH_4 production linearly with an increase in WDGS inclusion. Feeding steam-flaked corn-based diets reduced enteric CH_4 production by approximately 25 percent compared with cattle fed dry-rolled corn-based diets and reduced odor emissions from manure. When distillers grains were more than 30 percent of the diet dry matter enteric CH_4 emissions were increased by 20–30 percent. By eliminating WDGS from diets or using low concentrations in the rations allows one to reduce NH_3, volatile organic compounds, and H_2S emissions and, in some cases, reduce enteric CH_4 production. The use of steam-flaked corn instead of dry-rolled corn can reduce enteric CH_4

production and odor in resulting manures. These data can help producers make better decisions regarding feed ration formulation and environmental impacts.

Hales, K.E., Cole, N.A., and MacDonald, J.C. 2013. Effects of increasing concentrations of wet distillers grains with soluble in steam-flaked, corn-based diets on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. Journal of Animal Science 91:819-828.

Hales, K.E., Cole, N.A., and MacDonald, J.C. 2012. Effects of corn processing method and dietary inclusion of wet distillers grains with soluble on energy metabolism, carbon-nitrogen balance, and methane emissions of cattle. Journal of Animal Science 90:3174-3185.

Hales. K.E., Cole, N.A., and Varel, V.H. 2012. Effects of corn processing method and dietary inclusion of corn wet distillers grains with soluble on odor and gas production in cattle manure. Journal of Animal Science 90:3988-4000.

Component 4. Developing Beneficial Uses of Agricultural, Industrial, and Municipal Byproducts

Each year, millions of tons of agricultural, industrial, and municipal byproducts are generated that are considered to have little value, are classified as wastes, and often are disposed in landfills. Many of these byproducts have characteristics that make them prospectively useful for direct land application, soil reclamation and remediation, production of manufactured soils and composts, or feedstuffs for value added products. The utilization of these byproducts in agriculture and horticulture requires careful analysis and management. ARS is working on treatment technologies and management practices to make these products usable and reduce potential environmental hazards and disposal costs. Additionally, ARS is developing protocols and methodology standards that regulatory authorities can adopt to examine and approve byproducts for agricultural use.

Problem Statement 4A: *Enhance the Value of Agricultural, Industrial, and Municipal Byproducts by Developing Beneficial Uses.*
Agricultural, municipal, and industrial processes result in a wide array of byproducts. If properly processed and used, many of these byproducts may have specific benefits to water quality, soil quality, plant health, plant and animal production systems, and reduce undesirable air emissions. To achieve these benefits, the byproducts need to be used in an environmentally sound manner that reduces the cost of disposal or converts them into marketable assets.

Selected Accomplishments

Impact of gypsum applied to grass buffer strips on reducing soluble phosphorus in surface water runoff. Due to environmental concerns, improved methods to reduce phosphorus loading in surface waters associated with animal production are needed. Studies to evaluate the use of gypsum as a soil amendment to reduce phosphorus losses from poultry litter in forage-based production systems were conducted. Rainfall simulations were used to quantify the potential for gypsum to reduce phosphorus in surface water runoff. Gypsum applied to grass buffer strips was effective (32–40 percent) in reducing soluble phosphorus concentrations in surface runoff, whereas the untreated buffer strip was somewhat effective (18 percent) in reducing soluble phosphorus. This research indicates that gypsum could be utilized in filter strip areas where animal manures are used to reduce environmental degradation due to excess phosphorus.

Watts, D.B., and Torbert III, H.A. 2009. Impact of gypsum applied to buffer strips on reducing soluble P in surface water runoff. Journal of Environmental Quality 38:1511-1517.

Old tires are an effective slow-release zinc fertilizer. Waste rubber tires are a significant disposal problem in all States. Tires contain about 1.5 percent zinc, which is added to rubber to speed vulcanization. Zinc is also a required micronutrient for crop production, and some soils, particularly in the western U.S., require the addition of zinc fertilizer. Ground rubber was found to operate as a low-grade, slow-release zinc fertilizer. In addition, acid extraction of zinc from ground rubber tires produced both a zinc fertilizer for hydroponic production and a lower level of zinc for use as a rooting medium for hydroponic production. No zinc toxicity was observed.

Recycling old tires in this way provides a needed inexpensive fertilizer for producers while providing an economically valuable use for the hundreds of millions of waste tires generated each year in the United States.

Khoshgoftarmanesh, A.H., Eshghizadeh, H.R., and Chaney, R.L. 2010. Using acid-washed waste tire rubber in soilless media for tomato production. Journal of Plant Nutrition 7:69-72.

Khoshgoftarmanesh, A.H., Taheri, S., Shariatmadari, H., and Chaney, R.L. 2011. Kinetics of zinc release from ground tire rubber and rubber ash in a calcareous soil as alternatives to Zn fertilizers. Soil Science and Plant Nutrition 341:89-97.

Turning wood industry waste into nursery growing media. WholeTree (WT) and Clean Chip Residual (CCR) are byproducts of the forestry industry that contain high wood content and may be potential new nursery substrates. Initial immobilization of nitrogen is one concern when using these new substrates; however, the addition of composted poultry litter to substrates containing high wood content could balance initial nitrogen immobilization and provide an inexpensive fertilizer source for growers. ARS scientists at the National Soil Dynamics Laboratory conducted experiments on alternative substrate including poultry litter in nursery production. Results indicate that these species can be grown in WT and CCR substrates in a 6:1 volumetric ratio with composted poultry litter. Use of composted poultry litter in WT and CCR substrates could provide an alternative to traditional pine bark and peat-based combinations in container production while providing poultry producers an environmentally sound means of waste disposal. Wood industry waste can be used to extend pine bark supplies as a growing medium. With the recent decline in available pine bark supplies and the threat of continued decline, nursery growers have begun seeking possible alternatives or amendments to their standard growing media. WT and CCR are two possible substrate alternatives with commercial possibilities. Experiments show that with most species, nursery producers could amend their pine bark with up to 75 percent WT or 75 percent CCR with limited impact on crop growth. This information will allow growers to develop plans for extending existing pine bark supplies with WT or CCR.

Boyer, C.R., Fain, G.B., Gilliam, C.H., Gallagher, T.V., Torbert III, H.A., and Sibley, J.L. 2008. Clean chip residual as a substrate for perennial nursery crop production. Journal of Environmental Horticulture 26(4):239-246.

Boyer, C.R., Gilliam, C.H., Fain, G.B., Gallagher, T.V., and Torbert III, H.A. 2009. Production of woody nursery crops in clean chip residual substrate. Journal of Environmental Horticulture 27:56-62.

Boyer, C.R., Torbert III, H.A., Gilliam, C.H., Fain, G.B., Gallagher, T.V., and Sibley, J.L. 2012. Nitrogen immobilization in plant growth substrates: clean chip residual, pine bark and peat moss. International Journal of Agronomy DOI:10.1155/2012/978528.

Marble, S.C., Fain G.B., Gilliam, C.H., Runion, G.B., Prior, S.A., Torbert III, H.A., and Wells, D.E. 2012. Landscape establishment of woody ornamentals grown in alternative wood-based container substrates. Journal of Environmental Horticulture 30:13-16.

Marble, S.C., Gilliam, C.H., Sibley, J.L., Fain, G.B., Torbert III, H.A., Gallagher, T.V., and Olive, J.W. 2010. Evaluation of composted poultry litter as a substrate amendment for wholetree, clean chip residual, and pinebark for container grown woody nursery crops. Journal of Environmental Horticulture 28:107-116.

Conversion of feathers into bioplastic resins for nursery pot construction. Presently, the nursery industry uses soft plastic petroleum-based pots. These pots cannot be cost-effectively cleaned and reused, are not biodegradable, and often end up being discarded in landfill. One approach to reduce plastic waste from the horticulture industry is to use feathers to make biodegradable pots. Given that poultry feathers are entirely composed of the structural protein keratin, and as a natural biopolymer, it has the potential to be used to make horticulture pots. Also considering that more than 2 billion pounds of dry chicken feather waste is generated in the United States each year and is one of the most abundant materials in agricultural waste, reuse of feathers for horticultural pots would serve as a beneficial reuse for this agricultural waste. ARS partnered with the Horticultural Research Institute to develop a process for converting poultry feathers into biodegradable resins for use in commercial and consumer products, including growing containers that are 100 percent degradable, resulting in a patentable product.

Ahn, H.K., Huda, M.S., Smith, M.C., Mulbry, W.W., Schmidt, W.F., and Reeves III, J.B. 2011. Biodegradability of injection molded bioplastics containing polylactic acid and poultry feather fiber. Bioresource Technology 102:4930-4933.

Huda, M.S., Schmidt, W.F., Misra, M., and Drzal, L. 2013. Effect of fiber surface treatment of poultry feather fibers on the properties of their polymer matrix composites. Journal of Applied Polymer Science 128:1117-1124.

Biochars made from manures and crop residues improve soil carbon sequestration, water storage, fertility, and remove harmful chemicals. Investigators at the ARS laboratory in Florence, South Carolina, produced biochars, a charcoal-like product, during carbonization of manure and plant waste materials using both thermal and hydrothermal processing. Both of these processes were optimized to produce biochars with diverse chemical and physical properties. Laboratory research showed that biochars made from nut shells were effective at increasing soil carbon sequestration, whereas biochar made from grasses increased soil water storage. Manure biochars contained plentiful plant nutrients such as nitrogen, phosphorus, and potassium, but were blended with other plant-based biochars to produce a more nutrient-balanced fertilizer-like product. It was also discovered that hydrochar, the biochar made from hydrothermally processed poultry litter, can be used as an environmental adsorbent for effectively removing harmful chemicals such as endocrine disrupting chemicals and estrogens. Production of these biochars and their blends leads to an alternative use of agricultural byproducts that can increase soil carbon sequestration and water storage, provide essential plant nutrients, and reduce levels of contaminants in soils.

Cao, X., Ro, K.S., Chappell, M., Li, Y., and Mao, J. 2011. Chemical structures of swine-manure chars produced under different carbonization conditions investigated by advanced solid-state 13C nuclear magnetic resonance (NMR) spectroscopy. Energy and Fuels 25:388-397.

Sun, K., Ro, K.S., Guo, M., Novak, J.M., Mashayekhi, H., and Xing, B. 2011. Sorption of bisphenol A, 17a-ethinyl estradiol and phenanthrene on thermally and hydrothermally produced biochars. Bioresource Technology 102:5757-5763.

Revegetation of barren asbestos-emitting Superfund site using compost and gypsum. The Vermont Asbestos Group Superfund site is 300 acres of barren ground serpentinite rock that has remained barren for more than 50 years due to severe infertility and poor soil properties. Methods to achieve persistent revegetation of such sites are being tested in cooperation with the EPA and the Vermont Department of Environmental Conservation. On the basis of previous success using composts and biosolids in remediation of metal toxic soils, revegetation mixtures were designed and tested to alleviate both infertility and toxicity of the soils with grasses and legumes. Mixtures of manure composts with flue gas desulfurization-gypsum and nitrogen-phosphorus-potassium (NPK) resulted in immediate and strong revegetation in a greenhouse pot trial with potential cover crops. Two available commercial composts in northern Vermont were mixed with gypsum, NPK, and limestone for a field test of revegetation during August 2010, and extensive vegetative cover was obtained and is persistent. Alternative treatment by leveling and cover with 24 inches of topsoil was estimated to cost $200 million, whereas use of surface-applied compost mixtures should cost no more than $1.5 million and use locally available resources without removing topsoil from other locations.

Chaney, R.L., Newhart, G., Mahoney, M., and Schmeltzer, J. 2011. Ecosystem restoration of the long-barren serpentine mine waste at the Vermont Asbestos Group Mine Site. Proceedings of the 2011 International Phytotechnology Society Conference, Sept. 12-15. Portland, OR. ARS-266409.

Zinc toxicity to forest spreading near closed zinc smelter in Palmerton, Pennsylvania. Severe zinc phytotoxicity killed more than 1,000 acres of forest near a zinc smelter at Palmerton, Pennsylvania, which closed in 1980. Where soil amendments were used, effective revegetation has persisted and become more diverse. However, where no remediation activities have taken place, extreme soil acidity has slowly become worse due to acidic rainfall. Investigations were undertaken to evaluate understory vegetation in remaining forest on the south side of Blue Mountain. Based on analysis of soils and plants, and measurement of seedlings present, it is clear that soil toxicity is preventing establishment of all plant species under existing trees. Plant analysis shows that both zinc and manganese emitted by the smelter are contributing to toxicity and death of seedlings. Remediation tests using limestone and fertilizer show that the persistent toxicity of these extremely acidic soils can be reversed by raising soil pH. But in the absence of human action, continuing acidic rainfall will likely cause an increase in the barren area due to metal toxicity.

Beyer, W.N., Green, C.E., Beyer, M., and Chaney, R.L. 2013. Phytotoxicity of zinc and manganese to seedlings grown in soil contaminated by zinc smelting. Environmental Pollution 179:167-176.

Beyer, W.N., Krafft, C., Klassen, S., Green, C.E., and Chaney, R.L. 2010. Relating zinc contamination from smelting to injury to the forest near Palmerton, PA. Archives of Environmental Contamination and Toxicology 61:376-388. ARS-251929.

Gu, H.-H., Qiu, H., Tian, T., Zhan, S.-S., Deng, T.-H.-B., Wang, S.-Z., Tang, Y.-T., Chaney, R.L., and Qiu, R.-L. 2011. Effects of fly ash and steel slag on heavy metal accumulation in *Oryza sativa* L. planted on multi-metal contaminated acidic soil. Chemosphere 83:1234-1240.

Gu, H.H., Zhan, S.-S., Wang, S.-Z., Tang, Y.-T., Chaney, R.L., Fang, X.-H., Cai, X.-D., and Qiu, R.-L. 2011. Silicon-mediated amelioration of zinc toxicity in rice (*Oryza sativa* L.) seedlings. Plant Soil 350:193-204.

Khaokaew, S., Chaney, R.L., Landrot, G., Ginder-Vogel, M., and Sparks, D.L. 2011. Speciation and release kinetics of cadmium in an alkaline paddy soil under various flooding periods and draining conditions. Environmental Science and Technology 45:4249-4255.

Khaokaew, S., Landrot, G., Chaney, R.L., Pandya, K., and Sparks, D.L. 2012. Speciation and release kinetics of zinc in contaminated paddy soils. Environmental Science and Technology 46:3957-3963.

Siebielec, G., and Chaney, R.L. 2012. Testing amendments for remediation of military range contaminated soil. Journal of Environmental Management 108:8-13.

Phyto-ruminal bioremediation of soil tri nitro toluene (TNT). Explosive contaminated soils pose an environmental risk and require remediation. The ability of plants to bioremediate and phytoextract soil TNT was evaluated in greenhouse tests with ^{C}14-labeled TNT and three grass species. Plant roots and soil microbes caused extensive conversion of soil TNT into covalently linked bound residue in the soil or in plant roots, whereas repeated plant harvests found significant amounts of ^{C}14 from the TNT in plant shoots over the year-long study. No free TNT remained in soil or plants, showing the ability of soil and plants to achieve remediation of soil TNT risks. The plant-uptake research is linked to studies in which TNT was fed to sheep to evaluate metabolism of TNT by rumen organisms. Together, phytoremediation and ruminal-bioremediation are highly effective in reducing environmental risk from soil TNT.

Duringer, J.M., Craig, A.M., Smith, D.J., and Chaney, R.L. 2010. Uptake and transformation of soil [14C]-trinitrotoluene by cool-season grasses. Environmental Science and Technology 44:6325-6330.

Eaton, H.L., DeLorme, M., Chaney, R.L., and Craig, A.M. 2010. Identification of ovine ruminal microbes capable of biotransforming hexahydro-1,3,5-trinitro-1,2,5-triazine (RDX). Microbial Ecology 62:274-286.

Smith, D.J., Craig, A.M., Duringer, J.M., and Chaney, R.L. 2008. Absorption, tissue distribution, and elimination of residues after 2,4,6-trinitro[14C]toluene administration to sheep. Environmental Science and Technology 42:2563-2569.

Reducing bioavailability of soil dichloro diphenyl trichloroethane (DDT) to earthworms using compost and plants. Old orchards and other land may contain excessive residues of DDT and dichlorodiphenyldichloroethylene (DDE) from historic pesticide sprays. Because earthworms bioaccumulate DDE from soils, and some birds and small mammals ingest earthworms in large amounts, the most limiting risk pathway for soil DDE is earthworm bioaccumulation that might harm wildlife. Old orchard soils at Beltsville Agricultural Research Center contain sufficient DDE to require removal or other remediation at great expense, so testing the use of soil amendments to reduce earthworm DDT and DDE bioaccumulation was undertaken. Soils rich in DDT and DDE were collected from the field for a growth chamber test using Lumbricus terrestris earthworms, which require cool temperatures for full activity in soils. Several composts of manure and biosolids, and pine wood biochar were applied, and pots were planted with orchardgrass or not planted to determine whether plants could reduce DDE bioaccumulation as others have suggested. All of the composts and biochar significantly reduced DDE bioaccumulation by the earthworms during a 45-day exposure period after the plants were well established. No unusual metal accumulation by the earthworms was observed, indicating the value of the overall remediation treatment. Results were so successful that field tests to verify the pot experiments were funded. Complementary tests of DDX (the sum of DDT and its degradation products) and DDE bioavailability tests showed the strong ability of these physical chemical tests to predict earthworm bioaccumulation of DDT, DDE, and dieldrin. The newly developed test will provide information to industries and the EPA regarding reclamation of contaminated sites.

Andrade, N.A., Centofanti, T., McConnell, L.L, Hapeman, C.J., Torrents, A., Nguyen, A., Beyer, W.N., Chaney, R.L., Novak, J.M., Anderson, M.O., and Cantrell, K.B. 2013. Utilizing thin-film solid-phase extraction to assess the effect of organic carbon amendments on the bioavailability of DDT and dieldrin to earthworms. Submitted to Environmental Pollution.

Chemical species of nickel in xylem exudate of Alyssum corsicum. Using the nickel hyperaccumulator plant *Alyssum corsicum* to phytoextract nickel from mineralized or contaminated soils offers a commercial alternative to traditional mining, but via agricultural technology. A better understanding of how these plants achieve such remarkable accumulation and transport of nickel from soil to leaves is expected to aid in improving this technology or allow eventual transfer of genes to higher-yielding crop plants. Earlier published work suggested that nickel being translocated to plant shoots in the xylem fluid was predominantly chelated by histidine, but this was based on short-term studies and only in solution-grown plants. Several nickel hyperaccumulator *Alyssum* species were grown in nutrient solutions or in serpentine soils for 6 weeks before the stem was cut and xylem exudate collected for 1 hour. Modern analytical

methods allowed reliable detection of organic and amino acids under steady state hyperaccumulating conditions. Exudate nickel was commonly 3 mM; whereas histidine, citric acid, malic acid, and nicotianamine, the amino and organic acids previously reported to possibly be important chelators of nickel in these plants were typically no more than 0.10 mM, showing that nickel in xylem exudate is mostly not chelated but moves as a free cation. These findings support other research that suggests that the free cation is transferred across plant membranes by protein transporters. Similar results were found for six *Alyssum* hyperaccumulator species, and for both solution- and soil-grown plants, clearly contradicting previous reports on this topic.

Broadhurst, C.L., Tappero, R.V., Maugel, R.V., Erbe, E.F., Sparks, D.L., and Chaney, R.L. 2009. Nickel and manganese accumulation, interaction and localization in leaves of the Ni hyperaccumulators *Alyssum murale* and *Alyssum corsicum*. Plant and Soil 314:35-48.

Cabello-Conejo, M.I., Centofanti, T., Kidd, P.S., Prieto-Fernandez, A., and Chaney, R.L. 2013. Evaluation of plant growth regulators to increase Ni phytoextraction by *Alyssum* species. International Journal of Phytoremediation 15(4):365-375.

Cassina, L., Tassi, E., Morelli, E., Giorgetti, L., Remorini, D., Massai, R., Chaney, R.L., and Barbafieri, M. 2011. Exogenous cytokinin treatments of a Ni hyper-accumulator, *Alyssum murale*, grown in a serpentine soil: implications for phytoextraction. International Journal of Phytoremediation 13:(S1):90-101.

Centofanti, T., Siebecker, M.G., Chaney, R.L., Davis, A.P., and Sparks, D.L. 2012. Hyperaccumulation of nickel by *Alyssum* species is related to solubility of Ni mineral species. Plant and Soil 359:71-83.

Centofanti, T., Tappero, R.V., Davis, A.P., and Chaney, R.L. 2010. Chelator-buffered nutrient solution is ineffective in extracting Ni from seeds of *Alyssum*. International Journal of Phytoremediation 13:434-440.

Chaney, R.L., Broadhurst, C.L., and Centofanti, T. 2010. Phytoremediation of soil trace elements. In: Hooda P. (Ed.), *Trace Elements in Soils.* Oxford, UK: Blackwell; pp. 311-352.

Chaney, R.L., Fellet, G., Torres, R., Centofanti, T., Green, C.E., and Marchiol, L. 2009. Using chelator-buffered nutrient solutions to induce Ni-deficiency in the Ni-hyperaccumulator *Alyssum murale*. Northeastern Naturalist 16(Special Issue 5):215–222.

Fellet, G., Centofanti, T., Chaney, R.L., and Green, C.E. 2009. NiO(s) (bunsenite) is not available to *Alyssum* species. Plant and Soil 319:219-223.

McNear Jr., D.H., Chaney, R.L., and Sparks, D.L. 2010. The metal hyperaccumulator *Alyssum murale* uses nitrogen and oxygen donor ligands for Ni transport and storage. Phytochemistry 71:188-200.

Beneficial use of nickel hyperaccumulator plant as a nickel fertilizer. Research by ARS pecan nutritionists showed severe nickel deficiency has occurred in pecans in the United States, and nickel sulfate is marketed as a nickel fertilizer. Research was conducted to evaluate the use of nickel extracted by *Alyssum* nickel-hyperaccumulator biomass as an alternative nickel fertilizer. The *Alyssum* extract was just as effective as the nickel sulfate chemical and could be produced at far lower cost. This use of nickel salt and *Alyssum* extract or biomass is the subject of an Australian patent issued in 2010. Use of ground biomass to fertilize pecan and other crops that respond to fertilizer nickel could become an organic farming practice.

Wood, B.W., Chaney, R.L., and Crawford, M. 2006. Correcting micronutrient deficiency using metal hyper accumulators: *Alyssum* biomass as a natural product for nickel deficiency correction. HortScience 41:1231-1234.

Phytoextraction of cadmiumfrom soils containing excessive biosolids-applied cadmium. **E**xcessive cadmium in some historically biosolids-amended soils requires remediation before alternative land use may be permitted. ARS tested phytoextraction of cadmium from soils from the Metropolitan Water Reclamation of Greater Chicago. Swiss chard grown on the soils accumulated cadmium levels that highly exceeded international standards for cadmium in leafy vegetable crops, especially if the soils were acidified. Phytoextraction with cadmium-accumulating rice cultivars was unsuccessful under aerobic soil management needed for useful cadmium phytoextraction. Three newly identified Chinese cadmium hyperaccumulator herbaceous species were grown on the test soils, but either they did not phytoextract useful levels of cadmium, or they suffered phytotoxicity from metals other than cadmium and zinc in the soils, for which these species were tolerant. A corn inbred, B37, shown to accumulate much more cadmium than other corn inbreds was also tested in these soils and this plant grew well on the high metal soils. Because useful phytoextraction requires harvestable plant biomass rich in cadmium, corn appears to offer more effective annual cadmium removal than the other species tested. *Thlaspi* accumulated cadmium up to 900 mg/kg in shoots, but has a low yield and is short, making biomass harvest difficult. Even corn inbreds with cadmium at 40 mg/kg dry weight grown as a double crop when shoot biomass is maximum, would offer higher annual cadmium removal than other plants tested, although breeding to improve *Thlaspi* may offer more effective cadmium phytoextraction technology. Growth of corn inbred B37 on acidified soils is being undertaken, including a treatment in which normal subsoil is included below the high metal topsoil so that roots can obtain adequate iron using roots below the metal-rich depth. A report on the funded studies was submitted to the sponsor.

Broadhurst, C.L., Chaney, R.L., Davis, A.P., Cox, A., Kumar, K., Reeves, R.D., and Green, C.E. 2013. Growth and cadmium phytoextraction by Swiss chard, corn, rice, *Noccaea caerulescens* and *Alyssum murale* in pH adjusted biosolids amended soils. International Journal of Phytoremediation DOI:10.1080/15226514.2013.828015.

Simmons, R.W., Chaney, R.L., Angle, J.S., Kruatrachue, M., Klinphoklap, S., Reeves, R.D., and Bellamy, P. 2013. Towards practical cadmium phytoextraction with *Thlaspi caerulescens*. International Journal of Phytoremediation. In press.

Characterized the bioaccessibility of lead in urban garden soils. Urban soils are commonly contaminated with lead, zinc, and cadmium from both aerosol emissions and housepaint. Because soil ingestion can cause children to absorb excessive lead, the bioavailability and bioaccessibility of soil lead was examined using a new chemical extraction designed to correlate with bioavailability in test animals. This kind of chemical extraction is called bioaccessibility. Soil samples from orchards and long-term gardens in Baltimore, Maryland, and Washington, D.C., were tested for total and bioaccessible lead. The fraction of total lead from the garden soils that was bioaccessible was much less than had been found in mine and smelter contaminated soils, or the orchard soils. The regular addition of phosphate and compost to garden soils, plus regular tillage and cropping, hasten formation of low bioavailaility lead compounds in garden soils, causing the lead in garden soils to have lower risk than has generally been considered for lead-contaminated soils based on an EPA study of mine and smelter contaminated soils.

Scheckel, K.G., Chaney, R.L., Basta, N.T., and Ryan, J.A. 2009. Advances in assessing bioavailability of metal(loid)s in contaminated soils. Advances in Agronomy 104:1-52.

Zia, M.H., Codling, E.E., Scheckel, K.G., and Chaney, R.L. 2011. In-vitro and In-vivo approaches for the measurement of oral bioavailability of lead (Pb) in soil: a critical review. Environmental Pollution 159:2320-2327.

Biosolids-applied cadmium remains exchangeable in soils but has low phytoavailability due to the matrix of biosolids. Concerns have been raised for decades about possible excessive food-chain transfer of cadmium applied to soils in biosolids and other soil amendments. Applied cadmium remains in the soils for centuries, but earlier studies suggested that the inorganic matrix (iron and manganese oxides) substantially reduced the potential for plant accumulation of soil cadmium, and that this ability persisted. To test this concept soils were obtained from long-term biosolids-amended field plots with known application times and rates. All soils were brought to pH 6.5, and stable isotope cadmium was added at four rates. Plant uptake was a simple linear function of the added cadmium. The slope of this uptake was substantially lower for biosolids-amended soils (up to 10-fold) than for control soils from each of three locations where soils were obtained. Results are explained by the persistence of applied cadmium in adsorbed forms (i.e., it remains labile), but having lower phytoavailability because of the stronger adsorption of cadmium by the amended soils. A higher cumulative biosolids application rate reduced the slope for uptake of the added cadmium. The stable isotope confirmed that three rates of biosolids-applied cadmium remained available to the plant, but another biosolid had low lability. These findings confirm that the inorganic biosolids matrix strongly contributes to reducing the potential

for risk from biosolids-applied cadmium. These findings also apply to other elements from biosolids (e.g., zinc, copper, lead).

Chaney, R.L. 2010. Cadmium and zinc. In: Hooda P. (Ed.), *Trace Elements in Soils.* Oxford, U.K.: Blackwell; pp. 409-439.

Chaney, R.L. 2012. Food safety issues: mineral and organic fertilizers. Advances in Agronomy 117:51-116.

Kukier, U., Chaney, R.L., Ryan, J.A., Daniels, W.L., Dowdy, R.H., and Granato, T.C. 2010. Phytoavailability of cadmium in long-term biosolids amended soils. Journal of Environmental Quality 39:519-530.

Added zinc fertilizer plus limestone can reduce potential for lettuce uptake of cadmium from cadmium-mineralized natural California soils. Certain soils in California became cadmium-enriched from parent materials that were originally derived from marine shale deposits. These soils had only normal zinc levels, so the cadmium enrichment/mineralization was very different from most soil cadmium that had been previously studied. Because the soils are within California's valuable vegetable production region, studies were undertaken to find a method to reduce the potential for cadmium uptake by cadmium-accumulating crops such as Romaine lettuce and spinach. Adding limestone, which can greatly reduce cadmium accumulation by lettuce in soils that have been contaminated with zinc mine waste did not reduce cadmium accumulation. Taking previous studies further, a combination of limestone and zinc fertilizer was tested; liming can reduce zinc uptake, which can induce the plant to more strongly to take up zinc, but because cadmium is transported on the same carrier in roots as zinc, liming increased rather than reduced cadmium uptake. Addition of zinc along with limestone (to make the soil calcareous) caused a great reduction in lettuce cadmium, to below Codex (International food safety standards) limits in leafy vegetables. Field testing is needed to verify that this treatment will persistently reduce cadmium accumulation in lettuce and spinach. Lettuce with cadmium more than eight times the Codex limit have been observed in field grown crops on such soils.

Chaney, R.L., Green, C.E., Ajwa, H., and Smith, R. 2009. Zinc fertilization plus liming to reduce cadmium uptake by Romaine lettuce on Cd-mineralized Lockwood soil. Proceedings of the International Plant Nutrition Colloquium XVI (Aug. 25-28, 2009, Sacramento, CA); Paper 1252.

Chen, W., Li, L., Chang, A.C., Wu, L., Chaney, R.L., Smith, R., and Ajwa, H. 2009. Characterizing the solid-solution partitioning coefficient and plant uptake factor of As, Cd, and Pb in California croplands. Agricultural Ecosystems and the Environment 129:212-220.

Problem Statement 4B: *Increase Understanding of the Risks and Benefits of Using Byproducts in Agriculture and Horticulture.*

The U.S. Environmental Protection Agency is actively encouraging industrial materials recycling, with regulations having been adopted at the State level. At this time, State regulatory agencies lack evaluation tools for environmental acceptability of beneficial use of these

byproducts in agriculture or horticulture. ARS is providing critical information about constituent phyto- and bio-availability in byproduct amendments, and how these data can be used by State regulatory agencies to conduct pathway risk assessments and use decisions.

Risk assessment of spent foundry sands in soil-related applications. Each year, up to 10 million tons of spent foundry sands (SFS) generated in the United States are destined for disposal in landfills due to their assumed toxicity, but tests of SFS as a soil amendment showed that they did not pose a toxicity risk to either plants or earthworms. A comprehensive risk assessment conducted in cooperation with the EPA revealed that spent sands from iron, steel, and aluminum casting industries were low enough in trace element and toxic contents that they could be safely used as soil amendments or as a component of manufactured soils. The assessment considered multiple exposure routes to humans, livestock, wildlife, and soil organisms. Instead of disposal in landfills, use of SFS in both agriculture and horticulture will provide significant environmental benefits and savings to numerous industries.

Dungan, R.S. 2008. The characterization of trace metals and organics in spent foundry sands over a one-year period. Journal of Residuals Science & Technology 5(3):111-125.

Dungan, R.S., Huwe, J.K., and Chaney, R.L. 2009. Concentrations of PCDD/PCDFs and PCBs in spent foundry sands. Chemosphere 75:1232-1235.

De Koff, J.P., Lee, B.D., and Dungan, R.S. 2008. Amelioration of physical strength in waste foundry green sands for reuse as a soil amendment. Journal of Environmental Quality 37:2332-2338.

U.S. Environmental Protection Agency. 2012. Risk assessment of spent foundry sands in soil-related applications, post peer review draft. Washington, D.C.: U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery; October.

Risk assessment for beneficial use of flue gas desulfurization (FGD)-gypsum in agriculture. ARS scientists and others have been conducting research to evaluate the beneficial use of FGD-gypsum in agriculture. Ultimately, the adoption of FGD-gypsum use will depend on Beneficial Use Designation at the State level. ARS is cooperating with the EPA in conducting a full risk evaluation of this use to provide information needed at the State level to make regulatory decisions about FGD-gypsum use as fertilizer and soil conditioner. The electrical generating industry, which manufactures FGD-gypsum while removing sulfur dioxide (SO_2) from exhaust gases, now removes fly ash before removing SO_2, allowing the production of FGD-gypsum with very low levels of trace elements compared with earlier products. Field tests have been conducted to assess the ability of FGD-gypsum to reduce the runoff of phosphate from soils including soils amended with poultry litter on the surface of hay fields. To date, research has shown that application of FGD gypsum can significantly reduce runoff phosphorus and arsenic. Other research has not found adverse effects of soils amended with FGD-gypsum compared with unamended soils. In cooperative field tests, ARS and EPA have generated large numbers of water, soil, and plant samples. These samples are being tested using EPA-required procedures,

which are highly time-consuming. Several additional months are required to complete the analysis of samples from the completed field experiments. Simulated rainfall runoff water samples were analyzed for chromate and mercury shortly after generation to meet EPA requirements; no runoff water samples contained unallowable levels of mercury or chromate. These findings will provide EPA with additional information on the utilization of FGD-gypsum in agriculture.

Dungan, R.S., Chaney, R.L., Basta, N., Dayton, E., Taylor, T., and Davis, C. 2010. Risk characterization of spent foundry sands in soil-related applications. In press. [ARS-227029].

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APPENDIX 1

National Program 214 – Agricultural and Industrial Byproducts

ACCOMPLISHMENT REPORT 2009-2013

Research Projects in NP 214

1245-12000-040-00D
Developing beneficial uses of agricultural, industrial, and municipal byproducts; Eton Codling (P) and Rufus Chaney; Beltsville, Maryland.

1245-12630-005-00D
Developing analytical and management strategies to improve crop utilization of manure carbon, nitrogen, and phosphorus and reduce losses to the environment; Thanh Dao (P), Eton Codling, and John Meisinger; Beltsville, Maryland.

1245-12630-006-00D
Biological treatment of manure and organic residuals to capture nutrients and transform contaminants; Walter Mulbry III (P) and Clifford Rice; Beltsville, Maryland.

3620-63000-005-00D
Understanding the role of commensal anaerobic bacteria in odor, emissions, and antibiotic resistance from stored livestock manure; Terence Whitehead (P) and Michael Cotta; Peoria, Illinois.

3625-31000-004-00D
Animal and manure management for sustainable production and reduced environmental impact; Brian Kerr (P), Brad Bearson, Jerry Hatfield, and Cherie Zeimer; Ames, Iowa.

3655-12630-003-00D
Improvement of dairy forage and manure management to reduce environmental risk; William Jokela (P), Mark Borchardt, Wayne Coblentz, Mark Powell, Michael Russelle, and Peter Vadas; Madison, Wisconsin.

5310-32000-003-00D
Protection of food and water supplies from pathogen contamination; Abasiofiok Ibekwe (P) and Scott Bradford; Riverside, California.

5368-63000-001-00D
*Assessing atmospheric emissions from concentrated animal feeding operations in the Pacific Northwes*t; Robert Dungan (P), David Bjorneberg, and April Leytem; Kimberly, Idaho.

5438-41630-001-00D
Management of manure nutrients, environmental contaminants, and energy from cattle and swine production facilities; Bryan Woodbury (P), Roger Eigenberg, and Mindy Spiehs; Clay Center, Nebraska.

* Projects are listed and organized in Appendixes 1 and 2 according to the ARS project number used to track projects in the Agency's internal database. A (P) after a scientist's name indicates the project's principal investigator.

5440-12630-001-00D
Environmentally sound manure management for reduction of gas emissions, nutrients, and pathogens; Daniel Miller (P), Lisa Durso, John Gilley, and Brian Weinhold; Lincoln, Nebraska.

6209-31630-003-00D
Develop technologies to protect air quality, maintain production efficiency and enhance use of manure from Southern Great Plains beef & dairy agriculture; Noel Cole (P) and Richard Todd; Bushland, Texas.

6226-63000-003-00D
Manure management strategies to improve air and water quality; Philip Moore Jr. (P) and Ann Donoghue; Fayetteville, Arkansas.

6406-12630-006-00D
Safe management and use of manure, biosolids, and industrial byproducts; Johnie Jenkins (P), Ardeshir Adeli, John Brooks, Mike McLaughlin, Dana Miles, John Read, and Haile Tewolde; Mississippi State, Mississippi.

6420-12000-010-00D
Using agricultural and industrial byproducts to improve crop production systems and environmental quality; Henry Torbert III (P), Dexter Watts, and Thomas Way; Auburn, Alabama.

6445-12630-004-00D
Efficient management and use of animal manure to protect human health and environmental quality; Karamat Sistani (P), Carl Bolster, Kimberly Cook, John Loughrin, Nanh Lovanh, and Philip Silva; Bowling Green, Kentucky.

6612-32630-003-00D
Survival and transport of pathogens from animal production systems within landscapes of the southeastern USA; Michael Jenkins (P), Dinku Endale, and Harry Schomberg; Athens, Georgia.*

6657-13630-005-00D
Innovative bioresource management technologies for enhanced environmental quality and value optimization; Ariel Szogi (P), Keri Cantrell, Thomas Ducey, Patrick Hunt, Jeff Novak, Kyoung Ro, and Matias Vanotti; Florence, South Carolina.

** This project was terminated in 2012 due to the closure of the Athens location, but contributed to the current Action Plan.*

APPENDIX 2

National Program 214 – Agricultural and Industrial Byproducts

ACCOMPLISHMENT REPORT 2009-2013

Publications by Research Project

1245-12000-040-00D
Developing beneficial uses of agricultural, industrial, and municipal byproducts; Eton Codling (P) and Rufus Chaney; Beltsville, Maryland.

Heighton, L.P., Zimmerman, M., Rice, C., Codling, E.E., Tossell, J., Schmidt, W.F. 2012. Identification and quantification of inositol hexa-kis phosphate (IHP) in environmental samples at neutral pH using electro-spray ionization and raman spectroscopy. Journal of Agricultural and Food Chemistry 2:55-63.

Siebielec, G., Chaney, R.L. 2012. Testing amendments for remediation of military range contaminated soil. Journal of Environmental Management 108:8-13.

Eaton, H.L., De Lorme, M., Chaney, R.L., Craig, A.M. 2011. Identification of ovine ruminal microbes capable of biotransforming hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). Microbial Ecology 62:274-286.

Codling, E.E., Raja, A.W. 2012. Long term effects of fluidized bed material applied at disposal levels on soil metals and nutrient concentrations as related to soil depth. Soil Science 43:1720-1731.

Schmidt, W.F., Mookherji, S., Crawford, M.A. 2009. Unit cell volume and liquid phase immiscibility in oleate-stearate lipid mixtures. Chemistry and Physics of Lipids 158:10-15.

Dungan, R.S., Dees, N.H. 2009. The characterization of total and leachable metals in foundry molding sands. Journal of Environmental Management 90:539-548.

De Koff, J.P., Lee, B.D., Dungan, R.S. 2008. Amelioration of physical strength in waste foundry green sands for reuse as a soil amendment. Journal of Environmental Quality 37:2332-2338.

Kim, J., Dungan, R.S., Crowley, D. 2008. Microarray analysis of bacterial diversity and distribution in aggregates from a desert agricultural soil. Biology and Fertility of Soils 44:1003-1011.

Cassina, L., Tassi, E., Morelli, E., Giorgetti, L., Remorini, D., Massai, R., Chaney, R.L., Barbafieri, M. 2011. Exogenous cytokinin treatments of a Ni hyper-accumulator, Alyssum murale, grown in a serpentine soil: Implications for phytoextraction. International Journal of Phytoremediation 13(S1):90-101.

Khoshgoftarmanesh, A.H., Taheri, S., Shariatmadari, H., Chaney, R.L. 2011. Kinetics of zinc release from ground tire rubber and rubber ash in a calcareous soil as alternatives to Zn fertilizers. Soil Science and Plant Nutrition 341:89-97.

Beyer, W.N., Krafft, C., Klassen, S., Green, C.E., Chaney, R.L. 2011. Relating forest injury near Palmerton, PA to zinc contamination from smelting. Environmental Toxicology and Chemistry 61:376-388.

Duringer, J.M., Craig, A.M., Smith, D.J., Chaney, R.L. 2010. Uptake and transformation of soil [14C]-trinitrotoluene by cool-season grasses. Environmental Science and Technology 44:6325-6330.

Centofanti, T., Tappero, R.V., Davis, A.P., Chaney, R.L. 2010. Chelator-buffered nutrient solution is ineffective in extracting Ni from seeds of Alyssum. International Journal of Phytoremediation 13:434-440.

Projects are listed and organized in Appendixes 1 and 2 according to the ARS project number used to track projects in the Agency's internal database. A (P) after a scientist's name indicates the project's principal investigator.
* *Projects with asterisks were terminated during the 5-year span covered by this report, but contributed to the current Action Plan.*

Scheckel, K.G., Chaney, R.L., Basta, N.T., Ryan, J.A. 2010. Advances in Assessing Bioavailability of Metal(loid)s in Contaminated Soils. Advances in Agronomy 17:409-439.
Kukier, U., Chaney, R.L., Ryan, J.A., Daniels, W.L., Dowdy, R.H., Granato, T.C. 2010. Phytoavailability of Cadmium in Long-Term Biosolids Amended Soils. Journal of Environmental Quality 39:519-530.
Mcnear, D.H., Chaney, R.L., Sparks, D.L. 2010. The Metal Hyperaccumulator Alyssum murale Uses Nitrogen and Oxygen Donor Ligands for Ni Transport and Storage. Phytochemistry 71:188-200.
Khoshgoftarmanesh, A.H., Eshghizadeh, H.R., Chaney, R.L. 2010. Using acid-washed waste tire rubber in soilless media for tomato production. Journal of Plant Nutrition 7:69-72.
Chaney, R.L., Fellet, G., Torres, R., Centofanti, T., Green, C.E., Marchiol, L. 2009. Using Chelator-Buffered Nutrient Solutions to Induce Ni-Deficiency in the Ni-Hyperaccumulator Alyssum murale. Northeastern Naturalist 16 (Special Issue 5):215-222.
Fellet, G., Centofanti, T., Chaney, R.L., Green, C.E. 2009. NiO(s) (Bunsenite) is not Available to Alyssum species. Plant and Soil Journal 319:219-223.
Broadhurst, C.L., Tappero, R.V., Maugel, T.K., Erbe, E.F., Sparks, D.L., Chaney, R.L. 2008. Nickel and Manganese Accumulation, Interaction and Localization in Leaves of the Ni Hyperaccumulators Alyssum murale and Alyssum corsicum. Plant and Soil Journal 314:35-48.
Chaney, R.L., Li, Y., Chen, K., Angle, J., Baker, A.J. 2008. Effects of Cadmium on Nickel Tolerance and Accumulation in Alyssum species and Cabbage Grown in Nutrient Solution. Plant and Soil Journal 311:131-140.

1245-12630-005-00D

Developing analytical and management strategies to improve crop utilization of manure carbon, nitrogen, and phosphorus and reduce losses to the environment; Thanh Dao (P), Eton Codling, and John Meisinger; Beltsville, Maryland.

Dao, T.H., Cao, Q., Khosla, R., Cui, Z., Chen, X., Miao, Y. 2012. Quantifying spatial variability of indigenous nitrogen supply for precision nitrogen management in small scale intensive farming. Precision Agriculture 13(1):45-61.
Dao, T.H., Miao, Y., Zhang, F.S. 2011. X-ray fluorescence spectrometry-based approach to precision management of soil phosphorus and other mineral macronutrients. Agricultural Journal 103:1724-1733.
Palmer, R.E., Meisinger, J.J., Magette, W.L. 2011. Undisturbed soil columns for lysimetry I. Collection, field testing and construction. Applied Engineering in Agriculture 27(3):379-389.
Palmer, R.E., Hill, R.L., Meisinger, J.J., Magette, W.L. 2011. Undisturbed soil columns for lysimetry II. Miscible displacement and field evaluation. Applied Engineering in Agriculture 27(3):391-400.
White, K.E., Reeves, J.B., Coale, F.J. 2011. Mid-infrared diffuse reflectance spectroscopy for the rapid analysis of plant root composition. Geoderma 167:197-203.
Ahn, H., Smith, M.C., Ingram, S.K., White, J.W. 2010. Evaluation of biogas production by dry anaerobic digestion of switchgrass-animal manure mixtures. Applied Biochemistry and Biotechnology 160:965-975.
Pavinato, P.S., Dao, T.H., Rosolem, C.A. 2010. Tillage and phosphorus management effects on enzyme-labile bioactive phosphorus availability in Brazilian cerrado oxisols and temperature zone typic hapludults. Geoderma 156:207-215.
White, J.W., Coale, F.J., Sims, J., Shober, A.L. 2010. Phosphorus runoff from wastewater treatment biosolids and poultry litter applied to agricultural soils. Journal of Environmental Quality 39:314-323.
Fayer, R., Orlandi, P., Perdue, M.L. 2009. Virulence factor activity relationships for Hepatitis E and Cryptosporidium. Journal of Water and Health 7(1):55-63.
Kong, X., Dao, T.H., Qin, J., Qin, H. 2009. Effects of soil texture and land use interactions on organic carbon in soils in North China cities' urban fringe. Geoderma 154:86-92.
Reeves III, J.B. 2009. Does spectral format matter in diffuse reflection spectoscopy. Applied Spectroscopy 63:669-677.
Reeves III, J.B. 2009. Near- versus mid-infrared spectroscopy for soil analysis emphasizing carbon and laboratory versus on-site analysis: where are we and what needs to be done? Geoderma 158:3-14.

Rao, S.C., Dao, T.H. 2008. Relationships between immobilized phosphorus uptake in two grain legumes and soil bioactive p pools in fertilized and manure-amended soil. Agronomy Journal 100:1535-1540.

Heighton, L., Schmidt, W.F., Siefert, R.L. 2008. Kinetic and equilibrium constants of phytic acid, ferric and ferrous phytate derived from nuclear magnetic resonance spectroscopy. Journal of Agriculture and Food Chemistry 56:9543-9547.

1245-12630-006-00D

Biological treatment of manure and organic residuals to capture nutrients and transform contaminants; Walter Mulbry III (P) and Clifford Rice; Beltsville, Maryland

Chen, R., Yuea, Z., Deitza, L., Liu, Y., Mulbry III, W.W., Liao, W. 2012. Use of an algal hydrolysate to improve enzymatic hydrolysis of anaerobically digested fiber. Bioresource Technology. 108:149-154.

Lozano, N., Rice, C., Pagano, J., Zintek, L., Barber, L., Murphy, E.W., Nettesheim, T., Minarik, T., Schoenfuss, H. 2012. Tissue concentrations of organic contaminants in fish and their biological effects in a wastewater-dominated urban stream. Science of the Total Environment. 420:191-201.

Lozano, N., Rice, C., Ramirez, M., Torrents, A. 2012. Fate of triclosan and methyltriclosan in soil from biosolids application. Environmental Pollution. 160:103-108.

Mulbry III, W.W., Reeves III, J.B., Millner, P.D. 2012. Use of Mid- and Near-Infrared Spectroscopy to Track Degradation of Polyactide Eating Utensils and Containers During Composting. Internet Journal of Vibrational Spectroscopy. 109:93-97.

Adey, W., Kangas, P., Mulbry III, W.W. 2011. Algal turf scrubbing: cleaning surface waters with solar energy while producing a biofuel. Bioscience 61:434-441.

Ahn, H., Smith, M.C., Schmidt, W.F., Huda, M.S., Reeves III, J.B., Mulbry III, W.W. 2011. Biodegradability of injection molded bioplastics containing polylactic acid and poultry feather fiber. Bioresource Technology 102:4930-4933.

Bevacqua, C., Rice, C., Torrents, A., Ramirez, M. 2011. Steroid hormones in biosolids and poultry litter: A comparison of potential environmental inputs. Science of the Total Environment 409:2120-2126.

Ahn, H., Mulbry III, W.W., White, J.W., Ingram, S.K. 2010. Pile mixing increases greenhouse gas emissions during composting of dairy manure. Bioresource Technology 102:2904-2909.

Mulbry III, W.W., Kangas, P., Ingram, S.K. 2010. Scrubbing the Bay: Nutrient Removal Using Small Algal Turf Scrubbers on Chesapeake Bay Tributaries. Ecological Engineering 36:536-541.

Arikan, O., Mulbry III, W.W., Ingram, D.T., Millner, P.D. 2009. Minimally Managed Composting of Beef Manure at the Pilot Scale: Effect of Manure Pile Construction on Pile Temperature Profiles and the Fate of Oxytetracycline and Chlorotetracycline. Bioresource Technology 100:4447-4453.

Lozano, N., Rice, C., Ramirez, M., Torrents, A. 2009. Fate of triclosan in agricultural soils after biosolid applications. Chemosphere 78:760-766.

Mulbry III, W.W., Ingram, S.K., Buyer, J.S., Luthria, D.L. 2009. Extraction of fatty acids from dried freshwater algae using accelerated solvent extraction. Journal of the American Oil Chemists' Society 86:909-915.

Webber, D.F., Mickelson, S.K., Richard, T.L., Ahn, H. 2009. Effects of a livestock manure windrow composting site with a fly ash pad surface and vegetative filter strip buffers on sediment, nitrate, and phosphorus losses with runoff. Journal of Soil and Water Conservation 64(2):163-171.

Arikan, O., Mulbry III, W.W., Rice, C. 2008. Management of Antibiotic Residues from Agricultural Sources: Use of Composting to Reduce Chlortetracycline Residues in Beef Manure from Treated Animals. Journal of Hazardous Materials 164:483-489.

Glanville, T.D., Richard, T.L., Ahn, H., Shiers, L.E., Harmon, J.D. 2008. Soil contamination caused by emergency bio-reduction of catastrophic livestock mortalities. Journal of Water Air and Soil Pollution 198:285–295.

1265-12630-001-00D*

Developing tools to predict atmospheric fate of VOC & odorant emissions from ag operations; Laura McConnell (P), Cathleen Hapeman, and Walter Schmidt; Beltsville, Maryland.

Barth, E.F., Forbes, R., Clark, P., Foote, E., McConnell, L.L. 2010. Evaluation of odors associated with land application of biosolids. Journal of Residuals Science and Technology 7:73-80.

Sekyiamah, K., Kim, H., McConnell, L.L., Torrents, A., Ramirez, M. 2008. Identification of seasonal variations in volatile sulfur compound formation and emission from the secondary treatment system at a large wastewater treatment plant. Water Environment Research 80(12):2261-2267.

1265-63000-001-00D*

Prevalence and diversity of manure-associated pathogens in air and water; Daniel Shelton (P); Beltsville, Maryland.

Shelton, D.R., Karns, J.S., Sadeghi, A.M., Coppock, C.R., Pachepsky, Y.A. 2011. Relationship between eae and stx virulence genes and Escherichia coli in an agricultural watershed: Implications for irrigation water standards and leafy green commodities. Journal of Food Protection 74(1):18-23.

Zhang, L., Seagren, E.A., Davies, A.P., Karns, J.S. 2010. The capture and destruction of E. coli from simulated urban runoff using conventional bioretention media and iron oxide-coated sand. Water Environment Research 82:701-713.

Shelton, D.R., Karns, J.S., Park, C.H. 2008. A multiple protocol to improve diagnosis and isolation of shiga toxin-producing escherichia coli (stec) from human stool specimens. Diagnostic Microbiology and Infectious Disease 62(1):7-10. http://dx.DOI.org/10.1016/j.diagmicrobio.2008.05.001.

1915-12630-001-00D*

Nutrient cycling and utilization on organic dairy farms; Zhongqi He (P), John Halloran, Wayne Honeycutt, and Robert Larkin; Orono, Maine.

Fortuna, A., Honeycutt, C.W., Marsh, T.L., Griffin, T.S., Larkin, R.P., He, Z., Sistani, K.R., Albrecht, S.L., Woodbury, B.L., Torbert Iii, H.A., Powell, J.M., Hubbard, R.K., Eigenberg, R.A., Wright, R.J. 2011. Links among nitrification, nitrifier communities and edaphic properties in contrasting soils receiving dairy slurry. Journal of Environmental Quality 41:262-272.

He, Z., Zhang, H., Toor, G.S., Dou, Z., Honeycutt, C.W., Haggard, B.E., Reiter, M.S. 2010. Phosphorus Forms in Sequentially-Extracted Fractions of Biosolids and Broiler Litter. Soil Science 175:154-161.

Ohno, T., He, Z., Tazisong, I.A., Senwo, Z.N. Influence of Tillage, Cropping Management, and Nitrogen Source on Humic, Fulvic, and Water-Extractable Organic Matter Fractions: A Fluorescence Study. Soil Science 174:652-660.

He, Z., Endale, D.M., Schomberg, H.H., Jenkins, M. 2009. Total phosphorus, zinc, copper, and manganese concentrations in cecil soil through ten years of poultry litter application. Soil Science 174:687-695.

He, Z., Honeycutt, C.W., Griffin, T.S., Cade-Menun, B.J., Pellechia, P.J., Dou, Z. 2009. Phosphorus forms in conventional and organic dairy manure identified by solution and solid state P-31 NMR spectroscopy. Journal of Environmental Quality 38:1909-1918.

He, Z., Mao, J., Honeycutt, C.W., Ohno, T., Hunt, J.F., Cade-Menum, B.J. 2009. Characterization of plant-derived dissolved organic matter by multiple spectroscopic techniques. Biology and Fertility of Soils 45:609-616.

Waldrip-Dail, H., He, Z., Erich, M., Honeycutt, C.W. 2009. Soil phosphorus dynamics in response to poultry manure amendment. Soil Science 174:195-201.

He, Z., Tazisong, I.A., Senwo, Z.N., Honeycutt, C.W., Zhang, D. 2009. Nitrogen and phosphorus accumulation in pasture soil from repeated poultry litter application. Communications in Soil Science and Plant Analysis 40:587-599.

He, Z., Waldrip, H., Erich, M., Honeycutt, C.W., Senwo, Z.N. 2009. Enzymatic quantification of phytate in animal manure. Communications in Soil Science and Plant Analysis 40:566-575.

He, Z., Olk, D.C., Honeycutt, C.W., Fortuna, A. 2009. Enzymatically- and ultraviolet-labile phosphorus in humic acid fractions from rice soils. Soil Science 174(2):81-87.

Zhang, R., Wu, F., He, Z., Zheng, J. 2009. Phosphorus Composition in Lake Sediments From the Middle and Lower Reaches of Yangtze River Region and Southwestern China Plateau, China: a 31P NMR Study. Journal of Environmental Quality 38:353-359.

Tazisong, I.A., Senwo, Z.N., Taylor, R.W., He, Z. 2008. Hydrolysis of organic phosphates by commercially available phytases: Biocatalytic potentials and ion on their enzymatic activities. Journal of Food Agriculture and Environment 6:500-505.

He, Z., Honeycutt, C.W., Cade-Menun, B.J., Senwo, Z.N., Tazisong, I.A. 2008. Sequentially-Extracted Phosphorus from Poultry Litter and Soil: Enzymatic and 31P NMR Characterization. Soil Science Society of America Journal 72:1425-1433.

He, Z., Ohno, T., Wu, F., Olk, D.C., Honeycutt, C.W., Olanya, O.M. 2008. Capillary Electrophoresis and Fluorescence Excitation-Emission Matrix Spectroscopy for Characterization of Humic Substances. Soil Science Society of America Journal 72:1248-1255.

Burnett, S.E., Zhang, D., Stack, L.B., He, Z. 2008. Effects of Phosphorus on Morphology and Foliar Nutrient Concentrations of Hydroponically Grown Scaevola aemula R. Br. æWhirlwind BlueÆ. HortScience 43(3):902-905.

3620-63000-005-00D

Understanding the role of commensal anaerobic bacteria in odor, emissions, and antibiotic resistance from stored livestock manure; Terence Whitehead (P) and Michael Cotta; Peoria, Illinois.

Whitehead, T.R., Cotta, M.A. 2013. Stored swine manure and swine faeces as reservoirs of antibiotic resistance genes. Letters in Applied Microbiology 56:264-267.

Poulsen, H.V., Jensen, B.B., Finster, K., Spence, C., Whitehead, T.R., Cotta, M.A., Canibe, N. 2012. Microbial production of volatile sulphur compounds in the large intestine of pigs fed two different diets. Journal of Applied Microbiology 113:143-154.

Hamady, Z.Z., Scott, N., Farrar, M.D., Wadhwa, M., Dilger, P., Whitehead, T.R., Holland, K.T., Lodge, J.P., Carding, S.R. 2011. Treatment of colitis with a commensal gut bacterium engineered to secrete human TGF-beta1 under the control of dietary xylan. Inflammatory Bowel Diseases 17(9):1925-1935.

Whitehead, T.R., Cotta, M.A., Falsen, E., Moore, E., Lawson, P.A. 2011. *Peptostreptococcus russellii* sp. nov., isolated from a swine-manure storage pit. International Journal of Systematic and Evolutionary Microbiology 61(8):1875-1879.

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APPENDIX 3

National Program 214 – Agricultural and Industrial Byproducts

ACCOMPLISHMENT REPORT 2009-2013

Publications in Alphabetical Order by Lead Author

Abit Jr, S.M., Bolster, C.H., Peng, H., Walker, S. 2012. Investigating the role that biochar feedstock and pyrolysis temperature has on the transport behavior of *E. coli* in a biochar-amended soil under saturated and unsaturated conditions. Environmental Science and Technology 46:8097-8105.

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