United States Department of Agriculture

Research, Education & Economics

Agricultural Research Service

National Program Staff
December 2007

National Program 203 Air Quality Accomplishment Report 2002 – 2007

Table of Contents

Introduction

Air quality refers to the combination of physical, chemical, and biological constituents of air masses in the lower atmosphere with which humans, animals, plants, lands, and water bodies of the earth interact. These constituents may take the form of solids (such as suspended particulates), gases (such as oxygen and nitrogen), and or liquids (such as water droplets or vapor). The term air quality refers to the state of air with reference to its ability to maintain a high level of human health as the first priority, with secondary priorities associated with animal and environmental health. Air Quality was developed as a topic for an ARS National Program during 1997, and became a National Program during 1998.

This Accomplishment Report summarizes selected accomplishments that resulted from the ensuing research. These accomplishments are categorized in this report by the Program's major components:

The success of the Air Quality National Program, relative to the goals established in the Program's Action Plan, will be assessed by a panel of outside experts. An Executive Summary of their assessment report will be published on the ARS website during 2008 and will provide a basis on which to begin planning for a second 5-year research cycle in this National Program. For the next 5-year research cycle the Global Change National Program will be merged with the Air Quality Research Program and the Soil Resource Management Research Program to form the Soil and Air Resource Management National Program.

Agricultural air quality is emerging as an important issue to producers, concerned citizens, and those who create policy. The ARS Air Quality Program's vision is for Agricultural enterprises throughout the Nation free from air quality concerns. The research accomplishments reported by this report were conducted to make this vision a reality.

ARS is proud to submit this Accomplishment Report to the Assessment Panel, to our stakeholders and customers, and to the Nation. ARS National Program Staff is confident that the research performed under the Air Quality National Program reflects a productive research portfolio, given the funding levels involved. The Agency anticipates that the program will continue to serve as a source of innovation for our stakeholders, and looks forward to many future success stories and accomplishments.

Background

General

The Agricultural Research Service (ARS; http://www.ars.usda.gov/main/main.htm) is the intramural research agency for the United States Department of Agriculture (USDA; http://www.usda.gov/wps/portal/usdahome), and is one of four agencies of the Research, Education, and Economics USDA mission area. During 1998, ARS organized its research under a National Program structure to better manage and coordinate research efforts. These programs bring coordination, communication, and empowerment to the more than 1200 research projects carried out by ARS. Management of National Programs focuses on enhancing the relevance, quality, and impact of ARS research.

The Air Quality National Program (NP 203; http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=203) was formed with the mission to understand the processes affecting emissions of air pollutants from agricultural enterprises and the effects of air quality upon agriculture, to develop and test control measures, and to provide decision aids that will be useful in minimizing and reducing the emissions of agricultural air pollutants and predicting and mitigating the impacts of air quality upon agriculture. The Air Quality National Program mission follows the ARS Strategic Plan (http://www.ars.usda.gov/aboutus/docs.htm?docid=1766) which, in turn, is directed towards achieving the goals mandated by the USDA Research Education and Extension Mission Strategic Plan and the USDA Strategic Plan (http://www.usda.gov/ocfo/usdasp/usdasp.htm).

The boundaries of ARS national programs often overlap when working to solve agricultural problems and thus, many of the projects contributing to NP 203 also contribute to achieving goals of other programs. Air Quality research is very closely linked to other National Programs in the Natural Resources and Sustainable Agricultural Systems (NRSAS) program areas, specifically Water Availability & Watershed Management (NP 211); Soil Resource Management (NP 202); Global Change (NP 204); Rangeland, Pasture and Forages (NP 205); and Manure and Byproduct Utilization (NP 206). The Air Quality Program also links with National Programs in the Crop Production and Protection Area with Plant Biological and Molecular Processes (NP 302); and in the Nutrition, Food Safety/Quality Area with Quality and Utilization of Agricultural Products (NP 306) and Food Safety (Plant and Animal Products); NP 108). Descriptions of all of these programs can be found at on the ARS National Programs website (http://www.ars.usda.gov/research/programs.htm).

The goals of NP 203 not only support ARS priorities, but also strive to address problems of high national priority importance. Air quality has both local and global contexts. Odors emitted by a localized source, for example, may be readily detectable by humans within a relatively short distance as the compounds that are identified by the nose become dispersed. On the other hand, particulates of very small size may enter intercontinental air streams and travel around the globe, sometimes for years, as is exemplified by the colorful sunsets that follow periods of intense volcanic activity.

Agriculture is a necessary human activity that interacts with air; it both benefits from good quality air, and it contributes air pollutants. Agriculture needs air that is free of excessive amounts of such constituents as ozone, dust, suspended pesticides, and odors. But agriculture may also contribute these substances to the air in quantities that are offensive or even threatening to human and environmental health in downwind areas.

ARS has developed an Air Quality National Program because it believes that many problems associated with air quality degradation by agriculture can be reduced or eliminated through research to understand polluting processes, and application of that understanding to developing solutions. Similarly, it believes that air pollution impacts on agriculture can be resolved through research and development.

Planning, Review, and Implementation

Management of each of the ARS National Programs follows a 5-year program cycle consisting of planning, review, implementation, and assessment. During January 2000, ARS met with representatives of its customers and stakeholders in Sacramento, California, to explore problems associated with agriculture and air quality. This meeting was the first step towards developing a list of high-priority research needs and a research program to address those needs. An important source of input to the meeting was the Agricultural Air Quality Task Force (the Task Force), which had previously provided a list of research needs to the Secretary of Agriculture. The U.S. Environmental Protection Agency (EPA) has been actively seeking ARS research in several agricultural air quality topic areas so that it might base its regulations on scientifically sound data.

After the meeting, ARS research personnel met to begin the process of developing the research program, using all of the available inputs.

Problems Identified by Customers

Based on customer issues raised at the workshop, ARS research in agricultural air quality was organized into five categories, hereafter referred to as 'components' of the ARS Air Quality National Program:

Particulate Emissions: This component addresses particulate matter (PM) regulated under the National Ambient Air Quality Standards (NAAQS) which set maximum concentration limits for PM in the ambient air. PM is currently regulated in terms of particle of less than or equal to a nominal 10 and 2.5 micrometer aerodynamic equivalent diameter (AED), referred to as PM_{10} and $PM_{2.5}$, respectively.

Ammonia and Ammonia Emissions: Human activities have more than doubled the cycling of reactive nitrogen cycling through the world's ecosystems, causing a cascade of potentially negative environmental effects including excessive nitrogen enrichment of sensitive ecosystems, acid rain, particulate matter formation and visibility impairment. Ammonia is a major form of reactive nitrogen in the atmosphere and concentrated animal agriculture is a major source of ammonia. Ammonia is not a regulated criteria pollutant, but it is a precursor and component of secondary particulates ($PM_{2.5}$), which are regulated.

Malodorous Compounds: Although not regulated, offensive odors from animal production operations are a major nuisance and may have health impacts.

Ozone Impacts: The amount of ozone in the lower atmosphere is expected to increase with increasing mean ambient air temperatures. High concentrations of ozone in the lower atmosphere result in reduction of crop yields by up to 20%. Carbon dioxide (CO_2) may have a mitigating effect on these losses.

Pesticides and Other Synthetic Organic Chemicals: Volatilized pesticides are a complex of very fine liquid particulates and gaseous phase compounds, or may be attached to particulates from other agricultural or non-agricultural sources. Behavior of a pesticide in the environment is the result of many complex processes, mechanisms, and interactions that affect movement and transformation.

All components except Ozone Impacts focus on understanding and reducing emissions by agriculture. Ozone research will focus on protecting agricultural productivity from excessive ozone.

The division between the Air Quality National Program components is not always clear. Ammonia near the source of emission may be an odor issue, among others. It also often interacts with other pollutants to form particulates. The Particulate Emissions component of the Air Quality National Program was delineated because of agricultural contributions of what is called "fugitive dust" by agricultural operations or by wind erosion to air masses that sometimes cause air quality to fall below EPA's National Ambient Air Quality Standards. However, odors may also be associated with particulates. Ammonia, as stated, is a

precursor for particulates, and pesticides may be emitted as particulates or they may be precursors of particulates. Thus, an interested reader needs to peruse most components of this national program for a complete view of the particulates issue.

The following sections discuss each of the Air Quality National Program components. Component issues are stated briefly; the state of knowledge is discussed; and research goals are defined. All of the goals listed were not fully addressed. Those that are addressed were of the highest priority and appeared in the research plans developed for the ensuing five years.

How this Report was Constructed and What it Reflects

Information about NP 203 achievements and their impact is organized in this report according to National Program research components and program goals, as described in the Air Quality National Program Action Plan. The report first outlines the five NP 203 Research Components. These are followed by selected accomplishments and include the impact and/or potential of those achievements to solve the problems and meet the needs identified by the customers and stakeholders in the NP 203 action plan.

For the most part, the content of this report is derived from NP 203 scientists who were asked to summarize their project's major accomplishments during the last five years in terms of impact, and provide key references documenting those accomplishments. Consequently this report does not include all accomplishments achieved in the national program but rather, those key accomplishments selected by the National Program Leaders who authored this report. As a result, this report encompasses a subset of the total spectrum of NP 203 accomplishments, chosen to illustrate and exemplify the total progress and achievements at the National Program level. This document reports only selected refereed publications, patents, and grants as supporting documentation and does not include the large number of abstracts and manuscripts presented at workshops, symposia and interagency conferences.

Action Plan Components and Plans to Address Problems

It was determined that research would focus on needs expressed by customers and workshop participants:

Component I: Particulate Emissions

Goals: Understand the process of air pollution emissions from agricultural enterprises and the effects of air quality upon agriculture; develop and test control measures; develop decision aids that will be useful in minimizing and reducing agricultural PM, and predicting and mitigating the negative impacts of PM agricultural production and processing efficiencies. Current research is focused on the PM emissions associated with wind erosion, on-farm operations, agricultural commodity processing, and smoke from agricultural burning.

Projected Outcomes of Particulate Emissions Research: A reliable scientific basis for improving fugitive dust prediction, developing site-specific control practices, and assessing damage and environmental impact both on-and off-site. This research will foster sustainable agricultural systems that prevent emission of particulates that harm human health and the environment.

Component II: Ammonia and Ammonia Emissions

Goals: Develop methodologies for quantifying ammonia emission and emission factors from concentrated animal agriculture; develop abatement measures to reduce ammonia emission; and understand and model the physical, chemical, and biological processes affecting ammonia emission.

Projected Outcomes of Ammonia and Ammonia Emissions Research: Whole farm management plans that reduce ammonia emissions from farms; a basic understanding of the processes involved in nitrogen transport and ammonia emissions to develop models for whole-farm nitrogen management; management systems that improve animal and farm-level nitrogen utilization and contain atmospheric

ammonia within farm boundaries; models that allow producers to predict potential ammonia losses resulting from changes in any component within their production system.

Component III: Malodorous Compounds
Goals: Quantification of emissions of malodorous materials from livestock production systems and development of transport models to describe movement and dispersion of these materials.

Projected Outcomes of Malodorous Compound Research: Development of emission inventories for malodorous compounds and materials from livestock operations based on management practices and facility design; development of transport models for the movement of malodorous compounds and materials from livestock production facilities for local and long-range transport; development of producer decision making tools for designing livestock facilities and practices that benefit both growers and neighbors.

Component IV: Ozone Impacts
Goal: Assess the effects of ozone and the interaction of ozone and carbon dioxide upon crop production and study of the basis for developing ozone-tolerant crop varieties.

Projected Outcomes of Ozone Research: Data to determine the economic costs of ozone pollution to crop production; increased predictability of the future effects of ozone on crop production in a changing climate; a scientific basis for choosing among management options to limit ozone impacts on crop production.

Component V: Pesticides and Other Synthetic Organic Compounds
Goals: Understand the biological, physical, and chemical mechanisms that influence pesticide volatilization and transport; understand transport processes; understand the impacts of deposition; and develop means to reduce emissions.

Projected Outcomes of Pesticides and Other Synthetic Organic Compounds Research: Tools and methods to quantify the occurrence of pesticides and synthetic organic chemicals within the soil, air, water continuum and the transfer between environmental systems; reduction in the occurrence of volatile pesticides and other synthetic organic chemicals, including newly developed pesticides, in the atmosphere; improved understanding of the processes and mechanisms that affect movement and transformation will be used to develop models and better management practices to reduce pesticide emissions. A cleaner atmosphere to protect public health and sensitive ecosystems from pesticide contamination.

Program Component I: Particulate Emissions

Topic: Sampling Methodology
Goals: Develop quantification methods to assess particulate emissions from a wide variety of farming operations.

Summary: Numerous theoretical and experimental studies were conducted to determine the errors associated with current PM_{10}, $PM_{2.5}$, and PM_{coarse} ambient and stack samplers. Design and development of a low volume TSP ambient air sampler, a TSP point source sampler for harvesting equipment, airflow control systems for PM samplers, integrated data handling systems for airflow and meteorology data, and operational specific sampling protocols. The work is resulting in improved data quality obtained by agricultural PM studies, reduced human errors, reduced data handling, and is leading to universal agricultural PM emissions data that is in a form suitable for application to future PM indicators

Selected Accomplishments

- **Effectiveness of PM samplers in measuring PM emitted from agricultural sources**. Various agricultural operations across the United States are encountering difficulties in complying with current air pollution regulations for PM. A primary component of this problem is sampler effectiveness or how well current PM samplers work in agricultural environments. Numerous theoretical and experimental studies have been conducted to determine the errors associated with current less than 10 microns diameter (PM_{10}), less than 2.5 microns ($PM_{2.5}$), and PM_{coarse} (PM_{coarse} = PM_{10} - $PM_{2.5}$) ambient and stack samplers. Theoretical models have predicted that PM_{10}, $PM_{2.5}$, and PM_{coarse} ambient air samplers would over-estimate PM concentrations by a factor of 3.2, 14.0, and 3.4, respectively. These models predicted that PM_{10} stack samplers over-estimate PM concentrations by a factor of 4.5. Of course these estimates are dependent on the characteristics of the PM emitted from the source. Field studies have indicated that the sampling errors are significantly larger than those predicted by the theoretical models, for example: 1) PM_{10} ambient sampler errors from a cotton gin field study were 1.6 times greater than those predicted by the theoretical models; and $PM_{2.5}$ stack sampler errors from a cotton gin field study were 4.4 to 7.7 times greater than those predicted by the theoretical models. This work documents limitations associated with current PM samplers. Articles discussing this research have appeared in over 40 newspapers and trade magazines.

Buser, M.D., Parnell, Jr., C.B., Lacey, R.E., Shaw, B.W. and Auvermann, B.W. 2001. Inherent biases of PM10 and PM2.5 samplers based on the interaction of particle size and sampler performance characteristics. ASAE Paper No. 01-1167. American Society of Agricultural Engineers. St. Joseph, MI.

Buser, M.D., Parnell Jr., C.B., Shaw, B.W., and Lacey, R.E. 2003. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: Background and theory. In: Air Pollution from Agricultural Operations III. p. 62-72.

Buser, M.D., Parnell Jr., C.B., Shaw, B.W., and Lacey, R.E. 2003. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: PM10 and PM2.5 ambient air samplers. In: Air Pollution from Agricultural Operations III. p. 45-61.

Buser, M.D. 2004. Errors associated with particulate matter measurements on rural sources: Appropriate basis for regulating cotton gins. Texas A&M Univ. 348 pp. (Dissertation)

Shaw, B.W., Lacey, R.E., Capareda, S., Buser, M.D., Parnell Jr., C.B., Wanjura, J.D., Wang, L. and Faulkner, W.B. 2004. Application of the National Ambient Air Quality Standards (NAAQS) in urban versus rural environments. ASAE Paper No. 044016. American Society of Agricultural Engineers, St. Joseph, MI.

Buser, M.D. and Holt, G.A. 2005. Inherent errors associated with PM10 stack samplers due to the interaction of particle size and sampler performance characteristics. ASAE Paper No. 054012. American Society of Agricultural Engineers, St. Joseph, MI.

Wang, L., Parnell, C.B., Shaw, B.W., Lacey, R.E., Buser, M.D., Goodrich, L.B. and Capareda, S.C. 2005. Correcting PM10 over-sampling problems for agricultural particulate matter emissions: Preliminary study. Trans ASAE. 48(2): 749-755.

Wanjura, J.D., Buser, M.D., Whitelock, D.P., Capareda, S.C., Parnell, Jr., C.B., Shaw, B.W. and Lacey, R.E. 2005. Update on the development of a method to determine PM sampler performance characteristics using field data from collocated samplers. ASAE Paper No. 054015. American Society of Agricultural Engineers, St. Joseph, MI.

Buser, M.D., Parnell, Jr., C.B., Shaw, B.W. and Lacey, R.E. 2007. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: ambient PM2.5 samplers. *Trans. ASABE*. 50(1): 241-254.

Buser, M.D., Parnell, Jr., C.B., Shaw, B.W. and Lacey, R.E. 2007. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: Ambient PM10 samplers. *Trans. ASABE*. 50(1): 229-240.

Buser, M.D., Parnell, Jr., C.B., Shaw, B.W., and Lacey, R.E. 2007. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: Background and theory. *Trans. ASABE*. 50(1): 221-228.

Grant: CSREES NRI Air Quality "Inherent PM10 and PM2.5 stack sampling errors due to the interaction of particle size and sampler performance characteristics", 2004 , $196,646.00.

- **PM sampler design and development**. Many PM samplers are currently commercially available for measuring ambient and stack total suspended particulate (TSP), PM_{10}, and $PM_{2.5}$ emissions. However, the majority of these samplers were developed to operate in an urban environment where the PM is generally smaller than that associated with agricultural operations. Many reports have discussed the errors and uncertainties that arise when using these samplers in locations in which they were not designed to operate, creating a genuine need for environment and operation specific samplers. Great strides have been made in the design and development of a low volume TSP ambient air sampler, a TSP point source sampler for harvesting equipment, airflow control systems for PM samplers, integrated data handling systems for airflow and meteorology data, and operational specific sampling protocols. All of these advancements were made in an effort to improve the quality of the data obtained in agricultural PM studies, reduce human errors, reduce data handling, and to aid in generating universal agricultural PM emissions data that is in a form that can be applied to future PM indicators (e.g. PM_{coarse}, PM_1).

  Provisional Patent Application No. 60,771,763, Buser, M.D., Whitelock, D.P. and Wanjura, J.D. Low volume total suspended particulate sampler head. February 9, 2006.

Topic: PM Source Concentration Estimates

Goal: Characterize PM emissions generated from various agricultural operations during normal operation and those generated from high wind events. The PM characteristics of interest include: TSP, PM_{10}, and $PM_{2.5}$ emission factors and the particle size distribution characteristics of the PM being emitted.

Summary: A relatively large percentage of material eroded from summer fallow field in the Columbia Plateau region of the Pacific Northwest was PM_{10} and were under-estimated by WEPS model. Other wind erosion controls in addition to buffer strips are necessary to protect critical downwind sites near source fields. Beef cattle feedyards are not significant generators of $PM_{2.5}$, but have the potential to exceed the PM_{10} NAAQS. An American Society of Agricultural and Biological Engineers standard was developed to define terminology, cotton gin process streams, emission points, and methods for calculating cotton gin emissions. Observed differences of two-row and six-row harvester emission levels provides justification for granting emission reduction credits when using larger harvesting machinery. Sources of PM_{10} and $PM_{2.5}$ generated by wind erosion were quantified.

Selected Accomplishments

- **Quantifying PM_{10} losses from agricultural fields during high wind events**. When wind events occur throughout the Columbia Plateau region of the Pacific Northwest topsoil is removed from agricultural lands, creating serious air quality issues. The Wind Erosion Prediction System (WEPS) was developed as a tool to predict the amount of topsoil removed during the wind events. WEPS includes the capability to predict PM_{10} emissions; however, the model has not been field proven on agricultural lands. Extensive PM_{10} sampling has been conducted in agricultural settings during wind events and these data has been compared to the predicted PM_{10} WEPS estimates. The field measurements indicated that a relatively large percentage of material eroded from summer fallow was PM_{10}. In comparing the field data to the model data, the PM_{10} concentrations to total soil loss were under-estimated by the WEPS model. The complexity of physical properties and surface characteristics affecting soil abrasion and suspension of PM_{10} requires further work to improve the WEPS model with the goal of identifying land management practices that will improve air quality.

Feng, G. and B.S. Sharratt. 2007.Validation of WEPS for soil and PM10 loss from agricultural fields within the Columbia Plateau of the Unites States. *Earth Surface Processes and Landforms*. 32:743-753.

Sharratt, B.S., G. Feng, and L. Wendling. 2007. Loss of soil and PM10 from agricultural fields associated with high winds on the Columbia Plateau. *Earth Surface Processes and Landforms*. 32:621-630.

Sharratt, B.S. and D. Lauer. 2006. Particulate matter concentration and air quality affected by windblown dust in the Columbia Plateau. *Journal of Environmental Quality*. 35:2011-2016.

Feng, G. and B. Sharratt. 2005. Sensitivity analysis of soil and PM10 loss in WEPS using the LHS-OAT method. *Trans. ASAE*. 48:1409-1420.

Kjelgaard, J., B. Sharratt, I. Sundram, B. Lamb, C. Claiborn, K. Saxton, and D. Chandler. 2004. PM10 emission from agricultural soils on the Columbia Plateau: comparison of dynamic and time-integrated field-scale measurements and entrainment mechanisms. *Agricultural and Forest Meteorology*. 125:259-277.

- **Deposition effects of PM generated from wind erosion on plants, field, and water quality**. Dust deposition near eroding source fields can damage plants, and contaminate both soils and water bodies. Dust emitted and the fraction deposited within 200 m of an eroding source field was measured over 3 years. The deposition of various particles sizes could be simulated using a line source diffusion model with inputs of wind speed and particle-fall speed. An average of 43 % of the emitted dust was deposited within 200 m of the source field on a small grain field, but only 12 to 15 % would be trapped in a 10 m-wide vegetative buffer at the source field boundary. Thus, to protect critical downwind sites near source fields other wind erosion controls in addition to buffer strips are necessary. This work also demonstrated that it is necessary to

reduce emitted dust fraction available for long-range transport in diffusion models. The U.S. Environmental Protection Agency now recommends modelers use only a portion of the emitted dust based on the trapping capabilities of land cover surrounding the source.

Hagen, L.J., Van Pelt, S., Zobeck, T.M. and Retta, A. 2006. Dust deposition near an eroding source field. *Earth Surface Processes and Landforms*, 32:281-289.

- **PM emissions from beef feedyards and dairies**. Fundamental information on PM emissions from dairies and beef cattle feedyards in the literature is limited. Studies were conducted to determine concentrations and the particle size characteristics of PM emitted for four feedyards and four dairies in the Southern Great Plains using a variety of sampling methods and devices. Results from the studies showed that PM_{10} levels exceeded the NAAQS only on a few occasions which generally occurred near the facilities housing structures and there were no $PM_{2.5}$ levels which exceeded the NAAQS. On average PM_{10} concentrations were 2.5 times greater than the $PM_{2.5}$ concentrations and concentrations were approximately 50% greater in summer than in the winter. Based on the methodologies used, these results suggest that beef cattle feedyards are not significant generators of $PM_{2.5}$, but have the potential to exceed the PM_{10} NAAQS.

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

- **PM emission factors for cotton gins**. As federal and state PM regulations evolve, so must the cotton gin PM emission factors. For example, $PM_{2.5}$ is currently listed as a federal criteria pollutant, however very limited $PM_{2.5}$ information exists for cotton gins. Further, as new cotton gin equipment, equipment configurations, process stream, and abatement technologies emerge; updates and additional PM emissions data must be generated. Research focused on characterizing cotton gin PM emissions, comparing stack sampling to boundary line sampling, and evaluating the crustal components of cotton gin emissions has been conducted. This research has addressed an immediate issue facing the cotton ginning industry. An additional tool was developed to aid in overcoming the communications issues between regulators, ginners, and researchers. This tool, an American Society of Agricultural and Biological Engineers standard, was developed to define terminology, cotton gin process streams, emission points, and methods for calculating cotton gin emissions.

  Buser, M.D., Parnell, Jr., C.B., Shaw, B.W. and Lacey, R.E. 2003. Characteristic particle size distribution for cotton gins: Based on the 1996 AP-42 emission factors. ASAE Paper No. 03-4113. American Society of Agricultural Engineers, St. Joseph, MI.

  Baker, K.D., Hughs, S.E. and Buser, M.D. 2004. Comparison of source testing and boundary line testing for emissions from a cotton gin. ASAE Paper No. 044011. American Society of Agricultural Engineers, St. Joseph, MI.

  Hughs, S.E., Armijo, C.B., Whitelock, D.P. and Buser, M.D. 2005. Particulate emission profile of a New Mexico cotton gin. ASAE Paper No. 051103. 2005. American Society of Agricultural Engineers, St. Joseph, MI.

- **Cotton harvesting PM emission factors**. Cotton producers in some states are facing intensified air pollution regulation due to poor ambient air quality and a lack of accurate PM emission factor data. Some cotton producers are now required to obtain air quality permits and submit plans detailing the management practices that will be implement to help reduce fugitive PM emissions. PM emissions from cotton picking operations using two-row and six-row pickers were measured using two protocols. The first protocol used dispersion modeling and ambient PM concentrations measurements to calculate emission factors while the second protocol was based on measurements collected onboard

a six-row picker in the field. Results indicated that the PM emission factors for cotton picking using two-row and six-row harvesters are 0.8 and 0.6 lbs/acre, respectively. Further, emission factors developed from onboard measurements contained less uncertainty than the emission factors currently used in the regulatory process. The observed differences in the two-row and six-row harvester emission demonstrates that using larger harvesting machinery could result in emission reduction credits.

Wanjura, J.D., Parnell, Jr., C.B., Shaw, B.W. and Capareda, S.C. 2006. Particle size distribution of PM emitted from cotton harvesting. ASAE Paper No. 064168. American Society of Agricultural Engineers, St. Joseph, MI.

- **PM_{10} and $PM_{2.5}$ fractions for wind erosion of soils**. Wind erosion of soils generates fine particulates that are health hazards by three major processes: entrainment (emission) of loose aggregates, abrasion from immobile clods/crusts, and breakage of saltating aggregates. Some of the generated particles are PM_{10} or $PM_{2.5}$ and are regulated as health hazards. Parameters must be established for these processes to improve prediction of PM_{10} generation by erosion models. The relative breakage rates of saltation-size aggregates to suspension-size were determined for soil samples from nine western states as functions of soil properties. On average, five percent of the suspension-size soil created by breakage was PM_{10} and 15 percent of the PM_{10} was $PM_{2.5}$. This information will allow erosion models such as the Wind Erosion Prediction System to estimate PM_{10} and $PM_{2.5}$ generation across a range of soils and environmental conditions.

Hagen, L.J. 2004. Fine particulates (PM10 and PM2.5) generated by breakage of mobile aggregates during simulated wind erosion. *Trans. ASAE* 47(1):107-112

Topic: Controlling PM Emissions
Goal: Develop practical and economical control technologies and strategies for reducing PM emissions from agricultural operations.

Summary: A PM abatement device system has been constructed and used to evaluate equipment such as baffle type pre-separators and cyclones. This work has led to design modifications, new technologies, and a better understanding of design and size effects on collection efficiencies. Modeling with WEPS has been used to design a confined sediment disposal facility based on minimizing PM emissions due to wind erosion. This model has also been shown to provide more spatially explicit and accurate assessments of wind erosion risks as affected by changing agricultural management.

Selected Accomplishments

- **PM abatement device design, development, and evaluation**. As federal and state PM regulations change in terms of the specified indicator (e.g. total suspended particulate, PM_{10}, $PM_{2.5}$), the basis for determining abatement technology efficiencies must change. In the 1970's, total suspended particulate (TSP) was the regulated pollutant and numerous reports were published comparing various cyclone designs and TSP collection efficiency. Currently, $PM_{2.5}$ is a regulated pollutant and there are very few reports comparing cyclone designs and $PM_{2.5}$ collection efficiency. A PM abatement device evaluation system has been designed, developed, and constructed and has been used to evaluate baffle type pre-separators, series cyclones, and the scalability of cyclones. These studies have shown that two 1D3D cyclones in series were more effective (97%) than a single 1D3D cyclone (91%); defined optimum baffle placement and inlet air velocity in terms of collection efficiency for the baffle-type pre-separator; and provided fundamental scalability cyclone research which showed that collection efficiency for 10 micron PM decreased from 99.5% to 94.5% as cyclone diameter increased from 6 to 36 in. In addition to evaluating and improving current device/system designs, new abatement

technologies are being developed such as a device for reducing PM emissions from almond and pecan harvesting operations.

Actual or potential economic impact: A series cyclone study was perused to show that a relatively low capital and maintenance cost abatement technology (series cyclones) could be used to reduce PM emissions from a livestock feed calcium processing plant that emits a relatively small PM (mass median diameter of 8.0 micrometers equivalent spherical diameter). This plant cleans and dries the product and all material that is emitted from the abatement system is a salable product. Based on the laboratory results, series cyclones were installed at a full scale plant prior to the plant's bag house. Reconfiguring the plant abatement system in this manner reduced the plant's emissions by 98.7% and increased the plant's profits by $470,423 per year simply by not allowing the salable material to be emitted into the air.

Wang, L., Buser, M.D., Parnell, Jr., C.B. and Shaw, B.W. 2002. Effect of air density on cyclone performance and system design. ASAE Paper No. 02-4216. American Society of Agricultural Engineers, St. Joseph, MI.

Wang, L., Buser, M.D., Parnell, Jr., C.B. and Shaw, B.W. 2003. Effect of air density on cyclone performance and system design. *Trans ASAE*. 46(4): 1193-1201.

Wang, L., Wanjura, J.D., Faulkner, B., Parnell, Jr., C.B., Shaw, B.W., Lacey, R.E., Capareda, S.C. and Buser, M.D. 2004. Study of "baffle-type pre-separator plus cyclone" abatement systems for cotton gins. ASAE Paper No. 044017. American Society of Agricultural Engineers, St. Joseph, MI.

Whitelock, D.P. and Buser, M.D. 2005. Multiple series cyclones for fine dust. ASAE Paper No. 054014. American Society of Agricultural Engineers, St. Joseph, MI.

Faulkner, W., Buser, M.D., Whitelock, D.P. and Shaw, B. 2006. Effects of cyclone diameter on performance of 1D3D cyclones: Collection efficiency. ASAE Paper No. 064165. American Society of Agricultural Engineers, St. Joseph, MI.

Buser, M.D., Whitelock, D.P., Holt, G.A., Armijo, C.B. and Wang, L. 2007.Collection efficiency evaluation of baffle-type pre-separator configurations: Effects of baffle location and inlet velocity. *Applied Engineering in Agriculture*. 23 (3): 347-355.

Faulkner, W., Buser, M.D., Whitelock, D.P. and Shaw, B. 2007. Effects of cyclone diameter on performance of 1D3D cyclones: Collection efficiency. *Trans ASABE*. 50(3): 1053-1059.

Whitelock, D.P. and Buser, M.D. 2007. Multiple series cyclones for high particulate matter concentrations. *Applied Engineering in Agriculture*. 23(2): 131-136.

Cotton Incorporated Reimbursable Cooperative Agreement No. 58-6208-4-037 entitled "Collection Efficiencies of Cotton Gin Abatement Devices in Terms of TSP, PM10, and PM2.5" $80,000.00, 2004-2007

- **WEPS model used in the design of a confined disposal facility (CDF)**. The U.S. Army Corps of Engineers (USACE) is constructing a 90 acre confined disposal facility in East Chicago to hold contaminated sediments dredged from Indiana Harbor. The USACE and EPA funded $60,000 to ARS with a request that the WEPS model be used to determine the wind erodibility of the sediments. The model showed that the emissions from the CDF would exceed the operating permit allowable limit; therefore, the model was used in simulating a range of erosion control measures that could be used to bring the facility into compliance. The WEPS model was used to simulate hourly dust emissions from the CDF with the recommended erosion controls so EPA could determine offsite impacts using

their risk assessment models. This work contributed to minimizing the environmental impact of the CDF which will be filled during the next 30 years.

- **Using WEPS to map wind erosion risk**. Combining digital soils maps, weather data, and land management descriptions (crop rotations plus cultivation practice), the wind erosion risk on soils/land in the dominantly agricultural portion of Alberta, Canada was evaluated using the WEPS model. Since WEPS calculates erosion on farm field sized areas it requires specific environmental and management information. We used a quarter section (65 ha or 160 acres) fields as the typical situation for a WEPS estimation. Using these data, erosion risk in Alberta was obtained by the sum of the separate contributions of each soil-management-climate combination. The WEPS model with appropriate databases provided Canadians with a means to make more spatially explicit and accurate assessments of wind erosion risks as affected by changing agricultural management.

  Coen, G.M., J. Tatarko, T.C. Martin, K.R. Cannon, T.W. Goddard, and N.J. Sweetland. 2003. A Method for Using of WEPS to map Wind Erosion Risk Assessment of Alberta Soils. *Environmental Modeling and Software*. Vol. 19, No. 2, pp 185-189.

- **Wind erosion and its control: An educational video**. Seventy years after the Dust Bowl, wind erosion continues to threaten the sustainability of our nations' natural resources. The Natural Resources Conservation Service (NRCS), the primary agency responsible for transferring research and knowledge about wind erosion, expressed the need for training materials in wind erosion and its control. In addition, the Cooperative Extension Service, the U.S. Forest Service, and US Bureau of Land Management, as well as universities and conservation districts are involved in the transfer of wind erosion technology. An educational video/DVD was produced which describes the physical basis for wind erosion processes and control systems. Graphics, including photos, video, and computer animation of the physical principles of wind erosion were utilized. The video emphasizes farming systems which target a goal of zero soil loss from wind erosion. More than 912 copies of the video have been distributed to customers.

  Tatarko, J. 2003. Soil Erosion by Wind and its Control. Video/DVD. USDA-ARS-WERU, Manhattan, KS. http://www.weru.ksu.edu/new_weru/multimedia/ControlVideo/

  Grant: USDA-NRCS, Environmental Quality Incentives Program (EQUIP), J. Tatarko (PI)) “Educational tools for wind erosion control”. $53,426, 1999-2003.

Topic: Modeling

Goal: Evaluate, design, develop, and implement scientifically sound PM emission prediction tools that can be used by industry, regulatory agencies, and researchers to estimate the downwind TSP, PM_{10}, and $PM_{2.5}$ concentrations being emitted from agricultural sources.

Summary: Development of a state-of-the-art comprehensive, process based wind erosion simulation tool designed for conservation and environmental planning and education continued. The Wind Erosion Prediction System (WEPS) will be implemented by the Natural Resources Conservation Service (NRCS) in field offices throughout the U.S. in 2008 and is also being used by other domestic and international users as a tool for improving soil and air quality. An interface was created in response to stakeholder request that can then execute only the WEPS erosion sub-model component code to determine if erosion would occur for a specific situation, and if so, how much and in what direction eroded soil would leave the site. The WEPS model validation by field soil loss measurements continued.

Selected Accomplishments

- **Wind Erosion Prediction System (WEPS) process based wind erosion simulation tool**. The WEPS is a state-of-the-art comprehensive, process based wind erosion simulation tool designed for conservation and environmental planning and education. It will be implemented by the Natural Resources Conservation Service (NRCS), who has provided funding to support WEPS development, in field offices throughout the US during 2008. WEPS is also being used by other agencies and entities as a tool for improving soil and air quality. As such it is essential that the model be easy to understand and operate. To this end, a comprehensive WEPS User Manual and online help system have been developed and implemented. In addition, training materials including a PowerPoint slide presentation and video tutorials have been developed NRCS is expected to be a major user of WEPS. To ensure that WEPS would meet their agency's needs for an easy to use tool for conservation planning, site assessment, program sign up requirements and national erosion inventory evaluations, ARS worked in close collaboration with NRCS during model development, with an NRCS liaison stationed within the ARS research unit. Several workshops were held to identify the unique needs for wind erosion prediction technology within NRCS and understand how it would need to be packaged for delivery. A "User Requirements Document" was developed to guide development of the WEPS package.

  On April 4, 2004, ARS transferred a beta version of WEPS 1.0 to NRCS for evaluation and testing.

- **Development of a Single-event Wind Erosion Evaluation Program (SWEEP)**. Many potential users of wind erosion prediction technology don't require a full daily time step model like WEPS 1.0. Contractors, construction site managers, etc. may be only interested in the amount of soil lost under specific wind and surface conditions or even just an estimate of the probability a site will be susceptible to wind erosion under specified surface conditions. To meet these unique needs, a special user interface was developed to collect the specific site and wind conditions. This interface can then execute only the WEPS erosion submodel component code to determine if erosion would occur, and if so, how much and in what direction it would leave the site. Additionally, by employing the WEPS stochastic wind generator (windgen) and the windgen wind database, SWEEP could also be used to determine the threshold wind speeds (it may vary by direction) for the specified surface and the probability that it would occur based upon the statistical information stored in the wind database records. http://www.weru.ksu.edu/weps/wepshome.html. The following technology transfer activities were conducted: workshops and seminars at three U.S. Universities; WEPS Workshop for Sino-U.S. Joint Center for Soil and Water Conservation and Environmental Protection at Northwest A and F University, Yangling, China; presentations at four Universities in China; WEPS training/workshops/seminars in The Netherlands, Belgium, Italy, Mexico, Inner Mongolia, Corps of Engineers, the Soil and Water Conservation Society Annual Meetings (04, 05, and 06), and the American Society of Agricultural and Biological Engineers (07). The WEPS erosion submodel was validated by field soil loss measurements. Soil loss from wind erosion events on a range of small crop land fields in six U.S. states and in Germany were collected by collaborating researchers. These were used in the analyses to validate the WEPS Erosion submodel. There was reasonable agreement between the model predictions and field measurements. This work met an NRCS requirement as well as that of other customers for scientific validation of models they plan to use.

  Hagen, L.J. 2004. Evaluation of the Wind Erosion Prediction System (WEPS) Erosion Submodel on Cropland Fields. *Environmental Software & Modeling*, 2:171-176.

  Funk, R., E.L. Skidmore, and L.J. Hagen. 2004. Comparison of wind erosion measurements in Germany with simulated losses by WEPS. *Environmental Software & Modeling*, 2:177-183.

- **Improved soil surface algorithms for WEPS**. During significant wind erosion events the soil surface is continually modified, however, erosion models rarely account for these changes. Updating the surface improves accuracy of the WEPS model and allows users to distinguish between events

with a limited supply of mobile soil and unlimited events. This capability greatly improves assessment of field scale effects on soil loss from wind erosion. It also allows users to learn the likely surface conditions at the end of wind storms. This enables users to determine if additional control measures such as emergency tillage are needed and to design improved control systems. The code is included in the WEPS model which is being implemented nationwide by NRCS.

Hagen, L.J. 2007. Updating soil surface conditions during wind erosion events using the Wind Erosion Prediction System (WEPS). American Society of Agricultural and Biological Engineers Paper No. 072257, St. Joseph, Mich: ASABE.

- **Coupling of Meteorological, Air Quality, and Erosion Models for Regional Air Quality Assessments**. Since natural dust emissions are an important factor in air quality, a modeling effort to quantify their sources and evaluate their impact on the population was initiated. The goal is to study the atmospheric processes leading to the generation and transport of particulates on local, regional, and global scales. This specific project focus is the dry bed of Lake Texcoco near Mexico City, which generates an estimated 40% of the suspended particles in some regions of the valley of Mexico. The investigators use the Erosion submodel of WEPS coupled with the Meteorology, Chemistry, and Climate Model (MCCM) to simulate emission and transport of fine dust from the lake. A field sampling program to assess the accuracy of the WEPS Erosion submodel in simulating dust emissions was also conducted.

  Diaz, E. 2005. Particulate modeling of PM10 emitted by aeolian erosion in the Valley of Mexico. Masters Thesis. National Autonomous University of Mexico, Mexico City, Mexico.

- **Abrasive impact energy and sand discharge rates**. Most wind tunnel studies of plant damage by PM have positioned the test plants similar to those at an upwind field boundary. In a new wind tunnel study, we found that at any given erosive wind speed the abrasive energy per unit of passing sand grains impacting above the soil surface was much greater at the upwind boundary than among simulated plants downwind from the boundary. The height of the plant leaves also changed the vertical distribution of abrasive energy in the plant canopy. Leaves positioned above the saltation zone reduced discharge more than the same leaves positioned to intercept sand in the saltation zone. These data will be used to improve predictions of plant damage to seedlings and predictions of soil loss by wind erosion.

- **Low-level point source dispersion modeling**. Various state regulatory agencies are using EPA approved dispersion models to predict potential PM off-property exposure levels from complex agricultural sources such as dairies, cattle feedlots, and cotton gins. These models were originally developed for tall stacks (e.g. coal fired power plant stacks). Current literature suggests that there are fundamental problems that should be addressed when applying these models to low-level point sources. Research efforts in this area have focused on comparing the outputs from various dispersion models such as AERMOD and ISCST3 to actual field data, evaluating and exploring methods of dealing with PM deposition within the models, using models to make facility or abatement device recommendations, and using models to generate source specific emission factors.

  Wanjura, J.D., Parnell, Jr., C.B., Lacey, R.E., Shaw, B.W. and Buser, M.D. 2003. Dispersion modeling of agricultural low point sources. ASAE Paper No. 03-4117. American Society of Agricultural Engineers, St. Joseph, MI.

  Wanjura, J.D., Buser, M.D., Parnell Jr., C.B., Shaw, B.W. and Lacey, R.E. 2005. A simulated approach to estimating PM10 and PM2.5 concentrations downwind from cotton gins. *Trans ASAE*. 48(5): 1919-1925.

Wang, L., Parnell, Jr., C.B., Buser, M.D., Shaw, B.W., Lacey, R.E. and Capareda, S.C. 2005. Particle size distribution in the downwind plume and its impact on ambient PM10 monitoring for agricultural emissions. ASAE Paper No. 054046. American Society of Agricultural Engineers, St. Joseph, MI.

Lange, J.M., Wanjura, J.D., Skloss, S.J. and Parnell, Jr., C.B. 2007. Emission factors for cattle feedlots in Texas based on particle size using ISCST3 and AERMOD. ASAE Paper No. 074106. American Society of Agricultural Engineers, St. Joseph, MI.

Wang, L. Parnell, Jr., C.B. and Buser, M.D. 2007. Theoretical study of the impact of particulate matter gravitational settling on ambient coarse particulate matter monitoring for agricultural emissions. *Air & Waste Manage. Assoc.* 57:111-115.

Topic: Biological Composition of PM

Goal: Characterize potential airborne biological components, including pathogens, present in agricultural PM emissions.

Summary: Research has shown that a fatty acid analyses of PM collected on a filter can produce a "fingerprint" that is unique to a given soil at a given time. This receptor analysis or source detection technology is a major advancement for identifying sources of non-point and point source PM emissions. Research on the emissions from feedyards and dairies were evaluated and it was determined that it would be unlikely for pathogens such as *Escherichia coli* and *Salmonella* spp. to be trans-located to downwind neighbors and livestock. Other feedyard research indicated that vegetation class, vegetation pattern, soil phosphorus class, and soil depth influenced microbial and fungal populations which suggest that feedyards can affect native soil microbial and fungal populations downwind of the feedyard.

Selected Accomplishments

- **Source identification of displaced soil particles using biomarkers**. In receptor analysis, it is often difficult to differentiate among geologic particles. However, the biological portion of the soil can aid in determining the source of geologic material. Fatty acid analyses of soils yield characteristic "fingerprints" that are unique to a given soil at a given time. These fingerprints allowed for the identification and quantification of PM-size material from the biological composition of particulates. Fingerprints of eroded soil were successfully categorized by soil type; road dust was distinguished from cropland soils; and minute quantities of soil on air filters and in sediment were successfully identified. This receptor analysis or source detection technology is a major advancement for identifying sources of non-point and point source PM emissions.

  Acosta-Martínez, V., T. M. Zobeck, T. E. Gill, and A.C. Kennedy. 2003. Enzyme activities and microbial community structure in semiarid agricultural soils. *Biology and Fertility of Soils*. 38:216-227.

  Banowetz, G. M., G. W. Whittaker, K. P. Dierksen, M.D. Azevedo, A.C. Kennedy, S. M. Griffith, and J. J. Steiner. 2006. Fatty acid methyl ester analysis to identify sources of soil in surface water. *Journal of Environmental Quality*. 35:133–140.

  Halvorson, J. J., J. L. Smith, and A. C. Kennedy. 2005. Lupine effects on soil development and function during early primary succession at Mount St. Helens. pp. 243-254. In: V. H. Dale, F. J. Swanson and C. M. Crisafulli (eds.) Ecological Responses to the 1980 Eruptions of Mount Saint Helens. Springer – Verlag, New York, NY.

- **Pathogens and endotoxins associated with feedyards and dairy PM**. Pathogen and endotoxin content of the PM emitted from feedyards and dairies have not been extensively studied. The concentration of bioaerosols and endotoxins in four feedyards and four dairies on the Southern High Plains were determined using biological cascade impactors and passive media plates. Results showed

no viable Gram-negative bacteria in the samples from either the feedyards or the dairies, although Gram-positive bacterial, fungal pathogens, and endotoxins were identified. Gram-negative and Gram-positive pathogens and yeasts were recovered from inside milking parlors. Enteric Gram-negative bacteria were isolated from feedyard retention ponds, but very few could be isolated from air 5 cm above the pond surface. Results from this research indicate that few culturable Gram-negative pathogens can be isolated in air at feedyards and dairies probably because they are rapidly killed by desiccation and ultra-violet light. Based on this research, it is unlikely that pathogens such as *Escherichia coli* and *Salmonella* spp. will be trans-located to downwind neighbors and livestock.

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

- **Long term effect of CAFO's on microbial populations associated with native pasture**. The 30-year effect (1970 to 2000) of a 25,000-head beef cattle feedyard upon a downwind native shortgrass pasture was previously documented. Vegetation changes and a soil phosphorus (P) gradient with respect to distance from the feedyard were determined; however, little is known about the effects of feedyards on soil microbial populations in local native pastures. This study evaluated the effects of vegetation, soil depth, and soil P on soil microbial populations using denaturing gradient gel electrophoresis-polymerase chain reaction (DGGE-PCR) employing universal prokaryotic 16S PCR primers 1092F and 1392R and soil fungal populations using DGGE-PCR employing universal fungal 18S PCR primers FF390 and FR1-GC. Results from the study indicated that vegetation class, vegetation pattern, soil P class, and soil depth influenced microbial and fungal populations. Thus, feedyards can affect native soil microbial and fungal populations downwind of the feedyard.

Topic: PM Effect on Animal Health
Goal: Determine the effects of PM emissions on animal health and production.

Summary: Research has demonstrated that it is possible for endotoxins and fungal mycotoxins commonly found in manure based PM to induce clinical signs in goat under laboratory conditions. The ability to quantify the effects of pathogens on animal health and production are essential in estimating the economic justification of PM control technologies and practices. Other research has evaluated the effects of Class C fly ash, commonly used in livestock pens where muddy conditions exist, on lung damage in cattle and has found that the product is a safe product to use for resurfacing feedyard pens.

Selected Accomplishments

- **Pathogens associated with feedyard PM**. Pathogens attached or contained in feedyard PM could potentially affect the performance and health of livestock, employees, and neighbors. Studies were conducted to evaluate the pathogenicity of bacteria, six fungi, fungal mycotoxins, and endotoxin normally present in feedyard PM. In the studies, goats were exposed to high PM concentrations within a semi-sealed tent or via intratracheal or transthoracic challenge. Results showed that the fungi Mucor, Aspergillus, Chaetonium, Tricoderma, and Stachybotrys were the most pathogenic and that high concentrations of aerosolized endotoxin from manure PM induced a fever and an increase in total white blood cells within 24 hours of inhalation. After several days of exposure, the goats developed resistance to the endotoxin. This research demonstrates that it is possible for endotoxins and fungal mycotoxins to induce clinical signs in goats under these artificial conditions. This type of data should be considered when determining the true costs of PM on calf morbidity, animal production, and human health issues in comparison to the costs of PM control systems or management practices.

Purdy, C.W., D.C. Straus, N. Chirase, D.B. Parker, J.R. Ayers, and M.D. Hoover. 2002. Effects of aerosolized feedyard dust that contains natural endotoxins on adult sheep. *American Journal of Veterinary Research*. 63:28-35.

Purdy, C.W., D.C. Straus, N. Chirase, N., D.B. Parker, J.R. Ayers, and M.D. Hoover. 2002. Effects of aerosolized endotoxin in feedyard dust on weanling goats. *Small Ruminant Research*. 46:133-147.

Purdy, C.W., D.C. Straus, D.B. Parker, J.R. Ayers, and M.D. Hoover. 2002. Treatment of feedyard dust containing endotoxin and its effect on weanling goats. *Small Ruminant Research*. 46: 123-132.

Chirase, N.K., C.W. Purdy, and J. Avampato. 2004. Effect of simulated ambient particulate matter exposure on performance, rectal temperature and leukocytosis of young Spanish goats with or without tilmicosin phosphate. *Journal of Animal Science*. 82:1219-1226.

Purdy, C.W., R.C. Layton, D.C. Straus, and J.R. Ayers. 2005. Virulence of fungal spores determined by tracheal inoculation of goats following inhalation of aerosolized sterile feedyard dust. *American Journal of Veterinary Research*. 66:615-622.

Purdy, C.W., D.C. Straus, and M.D. Hoover. 2006. Fever and leukocytosis responses in goats to inhaled endotoxin are dose-dependent. *Small Ruminant Research*. 70:140-144.

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

- **Effects of PM emissions on livestock respiratory disease**. The effects of feedyard PM on the incidence and severity of respiratory disease in ruminants is unknown. Experiments were conducted to study the effects of feedyard PM inhalation on fungal bacterial and pathogenesis in non-immunosuppressed goats. Goats were either untreated or were pretreated with fine PM comprised of feedyard manure or fly ash. Fine feedlot manure PM appeared to increase the speed of induced fungal respiratory disease; whereas, fly ash dust did not. These results suggest that fine PM may potentially increase the incidence of respiratory disease in ruminants and that controlling feedyard dust may have beneficial effects on animal health. This type of information will be critical to analysis of the cost-benefit ratio of feedyard PM control measures.

Purdy, C.W., D.C. Straus, N. Chirase, J.R. Ayers, and M.D. Hoover. 2003. Effects of aerosolized dust in goats on lung clearance of Pasteurella and Mannheimia species. *Current Microbiology* 45:174-179.

- **Applying fly ash in feedyard pens is relatively non-toxic to ruminants**. Fly ash, a by-product from the burning of coal, is sometimes applied to the surface of feedyard pens to make a semisolid surface that is less prone to muddy conditions. When the fly ash is applied to the pens, PM is dispersed into the air and could potentially cause lung damage in cattle. The particle diameter of fly ash ranges from 0.1 to 130 micrometers with mass median diameter of 17.8 micrometers. A study was conducted to test the toxicity of dispersed Class C fly ash in goats by exposing them to the dispersed material in a controlled environment. Following the final exposure periods, gross and histological examination the lungs was conducted. Results showed no gross lesions or histological lesions attributable to the fly ash inhalation. This research has shown that Class C fly ash is a safe product to use in resurfacing feedyard pens.

Purdy, C.W., D.C. Straus, and J.R. Ayers. 2005. Effect of aerosolized class C fly ash in weanling goats. *American Journal of Veterinary Research*. 66:991-995.

Program Component II: Ammonia and Ammonia Emissions

Topic: Measurement and Quantification of Ammonia Emissions
Goals: Develop methods to measure ammonia emissions and establish emission factors for various agricultural activities.

Summary: A variety of methods to measure ammonia concentration and emissions were evaluated, including closed, flow-through chambers, mass balance methods, micrometeorological techniques, and dispersion models. These methods were used to reliably quantify emissions and emission factors at animal production facilities. Significant findings were: i) flux chambers were not an appropriate methodology to determine absolute emission values; ii) in cattle feedyards, annualized ammonia-N emission from feedyard pens determined by micrometeorological methods and mass balance methods was about one-half the N fed to cattle, with summer emission twice that of winter. The spatial and temporal dynamics of ammonia emissions show that a single ammonia emission factor for beef feedyards is not appropriate. Large variation of ammonia emissions within and among days occurs. Part of the variation is induced by management of the building and presence of animals. Ammonia concentrations were affected by the turbulence structure adjacent to the building. These results demonstrate that emission rate calculations will require determination of turbulence as part of the measurement technique and innovative measurement technologies such as light detection and ranging (Lidar) to fulfill measurement needs.

Selected Accomplishments

- **Ammonia flux measurement methods assessed**. There is uncertainty in the reliability of measurement procedures for ammonia emissions such that accurate characterizations needed for emission control evaluations and for setting policy is lacking. Multiple measurement methods were tested at a 45,000 head commercial beef cattle feedyard and compared to the results of a total nitrogen balance. The flux-gradient micrometeorological method and a backward Lagrangian Stochastic model gave results similar to total nitrogen balance. A box model gave similar average emissions but was inconsistent. In a lab-scale system test, ammonia flux measured using flux chambers with air exchange rates of 8 turnovers per minute or fewer, were less than 50% of the measured flux from an unimpeded surface; at exchange rates of 2 turnovers per minute treatment differences could not be accurately measured. Different measurement methodologies can yield very different results for ammonia emissions from feedlots. The flux-gradient micrometeorological method and a backward Lagrangian Stochastic model offer more reliable measurements. Flux chambers are not appropriate for obtaining accurate estimates of ammonia flux from retention ponds or pen surfaces.

  Baek, B., R.W. Todd, N.A. Cole, and J. Koziel. 2006. Ammonia and hydrogen sulfide flux and dry deposition velocity estimates using vertical gradient method at a commercial beef cattle feedlot. *International Journal Global Environmental Issues.* 6:189-203.

- **Variability of ammonia emission from beef cattle feedyards**. There is concern that a single measurement of ammonia emissions from animal operations is not representative and would provide an inadequate basis for determining an emission factor. Ammonia concentrations and emissions were measured at a Southern High Plains 45,000 head commercial feedyard. Measured emissions averaged 44 to 60% of fed nitrogen during the summer and 15 to 40% of fed nitrogen during the winter; on an annual basis, ammonia emissions averaged 14.4 kg/head capacity, or 48% of fed nitrogen. Emissions were greater during the day than at night, and summer emissions were twice those during winter. These results illustrate the temporal dynamics of ammonia emissions, suggest that a single ammonia emission factor is not appropriate and provide a basis for developing and validating models of ammonia emissions from beef cattle feedyards. This information will benefit beef cattle producers and air quality regulators, who need accurate, scientifically determined emission factors for ammonia.

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

- **Basic data on ammonia emission from retention ponds acquired**. Feedyard runoff retention ponds are a potential source of ammonia emissions from beef cattle feedyards and thus these emissions need to be quantified and the significance of their impact understood. Potential ammonia losses were determined from retention pond water samples from three commercial feedyards using a lab-scale system. Decreasing pond water pH to approximately 6 (from a basal value of 8.5) decreased ammonia emissions for several days; however, after 6 days the pH returned to basal values and ammonia emissions increased. Ammonia emissions measured from a 45,000 head feedyard retention pond using a backward Lagrangian Stochastic method were less than 5% of the total losses from the feedyard. Estimates of emissions using a mechanistic model designed for swine lagoons gave reasonable estimates of emissions; whereas, a statistical model greatly overestimated emissions. The results indicate that ammonia emissions from feedyard retention ponds common in the Southern Great Plains are difficult to control and are small compared to ammonia losses from the feedlot pen surface.

- **Variability of ammonia emissions from swine production facilities characterized**. Ammonia emissions measurements from livestock production units have been made at few locations within facilities and over relatively short periods of time. These data inadequately represent emissions from critical sources and the entire animal production cycle, thus impeding development of emission controls and providing an inadequate basis for policy guidelines. Ammonia concentrations were measured at four locations adjacent to a swine grow-finish unit. These measurements were made continually for a week and then repeated every other week throughout the cycle of removing pigs from the barn at market weight through repopulation with small animals through the complete production cycle. Concentrations varied from 950 ppb at 6 m downwind of the exhaust fans to 23 ppb at 33 m downwind at a height of 1 m above the ground. Concentrations decreased very little with the 6 and 12 m height above the ground at the 33 m position. Typical concentrations adjacent to the exhaust fans were around 200 ppb with a decrease to less than 20 ppb at the 12 m height. Large variation of ammonia emissions within and between days occurred. Some variation was induced by management of the building and presence of animals. Ammonia concentrations were also affected by the turbulence structure adjacent to the building. Concentrations changed rapidly over a half-hour period. These results demonstrate that emission rate calculations will require determination of turbulence as part of the measurement technique and suggest the need for fast-response ammonia sensors when quantifying emissions from livestock production buildings.

- **Lidar measurements can help understand spatial and temporal variability of ammonia emissions from swine production facilities**. Extreme variations of ammonia concentrations with position adjacent to production building served as the impetus for Lidar studies of air-flow around buildings to document the turbulence structure induced by the buildings. These studies were conducted in cooperation with the University of Iowa and the Los Alamos National Laboratories. A particulate and water vapor Lidar system was positioned adjacent to a swine grow-finish unit. Measurements were made of PM and water vapor plumes emitted from the building throughout the day over the course of a four-week period. Concurrent measurements were made of the turbulence around the site with sonic anemometers at five different positions to capture the turbulent exchange in a number of different wind directions. Observations from the Lidar unit showed the vertical velocities of air ranged between 1 and 5 m s^{-1} which is much larger than expected. These data provide insights needed to develop guidelines for measuring emission rates from production buildings and to quantify atmospheric exchanges adjacent to buildings for coupling with dispersion models.

The information contributes to the elimination of a critical gap in the knowledge base needed by air quality regulators to understand the extreme variation present around swine production units.

Prueger, J., Eichinger, W., Hipps, L., Hatfield, J., and Cooper, D. 2007. Turbulence statistics in the flow field of a confined animal feeding operation. *Atmospheric Environment* (in press).

- **Ammonia emissions measured in a broiler house**: An understanding of the relationship between litter properties and gas fluxes is needed to develop alternative management strategies that control gas emissions while maintaining economically viable production systems. Gas fluxes from broiler litter, including ammonia, nitrous oxide, CO_2, and methane, were measured using a photoacoustic multigas analyzer and flux boxes systematically placed throughout the house along a set grid. Litter samples, taken at the same grid points, were used to determine litter pH, moisture, total Kjeldahl nitrogen, ammonium, nitrate, phosphate and total metals. Twenty-eight flocks had been grown on the litter prior to the summer flock sampling with chicks in the house at one (placement) and 21 (mid-growout) days of age. At one day of age during half-house brooding, average NH_3 flux was 498 mg/m^2 hr for the brood area and 372 mg/m^2-hr for the vacant end of the house. At day one, brood litter temperatures exceeded temperatures in the nonbrood half of the house by 3.3 C, and yielded an increase in ammonia flux of 126 mg/m^2 hr over the nonbrood area. Brood litter temperatures were 4 C less than nonbrood at day 21 which produced a decrease in average ammonia flux of 174 mg/m^2-hr for the brood area. Contour plots demonstrated a peak area for NH_3 flux in mid-growout approximately 7 m past the midpoint of the house (towards the fans) and correlated to high pH (~8), high litter moisture (~33%), and high CO_2 flux (12500 mg/m^2-hr). The importance of small environmental changes on pollutant gas concentrations in broiler houses is clearly shown. The work provides an applied approach for assessing ammonia emissions, quantifying factors affecting generation of emissions and how these factors can be controlled.

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

Topic: Quantifying Processes Contributing to Ammonia Emission
Goal: Understand ammonia emissions and their role in forming secondary particulates.

Summary: Researchers in Pennsylvania developed a process-based modeling approach for evaluating management effects on ammonia emissions and their interaction with other nutrient losses, farm performance, and farm profitability. Physical, chemical and biological processes that affect ammonia emission were studied with the goal of refining process-based models of ammonia emission from Texas beef cattle feedyards. Significant findings were: i) mathematical relationships to predict ammonia nitrogen losses from dairy cattle manure in the barn, during storage, following field application, and during grazing were integrated into a whole-farm simulation model to provide a tool for evaluating ammonia emissions.

Selected Accomplishments

- **Distribution of dry deposition of ammonia near a feedyard**. An understanding of the distribution of quantities of generated ammonia deposited downwind of concentrated animal feeding operations is needed as the deposits can affect nutrient-sensitive ecosystems. Researchers measured ammonia concentrations downwind of a 45,000 head commercial feedyard during the summer and winter and measured dry deposition of ammonia downwind of the yard using three surrogate surfaces and micrometeorology methods. Ammonia concentrations at heights of 1 and 3 meters decreased approximately 15% for each 100 meters downwind and approached background concentrations 800

meters downwind. Dry deposition measured with soil as the surrogate surface was 10 times greater than with glass beads or nylon screen, suggesting most of the dry deposition occurred via dust particles. Ammonia profiles downwind of the feedyard were erratic making measurements of dry deposition difficult when using micrometeorological methods. The results better define appropriate measurement methods needed to understand the dynamics and environmental impacts of ammonia emissions from concentrated animal feeding operations. The data provide a basis for defining control guidelines to limit the spatial impacts of deposited ammonia on surrounding ecosystems.

- **Influence of climatic factors on emissions of ammonia from swine lagoons**. There is a need to understand the importance of climatic factors on gas emissions from swine lagoons so that control technologies can be developed. Ammonia is a diffusive gas (as opposed to a biological gas such as methane) requiring that four important physical and chemical parameters be carefully observed and considered during measurements. These factors include the ammonium concentration of the aqueous solution, the temperature of the solution, the pH of the solution, and the turbulence of the air creating the transport process of the diffusive gas. The climatic effect of turbulence is the strongest factor effecting emissions on a short-term basis (two to three weeks), accounting for 70% of the transport influence. On a long term (6 to 12 months) basis, aqueous temperature is the next most dominant effect, influencing partial pressure of ammonia in aqueous solution. At about 3 degrees C, ammonia emissions cease regardless of turbulence or its chemical factors. The solution concentration and pH both influence the partial pressure of ammonia in solution, but most studies show that these factors are relatively constant in steady-state waste processing lagoons. Initial design features for the waste-management system usually determine these concentrations. The determination of the effect of climatic and physical factors on lagoon ammonia emissions led to the development of two statistical emissions models which are limited in scope (limited by the data upon which the models were developed) but are quite accurate in the geographic area where they were developed. A process model was developed and tested and found to perform well, regardless of geographical aspects. Understanding the impact of climatic factors on ammonia emissions has further defined appropriate measurement technologies for ammonia emissions. These studies suggest that ammonia emissions from lagoons can be reduced by management practices that reduce turbulence, decrease pH and manage temperature.

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

  Harper, LA.,, Sharp, R.R., Parkin, T.B., De Visscher, A., van Cleemput, O. and Byers, F.M. 2004. Nitrogen cycling in swine production systemd: Ammonia, nitrous oxide and dinitrogen gas emissions *Journal of Environmental Quality.* 33:1189-1201.

- **Influence of microclimate on emissions from manure storage systems**. Knowledge is limited on the microclimate and its variability around and within manure storage systems (earthen or concrete storage or lagoons) adjacent to swine production buildings. A study was conducted on the microclimate. Microclimatic variables of air temperature, relative humidity, windspeed, and wind direction and solar radiation at one location at each site were measured around lagoon systems in Iowa, Arkansas, and North Carolina. Microclimate surrounding the manure storage is dependent upon the interaction of the location, windspeed, wind direction, the surrounding vegetative cover and the general atmospheric conditions, and the time of year. Production complexes for animals create a unique microclimate for the manure storage system that affects the energy exchange rate between the surface of the manure storage system and the atmosphere. When the buildings shelter the manure storage from the wind movement there is less movement from the surface of the manure storage unit to atmosphere compared to conditions when the air moves directly across the manure storage unit. The emission rate from manure storage systems cannot be estimated by a general measurement of

windspeed at the location because of the effect of buildings on exchange rates. At the Iowa location, crop growth during the year also provided a sheltering effect on exchange rates. Understanding these processes demonstrate why production units produce different environmental impacts and dispersion characteristics. These findings can be used to assess the potential impact of tree barriers on the gas exchange processes at a swine production complex. Understanding and documenting these microclimatic processes contributed to an understanding of the variation in emission rates from different production units, and how these rates vary throughout the year. This information has helped producers and regulators to be more aware of the changes and potential atmospheric impacts from the complex structures around a swine production facility. This information has been valuable in the development of monitoring studies for emissions from different manure storage systems and to demonstrate the magnitude of the changes that occur in emission rates throughout a year.

- **Improved process model for ammonia emission from treatment lagoons**. Although many mathematical models have been used to predict ammonia emissions from anaerobic treatment lagoons, there is still a need for more accurate predictions. Challenges for more accurate ammonia volatilization predictions include three major factors: (1) lagoon water characteristics (ammonia concentration, solids content, and water temperature); (2) bubble formation due to microbial activities; and (3) weather conditions (wind speed and air temperature). An improved model that for the first time incorporates the impacts of bubble formation and varying wind speed on the ammonia volatilization process was developed. The new model was tested against ammonia emissions data generated over a one year period in three swine lagoons with distinctly different manure management and water quality characteristics: (1) traditional lagoon, (2) partially treated lagoon that received liquid manure after liquid-solid separation, and (3) treated lagoon that received liquid manure after separation of solids and removal of N and P. Internal bubbling of the non-treated lagoon increased ammonia volatilization rate during warm seasons. The new model accurately predicted the measured ammonia emissions in the three lagoons. Based on model theory and field measurements, ammonia emission from swine lagoons would be significantly under-estimated if either bubbling-enhanced mass transport or variable wind, are not taken into account. The new model not only provides more accurate predictions of ammonia emissions, but also uses factors that can be conveniently constructed from readily available data.

  Ro, K., Szogi, A., Vanotti, M. and Stone, K. 2007. Improved process model for ammonia volatilization from anaerobic swine lagoons under varying wind speeds and gas bubbling. *Trans. ASABE* (In press).

Topic: Reducing Ammonia Emissions.
Goal: Develop methods to suppress ammonia and ammonium emissions.

Summary: Abatement measures shown to effectively reduce ammonia emissions included reducing crude protein in cattle diets and using feed additive or feedlot surface amendments. Significant findings were: i) reducing crude protein in cattle diets from 13% to 11.5% decreased ammonia emission from 20-30%, although care had to be taken not to avoid reduced animal performance; feed additive and feedlot surface amendments such as alum, zeolite, urease inhibitors and corn oil reduced in vitro ammonia emission by 50%. ARS scientists developed innovative methods to enhance biological removal of N in wastewater containing high ammonia concentration through the use of bacterial immobilization technology. The technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The research has moved from bench to pilot to full-scale treatment systems. Beneficiaries of this work are livestock producers, industrialists, entrepreneurs, policy makers, environmental and health regulators, NRCS, and the general public.

Selected Accomplishments

- **Controlling ammonia emission with animal diet**. Control of animal diet is a means of reducing ammonia emission, however refinements are needed to assure that animal performance is not affected by diet changes. Laboratory and in-field studies were conducted to evaluate the effects of diet on ammonia emissions from beef cattle manure. Compared to feeding a 13% crude protein, steam-flaked corn-based finishing diet, feeding an 11.5% crude protein diet decreased average daily gain 5% and ammonia emissions by 25% due to decreased urinary nitrogen excretion. Decreasing dietary protein concentrations from 13 to 11.5% with 56 days left on feed (i.e. phase feeding) decreased average daily gain by 3% and potential ammonia losses by 22%. Oscillating dietary protein concentrations between moderately deficient and adequate concentrations at 48-hour intervals tended to improve cattle performance and to reduce potential ammonia losses by 15%. These results demonstrate that ammonia emissions from feedyards can be decreased by modification of the diet, while maintaining animal performance.

Cole, N.A., L.W. Greene, F.T. McCollum, T. Montgomery, and K. McBride. 2003. Influence of oscillating dietary crude protein concentration on performance, acid-base balance, and nitrogen excretion of steers. *Journal of Animal Science*. 72:2660-2668.

Gleghorn, J.F., N.A. Elam, N.A., M.L. Galyean, G.C. Duff, N.A. Cole, and J.D. Rivera. 2004. Effects of crude protein concentration and degradability on performance, carcass characteristics, and serum urea nitrogen concentration in finishing beef steers. *Journal of Animal Science*. 82:2705-2717.

Vasconcelos, J.T., L.W. Greene, N.A. Cole, and F.T. McCollum. 2004. Effects of phase feeding of protein on performance, blood urea nitrogen, and carcass characteristics of finishing beef cattle: I. Individually fed steers. 2004 Beef Cattle Research in Texas. p. 129-133.

Vasconcelos, J.T., L.W. Greene, N.A. Cole, and F.T. McCollum, F.T. 2004. Effects of phase feeding of protein on performance, blood urea nitrogen, and carcass characteristics of finishing beef cattle: II. Group fed steers. 2004 Beef Cattle Research in Texas. p. 135-139.

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

Cole, N.A., R.C. Schwartz, and R.W. Todd. 2005. Assimilation versus accumulation of macro- and micronutrients in soils: relations to livestock and poultry feeding operations. *Journal of Applied Poultry Research*. 14:393-405.

Todd, R.W., N.A. Cole, and R.N. Clark. 2006. Reducing crude protein in beef cattle diet reduces ammonia emissions from artificial feedyard surfaces. *Journal of Environmental Quality*. 35:404-411.

Vasconcelos, J.T., L.W. Greene, N.A. Cole, M.S. Brown, F.T. McCollum, and L. Tedeschi. 2006. Effects of phase feeding of protein on performance, blood urea nitrogen, manure N:P ratio, and carcass characteristics of feedlot cattle. *Journal of Animal Science*. 84:3032-3038.

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

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

- **Measurement of ammonia emissions from feedlot surfaces.** The integrated horizontal flux micrometeorological method along with gas washing and wet chemistry were successfully used to measure ammonia emissions from manure applied to 5-m diameter simulated feedyard surfaces to compare the effect of dietary crude protein on ammonia emissions during all seasons. Reducing crude protein in beef cattle diets from 13% to 11.5% significantly reduced nitrogen lost from manure as ammonia in summer, fall or spring, but not in winter; annual mean reduction was 24%. The method could be used to compare emission abatement treatments, quantify emissions from land application of manure, or from different emission source areas. Accurate, comparative studies using this methodology could potentially benefit cattle feeders, environmental managers or consultants who seek to apply abatement measures to reduce ammonia emissions, or air quality regulators who need scientifically based evaluations of abatement technologies.

- **Testing the effectiveness of amendments to reduce ammonia emissions**. Decreasing the loss of ammonia from the surface of beef cattle feedyards would improve air quality and increase the value of manure collected from the pens. A variety of individual chemicals and their mixtures that could potentially be feed additives or feedlot surface amendments were tested in a lab-scale system for their potential to decrease ammonia emissions from a mixture of beef cattle feces and urine. Several chemicals (alum, zeolite, urease inhibitor, corn oil) decreased ammonia emissions by 50% or more; however, mixtures of the chemicals did not produce an additive or synergistic effect on inhibition of ammonia production. Development of cost effective soil amendments or feed additives that inhibit ammonia emissions from feedlot surfaces could improve air quality at feedyards, decrease nuisance complaints, and improve the fertilizer value of collected manure.

Parker, D.B., S. Pandrangi, L.W. Greene, L.K. Almas, N.A. Cole, M.B. Rhoades, and J. Koziel. 2005. Rate and frequency of urease inhibitor application for minimizing ammonia emissions from beef cattle feedyards. *Trans. ASAE*. 48:787-793.

Cole, N.A., M.S. Brown, and V.H. Varel. 2007. Beef Cattle – Manure Management. IN: A.W. Bell, and W.G. Pond (eds.). Encyclopedia of Animal Science. Taylor and Francis, 1(1) 1-4.

- **Biological treatment to prevent ammonia losses from wastewater.** Treatment systems to manage nitrogen in wastewater depend on microbial transformations of nitrogen from ammonium to nitrate forms (nitrification) and from nitrate to nitrogen gas (denitrification). The nitrification step converts nitrogen to a form where it will not be emitted to the environment as ammonia gas. However, it is difficult to maintain a high population of nitrifying bacteria in animal wastewater with high ammonia and biochemical oxygen demand. ARS scientists adapted a Japanese municipal wastewater treatment technology to enhance removal of ammonia from swine wastewater. The research showed that with proper acclimation techniques, cultures of nitrifying bacteria could be adapted to high-ammonia strength wastewater and immobilized and used effectively to treat very concentrated (2600 ppm ammonia-N) animal wastewater. Nitrification rates of 650 grams of N per cubic meter of reactor per day with virtually no ammonia losses were obtained in a pilot study treating lagoon swine wastewater. A second pilot study successfully demonstrated the use of immobilization technology to efficiently treat N after solid-liquid separation of flushed swine manure as a viable treatment system alternative to lagoons. Odors are also eliminated in the process. The technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The research has moved from bench to pilot to full-scale treatment systems. Beneficiaries of this work are livestock producers, industrialists, entrepreneurs, policy makers, environmental and health regulators, NRCS, and the general public.

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

- **Bacteria propel gains in ammonia removal**. New, cost-efficient and large-scale methods of removing ammonia from livestock wastewater are needed. Tests were conducted with anammox -- a technology that uses rare anaerobic bacteria to convert nitrite and ammonium to harmless dinitrogen gas. Planctomycetes bacteria used in the anammox process were isolated from animal wastewater for the first time. They have also highlighted anammox's commercial potential by removing nitrogen from wastewater at rates higher than those achieved with conventional methods and at a lower cost. This finding can be of significant importance to farming systems because excess ammonia in modern, livestock production is a global problem, and the use of conventional biological nitrogen removal methods is usually hindered by operational cost, which can be lowered four-fold with the anammox process.

- **Control of ammonia emissions from wetlands**. There are concerns about the magnitude of ammonia volatilization from two popular types of wetland systems. It was determined that ammonia volatilization from emergent marsh areas of constructed wetlands was not the primary loss mechanism; it accounted for less than 16% of the nitrogen load. However, ammonia volatilization from the pond areas of the of marsh-pond-marsh constructed wetlands accounted for greater than 40% of the nitrogen load when the ammonia concentration of the wastewater was greater than 25mg nitrogen L^{-1}. Fortunately, ammonia volatilization can be reduced by lowering the ammonia concentration of the wastewater by nitrification conversion of the ammonia to nitrate prior to wetland application. Partial nitrification of the wastewater prior to wetland application also improved the efficiency of the wetlands to remove nitrogen via denitrification. This research was the first to directly measure ammonia volatilization from constructed wetlands treating animal wastewater. The work provides insights to the magnitude of ammonia volatilization from two popular types of wetland systems and highlights a method to reduce ammonia volatilization without compromising wetland treatment performance. These results will be useful for farmers who are looking for cost-effective nitrogen removal alternatives/supplements to land application, for regulators who are looking to ensure that agricultural waste management practices do not degrade both air and water quality, and for NRCS personnel who are looking for wetland design modifications that will maximize their nutrient removal potential.

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

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

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

can be altered through management. Covering lagoons can provide a cost-effective method for reducing emissions from lagoon systems and benefit producers that need to demonstrate alternative methods to reduce emissions.

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

- **Alum treatment of poultry litter as a means of reducing ammonia levels in poultry houses**. Phosphorus runoff and ammonia emissions are two of the biggest problems facing the animal industry. It was determined that when alum (aluminum sulfate), is added to poultry litter in commercial houses, ammonia levels in the houses are greatly reduced resulting in significantly healthier birds. Birds grown in alum-treated houses weigh more, they utilize their feed better, there is less bird death, and heating costs during winter months are significantly lower (due to less ventilation required to remove ammonia vapors). The use of alum in poultry houses is very cost effective; producers make an additional two dollars for every dollar spent. Alum-treated poultry litter applied to pastures reduced phosphorus runoff by 75% compared to untreated litter. Other benefits of treating litter with alum include a reduction in pathogen numbers; lower heavy metal and estrogen runoff from fields fertilized with litter, and higher yields from crops fertilized with alum. Approximately 600 million broilers are produced annually on alum-treated litter. The USDA NRCS developed a Conservation Practice Standard related to reduced ammonia emissions and phosphorus losses through the use of litter amendments such as alum.

- **Ammonia reduction in laying hen houses**. High rise laying hen houses have the highest level of ammonia of all animal rearing facilities, however due to logistical constraints, it is not possible to use dry alum as is done in broiler houses. A liquid alum delivery system was designed, developed, installed and tested in a high-rise laying hen house. Liquid alum is pumped through PVC lines to 130 nozzles attached to the floor of the second story of the high-rise house (under the hens). Alum applications can be made manually, on a timed basis, or applied automatically when ammonia levels are too high (the brain of the system is connected to electronic ammonia sensors at bird height). Data on ammonia levels, egg production, egg quality and manure chemistry were collected after the system was made operational. This patented system has been shown to reduce ammonia levels from over 90 ppm to less than 10 ppm for just a few dollars a day. The alum scrubs the ammonia out of the air, rather than preventing it from volatilizing. This is the most cost-effective way to control atmospheric ammonia levels. This improves worker safety in this environment, while improving egg production by the birds. On average the system used about $110 worth of alum per week, however, increased hen performance was valued at $536/week; resulting in a net return of $426/week. This system provides egg producers with a cost-effective means of improving egg production while making the work place safer.

Controlling emissions and pathogens with plant oils: Studies indicated that antimicrobial plant oils are effective additives to cattle and swine manure for control of odor emissions and fecal coliforms. Additions of thymol, carvacrol, or eugenol at 0.15 to 0.2% inhibit essentially all microbial metabolism in these manure slurries whereby no volatile fatty acids or gaseous products are produced. Concentrations of 0.1% destroyed the fecal coliforms which represent the majority of pathogenic microorganisms in manure slurries. Results from eugenol addition to cattle and swine manure were unique because eugenol stops volatile fatty acid production (odor), yet allows lactate accumulation. This effect rapidly lowers pH, and will likely conserve nutrients such as ammonia in manure slurries. Preliminary field trials in cattle feedlot pens indicate when thymol is incorporated into a granule, it reduces odor production (58%) and fecal coliforms (89%). Plant oils are natural compounds classified as GRAS (generally recognized as safe). If the method is cost-effective, plant oils may help cattle

and swine producers reduce odor and patogens in manure while helping to reduce ammonia emissions.

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

Varel, V.H., Wells, J., Miller, D.N. 2007. Combination of a urease inhibitor and a plant essential oil to control coliform bacteria, odor production, and ammonia loss from cattle waste. *J. of Applied Microbiology* 102:472-477.

- **Managing ammonia emissions from land applied manures**. Ammonia losses from manures result in an economic loss of N, degradation of air quality, and N enrichment of neighboring ecosystems. There is a paucity of U.S. data on field ammonia volatilization, despite the EPA guideline to develop ammonia control strategies for confined animal feeding operations. Ammonia volatilization from land application of manures was studied with micro-meteorology and wind tunnel techniques. Results show that dairy slurries lose 40% to 80% of their ammonium-N within 24 to 48 hours after surface application. Solid manures, such as poultry litter, had smaller losses of 10% to 30% over approximately one week. A practical method to manage ammonia from land applied manures is with rapid soil incorporation by tillage or injection, common tillage implements reduce losses from 50% to 95% compared to unincorporated surface applications. Research on ammonia losses from dairy slurries after collection, showed that adding alum or zeolites reduced losses 50%, by acidifying the slurry with alum or by sequestering ammonium-N on zeolite cation exchange sites. These results will impact ammonia control policies by providing real-world ammonia loss data and identifying the most useful ammonia conservation strategies for land applied manures. Reducing ammonia emissions will improve air quality and improve N use efficiency within animal production systems. This research benefits soil scientists, animal scientists, CSREES and NRCS agents who are developing nutrient management plans, the Dairy and Poultry Industries, and the regulatory agencies who are calling for ammonia control measures for large animal operations. Data from these studies formed the basis for an ammonia volatilization decision support system that is being used to update ammonia loss estimates in Nutrient Management Programs in the Northeastern U.S.

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

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

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

- **Systems of treatment technologies**. Systems of treatment technologies are needed that capture nutrients, reduce emissions of ammonia and nuisance odors, and kill harmful pathogens. A system of swine wastewater treatment technologies that accomplishes many of these tasks was developed. The system greatly increases the efficiency of liquid-solid separation by injection of polymer to increase solids flocculation. Nitrogen management to reduce ammonia emissions is accomplished by passing the liquid through a module where immobilized bacteria transform nitrogen. Subsequent alkaline treatment of the wastewater in a phosphorus module precipitates recoverable phosphorus and kills pathogens. Treated wastewater can be recycled to clean hog houses or for crop irrigation. The system was assessed in a full scale demonstration at a 4,400 head finishing farm in Duplin County NC as part of the Smithfield Foods-Premium Standard Farms/North Carolina Attorney General agreement to replace currently used anaerobic lagoons. The-wastewater treatment system was judged to be Environmentally Superior Technology because it was able to substantially eliminate ammonia

emissions, odors, pathogens and to prevent nutrient contamination of water. A lower-cost second generation of this system with the same performance characteristics has been developed. The system is currently in use on swine and dairy production facilities in North Carolina.

Szogi, A.A., Vanotti, M.B., Stansbery, A.E. 2006. Reduction of ammonia emissions from treated anaerobic swine lagoons. *Trans. ASABE* 49:217-225.

Vanotti, M.B., Szogi, A.A. 2007. Water quality improvements of CAFO wastewater after advanced treatment. *J. Environ. Quality* (In press).

Program Component III: Malodorous Compounds

Topic: Characterize emission of odor and odorous compounds from manures and biosolids.
Goals: Identify odor-producing agents; understand the biological and chemical processes that produce odors, emit them to the atmosphere, and govern their distribution and movement off-farm.

Summary: Field sampling and analysis techniques have been developed to probe and quantify emission of malodorous material from manure, wastewater, and air. These methods have been used to characterize and identify key odorants from animals, animal production facilities, manures, sludges/lagoons, biosolids, composts, and heat-dried materials. Methods have been used by wastewater treatment facilities for testing the effectiveness of odor mitigation technologies and regulators have used these methods to quantify the enteric emissions of dairy cows. This research has benefited farmers with no-cost soil amendments provided by wastewater treatment plants, while regulators in California removed dairy cows as the single largest source of ozone precursor molecules, saving the dairy industry over a billion dollars in potential mitigation costs.

Selected Accomplishments

- **New methods for assessing odor developed**. Traditional odor quantification techniques, such as dynamic dilution olfactometry, are inadequate due to the loss of the most odorous compounds through sorption and transformation during storage. Consequently, novel approaches are required to measure traces of these highly reactive volatile organic chemicals. New methods for assessing odor have been developed using odor intensity models, flux chamber measurements, and adaptation of existing GC-O (olfactometry) techniques. These new methods show good correlation with both odor intensity and hedonic tone along with the ability to identify key odorous compounds. Field sampling methods have also been developed to probe both animal waste and ambient air for odorous compounds. These new sampling techniques include twister stir analysis of animal waste, whole air and selective pre-concentration analysis of odorants. These sampling techniques have been coupled with multi-dimensional gas chromatography interfaced with mass spectrometers, olfactometers, and sulfur detectors for the capacity to quantify a number of key odorants. Further development of these new methods will accelerate the pace of determining the emissions of malodorous compounds from livestock operations and improving our knowledge of emission rates and inventories. This knowledge will be used to develop decision-making tools for producers and resource conservationists to protect rural community air quality.

Cook, K., M. Rothrock, J. Loughrin, and K. Doerner. 2007. Characterization of skatole-producing microbial populations in enrich swine lagoon slurry. *FEMS Microbiol. Ecol*, 60:329-340.

Gabriel, S.A., S. Vilalai, S. Arispe, H. Kim, L.L. McConnell, A. Torrents, and C. Peot. 2005. Prediction of Dimethyldisulfide Levels from Biosolids Using Statistical Modeling. *J. Environ. Sci. Health Pt. A.*, 40:2009-2025.

Kim, H., C. Nochetto, and L.L. McConnell. 2002. Gas Phase Analysis of Trimethylamine, Propionic and Butyric Acids, and Sulfur Compounds Using Solid Phase Microextraction. *Anal. Chem.*. 74:1054-1060.

Kim, H., L.L. McConnell, and P.D. Millner. 2005. Comparison of Odorous Volatile Compounds from 14 different Commercial Composts Using Solid Phase Microextraction. *Trans. ASABE*. 2005, 48:315-320.

Kim, H., L.L. McConnell, M. Ramirez, M. Abu-Orf, and C. Peot. Characterization of Odors from Limed Biosolids Treated with Nitrate and Athraquinone. *J. Environ. Sci. Health Pt. A.* 2005, 40:139-149.

Kim, H., S. Murtry, C. Peot, M. Ramirez, M. Strawn, and L.L. McConnell. 2002. Mechanisms for odor production during lime stabilization of municipal wastewater solids. *Water Science Technology*, 46:9–16.

Koelsch, R., B. Woodbury, D. Stenberg, D. Miller, and D. Schulte. 2004. Total reduced sulfur concentrations in the vicinity of beef cattle feedlots. *Appl. Eng. Agric*., 20:77-85.

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

Loughrin, J., and T. Way. 2006. An equilibrium sampler for malodors in wastewater. *Trans. ASABE*, 49:1167-1172.

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

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

Murtry, S., H. Kim, C. Peot, L.L. McConnell, M. Strawn, S. Thomas, and I. Dolan. 2003. Evaluation of Odor Characteristics of Heat-Dried Pellets. *Water Environ. Res.* 75:523-531.

Niu, G., L.L. McConnell, and V. Reddy. 2003. Propylene Glycol Vapor Contamination in Controlled Environment Growth Chambers - Toxicity to Corn and Soybean Plants. *J. Environ. Sci. Health Pt. A.* 40(3):443-448.

Sun, H., S. Trabue, W. Jackson, K. Scoggin, Y. Pan, Y. Zhao, J. A. Koziel and F. Mitloehner. 2007. Greenhouse gas and volatile organic compound emissions from dairy cows and their fresh waste. J. Environ. Qual. (In press).

Trabue, S. L., K. Scoggin, S. Tjandrakusuma, M. Rasmussen, and P. Reilly. 2007. Ruminal fermentation of propylene glycol and glycerol. *J. Agric. Food Chem*. 55:7043 -7051.

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

Trabue, S.L., K. Scoggin, F. Mitloehner, H. Li, R. Burns, and H. Xin. 2007. Field sampling method for quantifying sulfur compounds from animal feeding operations. Atmos. Environ. (In press).

Topic: Transport processes of odors and particulates

Goals: Develop transport models to quantify movement patterns and transport capacity of air moving away from livestock facilities and manure handling practices; determine the interactions of environmental parameters on transport and dispersion processes associated with gases and particulates from livestock operations.

Summary: Particulates are a major transport mechanism for malodorous compounds from livestock facilities and operations. Current models used to estimate transport of particles from livestock operations are overly simplistic and based on outdated assumptions that fail to capture the dynamics nature of boundary layers. Consequently, developing more realistic models will aid in our understanding of transport mechanisms of malodorous material.

Selected Accomplishments

- **Modeling of particulates from livestock facilities**. Advanced instruments utilizing 3D sonic anemometers, lasers, Lidar, and field mass spectrometers have been employed to demonstrate that patterns of particulate and gas movement are poorly characterized by Gaussian plume models. Lidar studies measuring movement of particulate plume dispersion from animal facilities demonstrate that movement is complex but orderly. This research reveals that current sampling techniques used to quantify emission of malodorous compounds will greatly underestimate the true emission from animal feeding operations. Further developments in these techniques and monitoring of various livestock facilities will aid in the development of realistic models that can be used to predict movement of malodorous material from animal facilities.

Eichinger, W., J. Pruegar, J. Cooper, J. Hatfield, L. Hipps, J. Nichols, R. Pfeiffer, and T. Sauer. 2007. Use of elastic Lidar to examine the dynamic of plume dispersion from an agricultural facility. *Atmos. Environ*. (In press)

Prueger, J., W. Eichinger, L. Hipps, J. Hatfield, and D. Cooper. Air flow distortion and turbulence statistics near an animal facility. *Atmos. Environ*. (In Press).

Topic: Odor mitigation strategies
Goal: Develop odor mitigation strategies for application at the emitting source.

Summary: Odor mitigation strategies have been developed that use modifications of animal diet formulations, manure additives, floating permeable materials over the surface of storage lagoons (biocovers) and wastewater treatment. Each of the methods showed demonstrated potential for significant reductions of odorous compound emissions. Crop fertilizer is produced as a by-product from the waste water treatment approach. Several patents were applied for.

Selected Accomplishments

- **Reduction in odor emissions through dietary formulations**. Animal whole-body retention of nutrients is approximately 50% of total dietary intake. Loss of nutrients through excretion results in much of the source material of the odorous compounds. Consequently, improved nutrient utilization and manipulations of diet formulations are practical production tools for the reduction of malodorous emissions from animal waste. Reduction in the dietary crude protein (CP) content of animal diets augmented with supplementary crystalline amino acids can reduce nitrogen excretion and potentially odorous emissions. Swine and cattle feed diets with lower CP have been shown to have lower nitrogen excretion along with reduction in a few odorous compounds in the manure, while diets higher in cellulose have increasing concentrations of certain odorants compared to standard diets. Modification of CP diet had no effect on hydrogen sulfide emission or sulfur excretion. Lower CP and higher cellulose diets did not impact a swine or cattle growth performance. Oscillating CP on finishing steers resulted higher phenolic content in manure compared to standard diets. The source of the supplemental dietary methionine does have a significant influence on the volatile sulfur compounds in broiler excreta. Further developments in diet formulation include reduction in total sulfur though replacement of sulfate salts with mineral oxides and phosphate salts and the effect biofuel byproducts have on animal emissions.

Archibeque, S. L., D. Miller, H. Freetly, E. Berry, and C. Ferrell. 2007. The influence of oscillating dietary protein concentration on finishing cattle. I. Feedlot performance and odorous compound production. *J. Anim. Sci*., 85:1487-1495.

Chavez, C., C. Goufal, J. Carey, R. Larcey, R. Beier, and J. Zahn. 2004. The impact of supplemental dietary methionine sources on volatile compound concentrations in broiler excreta. *Poult. Sci*., 83:901-910.

Kerr, B., C. Ziemer, S. Trabue, J. Crouse, and T. Parkin. 2006. Manure composition of swine as affected by dietary protein and cellulose concentration. *J. Animal. Sci*., 84:1584-1592.

Miller, D., E. Berry, J. Wells, C. Ferrell, S. Archibeque, and H. Freetly. 2006. Influence of genotype and diet on steer performance, manure odor, and carriage of pathogenic and other fecal bacteria. III. Odorous compound production. *J. Animal. Sci*. 84:2533-2545.

Panetta, D., W. Powers, H. Xin, B. Kerr, and K. Stalder. 2006. Nitrogen excretion and ammonia emission from pigs fed modified diets. *J. Environ. Qual*., 35:1297-1308.

Powers, W., S. Zamzow, and B. Kerr. 2007. Reduced crude protein effects on aerial emissions from swine. *Appl. Eng. Agric*., 23:539-546.

Roberts, S., H. Xin, B. Kerr, J. Russell, and K Bregendahl. 2007. Effects of dietary fiber and reduced crude protein on nitrogen balance and egg production in laying hens. *Poult. Sci*., 86:1716-1725.

- **Reduction of odor emissions through manure additives**. Microorganisms are the main agent responsible for the production of malodor compounds from animal manures. Fermentation of carbohydrates and proteins in animal manure are the main source material for many of the more malodorous compounds. Consequently, reduction in the microbial community's activity will lower production of malodor compounds. Plant essential oils with anti-microbial properties and urease inhibitors have the capacity to limit microbial activities and improve nutrient retention in stored manures. Thymol was successfully used to reduce the production of malodor compounds (i.e., volatile fatty acids) and reduce E. coli numbers in manure. Incorporating thymol into plant material increased longevity of the treatment in the field. Further developments in thymol field use will include development of granules that have a higher loading capacity of thymol for increased longevity per treatment along with cost analysis for treatment.

U.S. Patent 6,902,726, Varel, V "Reduction of odor gases from waste using plant-derived oils", 2005.

Varel, V. 2002. Carvacol and thymol reduce swine waste odor and pathogens: Stability of oils. *Curr. Microbiol*., 44:38-43.

Varel, V., and D. Miller. 2004. Eugenol stimulates lactate accumulation yet inhibits volatile fatty acid production and eliminates coliform bacteria in cattle and swine waste. *J. Appl. Microbiol*., 97:1001-1005.

Varel, V., and D. Miller. 2001. Plant derived oils reduce pathogens and gaseous emissions from stored cattle waste. *Appl. Environ. Microbiol.* , 67:1366-1370.

Varel, V., and D. Miller. 2003. Swine manure composition affects the biochemical origins, composition and accumulation of odorous compounds. *J. Anim. Sci*., 81:2131-2138.

Varel, V., and J. Wells.2003. Influence of thymol and a urease inhibitor on coliform bacteria, odor, urea, and methane from a swine production manure pit. *J. Environ. Qual*. 36:773-779.

Varel, V., D. Miller, and A. Lindsay. 2003 Plant oils thymol and eugenol affect cattle and swine wastes emissions differently. Water Sci. Techn., 50:207-213.

Varel, V., D. Miller, and E. Berry. 2006. Incorporation of tymol into corncob granules for reduction of odor and pathogens in feedlot cattle waste. J. Animal Sci., 84:481-487.

Varel, V., J. Wells, and D. Miller. 2007. Combination of a urease inhibitor and a plant essential oil to control coliform bacteria, odour production and ammonia loss from cattle waste. *J. Appl. Microb*., 102:472-477.

- **Reduction in odor emissions through use of biocovers**. Floating permeable material over the surface of storage lagoons is an economically feasible technology for controlling odors from animal waste. The commercial biocover (Biocap II) was tested and shown to reduce the flux of ammonia and hydrogen sulfide from a storage lagoon by over 50%; this was correlated to the development of a stable anaerobic floc on the bottom surface of the biocover. Floating vegetation mats are an effective tool in removing nutrients from lagoons and offer the potential added benefit of reducing odor. Nutrient removal was a function of total biomass of each plant species tested. Cattails and maidencane grew well on the floating mats, while soft rush grew poorly, indicating that this plant species is not suitable for growth in floating mats on lagoons.

  Hubbard, R., G. Gascho, and G. Newton. 2004. Use of floating vegetation to remove nutrients from swine lagoon wastewater. *Trans. ASAE*, 47:1963-1972.

  Petersen, S, and D. Miller. 2006. Greenhouse gas mitigation by livestock waste storage and lagoon covers. *J. Sci. Food Agric*. 86:1407-1411.

  Zahn, J., A. Tungand, B. Roberts, and J. Hatfield. 2001. Abatement of ammonia and hydrogen sulfide emission from a swine lagoon using a polymer biocover. *J. Air Waste Mange. Assoc*. 51:562-573.

- **Reduction in odor emissions through a wastewater treatment system.** A wastewater treatment system for swine operations was developed that uses a solid liquid separation, nitrification/ denitrification, and soluble phosphorus (P) removal processes. This waste treatment system removes excess P and allows waste to be used in a spray field. The P removed is package as a fertilizer, while the treatment system has been shown to reduce odorous compounds in the wastewater by over 95% along with pathogen loading. This technology was identified by state of North Carolina as environmentally superior to other systems of waste treatment. The success of this research has enabled further development of a second generation technology of solid liquid separation at a fraction of the original cost to the producer. The state of North Carolina has offered incentives to producers of existing swine operations with anaerobic lagoons for adopting these technologies.

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

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

  Loughrin, J., A. Szogi, and M. Vanotti. 2006. Reduction of malodours compounds from liquid swine manure by a multi-stage treatment system. *Appl. Eng. Agric*., 22:867-873.

Program Component IV: Ozone Impacts

Topic: Effects of ozone and the interaction of ozone and CO_2 upon crop production
Goals: Determine the effects of ozone and the interaction of ozone and CO_2 upon crop production.

Summary: Current ambient ozone concentrations in many regions of the U.S. reduce yields of ozone-sensitive crops (e.g., alfalfa, cotton, peanut, potato, soybean, wheat) by 5 to 15%. However, large differences in sensitivity to ozone exist among species and cultivars as heritable traits, presenting significant opportunities for introducing and improving the tolerance of crops to ozone to increase biomass and yield. Elevated atmospheric CO_2 levels usually ameliorate ozone damage. A concentration-dependent interaction between CO_2 and ozone was found in peanut and soybean and was attributed to reductions in ozone uptake and stimulated photoassimilation at elevated CO_2 levels. An experiment with rice indicated that gas treatment effects were modulated by planting density and temperature. This shows that future air quality research will benefit from ensemble analyses that include trace gas concentrations, meteorological factors and management practices.

Selected Accomplishments

- **Elevated CO_2 protects peanuts from the negative effects of ground level ozone**. Elevated ozone suppressed photosynthesis, biomass production and seed yield in a commercial variety of peanut (NC-V11). The detrimental effects of ozone were countered by elevated CO_2 in a concentration-dependent manner, confirming responses seen previously for other ozone-sensitive crops. Increasing concentrations of ground level ozone are expected to suppress peanut growth and yield, while increasing concentrations of CO_2 should moderate this effect. The net effect on peanut production will depend on the concentrations of ozone and CO_2 in future atmospheres and the ozone-sensitivity of the peanut varieties grown.

  Booker, F.L., K.O. Burkey, W.A. Pursley, and A.S. Heagle. 2007. Elevated carbon dioxide and ozone effects on peanut. I. Gas exchange, biomass, and leaf chemistry. *Crop Science* 47:1475-1487.

  Burkey, K.O., F.L. Booker, W.A. Pursley, and A.S. Heagle. 2007. Elevated carbon dioxide and ozone effects on peanut. II. Seed yield and quality. *Crop Science* 47:1488-1497.

- **Elevated CO_2 increases water use efficiency and protects plants from ozone**. Increasing concentrations of atmospheric CO_2 and ozone will likely affect agricultural hydrologic cycles. Whole-plant water loss was assessed in response to combinations of elevated CO_2 and ozone by measuring mass changes of potted plants placed on electronic balances in open-top chambers. Seasonal daily transpiration was 28% lower in plants treated with either twice-ambient CO_2 or 1.5 times ambient ozone compared with the control. Production water use efficiency of soybean increased by 44% under elevated CO_2 due to increased biomass and yield and decreased transpiration despite increased leaf area production. Production water use efficiency was lowered 10% by ozone due to suppressed growth and yield. These results indicate that elevated CO_2 will help to buffer soybean against ozone injury and water stress. Decreased water loss stemming from ozone-suppressed growth may be offset by evaporative losses from exposed soil surfaces due to reduced leaf area production.

  Booker, F.L., E.L. Fiscus, and J.E. Miller. 2004. Combined effects of elevated atmospheric carbon dioxide and ozone on soybean whole-plant water use. *Environmental Management*. 33:S355-S362.

- **The role of ozone flux and antioxidants in the suppression of ozone injury by elevated CO_2 in soybean**. Elevated CO_2 concentrations often lessen the deleterious effects of ozone, but the mechanisms responsible for this response remain unclear. Previous studies have indicated that CO_2 protection against ozone injury can be attributed to reduced ozone uptake in leaves, while other studies suggest that elevated CO_2 may simulate antioxidant metabolism. Soybean was exposed to combinations of CO_2 and ozone in open-top chambers, using experimental manipulations to generate treatments where ozone flux into leaves was similar under either ambient or twice-ambient CO_2 concentrations. Equivalent ozone fluxes that suppressed photosynthesis, growth, and yield at ambient CO_2 were much less detrimental to plants exposed to elevated CO_2. However, the protection provided by elevated CO_2 did not appear to be related to antioxidant enzymes (superoxide dismutase, glutathione reductase, and peroxidase) or metabolites (glutathione and ascorbic acid). Thus increases in atmospheric CO_2 will likely ameliorate ozone damage to many crops through a combination of reduced ozone uptake, stimulated photoassimilation and metabolic processes yet to be identified that utilize the additional carbon from photosynthesis.

  Booker, F.L., and E.L. Fiscus. 2005. The role of ozone flux and antioxidants in the suppression of ozone injury by elevated carbon dioxide in soybean. *Journal of Experimental Botany*. 56:2139-2151.

- **Comparative responses of container versus ground-grown soybean to elevated CO_2 and ozone**. Many studies of CO_2 enrichment and ozone effects on crops have used container-grown plants, but the applicability of such studies for predictions of crop performance under future climate scenarios has been questioned. Our field experiments with soybean grown in large (15 and 21 liter) pots and in the ground showed that elevated CO_2 increased yield and ozone suppressed it in both rooting environments. Elevated CO_2 also reduced the toxic effects of ozone. Overall, the relative effects of elevated CO_2 and ozone on aboveground biomass and seed yield were similar for plants grown in pots compared with plants grown in the ground. However, when soybean was grown in the ground and in pots under ambient and elevated CO_2 at equal planting densities, per plant yields were about 17% less in container-grown plants at both levels of CO_2, possibly due to higher daytime soil temperatures in containers. The results indicate that plants grown in large containers provide reliable relative estimates of CO_2 and ozone effects on soybean growth and yield while effects on production are better assessed with plants grown in the ground.

  Fiscus, E.L., F.L. Booker, J.-J.B. Dubois, T.R. Rufty, J.W. Burton and W.A. Pursley. 2007. CO_2 enhancement effects in container- versus ground-grown soybeans at equal planting densities. *Crop Science* 47:2486-2494.

  Booker, F.L., J.E. Miller, E.L. Fiscus, W.A. Pursley, and L.A. Stefanski. 2005. Comparative responses of container-versus ground-grown soybean to elevated CO_2 and O_3. *Crop Science* 45:883-895.

- **Ozone, plant competition and temperature affect the CO_2 enhancement response in rice**. Rice plants grown over a range of planting densities and reciprocal combinations of high and low ozone and CO_2 concentrations showed that while the response to ozone alone was consistent, the level of damage was dependent on planting density and temperature during flowering. For example, at low planting densities, the productivity per plant was reduced more by ozone, and increased more by elevated CO_2 than at high densities. High temperatures during flowering in one year of the experiment severely limited productivity at elevated CO_2 because accelerated development in that treatment forced flowering to occur during the high temperature window, leading to a negative CO_2 enhancement ratio (ER). This experiment suggests that the ER may be limited in future climates by high temperatures as well as other limiting resources at high planting densities. That is, to gain full production advantage of the effects of elevated atmospheric CO_2, especially in the presence of air pollutants, it may be necessary to increase inputs of nutrients or other resources. Additionally, higher global temperatures may lead to increasing yield losses due to increased numbers of high temperature episodes during sensitive developmental periods.

  Reid, C.D. and E.L. Fiscus.2007. Ozone and density affect the response of biomass and seed yield to elevated CO_2 in rice. *Global Change Biology* (In press).

- **Decomposition of soybean grown under elevated concentrations of CO_2 and ozone**. Increasing concentrations of atmospheric CO_2 and ground-level ozone have the potential to affect decomposition processes through changes in plant chemistry and productivity. For soybean grown under combinations of low and high concentrations of CO_2 and ozone in open-top field chambers, elevated CO_2 increased aboveground residue production by 28–56% while elevated ozone suppressed it by 15–46%. The inhibitory effects of added ozone were largely negated by elevated CO_2. Plant residue chemistry was marginally affected by the elevated gas treatments. It was concluded that the primary influence of elevated atmospheric CO_2 and ozone on decomposition processes will be largely realized through changes in plant residue production, which is increased by elevated CO_2 and suppressed by ozone. Effects on production will include changes in inputs to the soil of mineral nutrients and organic compounds, including recalcitrant carbon compounds, that are likely to influence soil microbiology, nutrient cycling, and carbon sequestration processes.

  Booker, F.L., S.A. Prior, H.A. Torbert, E.L. Fiscus, W.A. Pursley, and S. Hu. 2005. Decomposition of soybean grown under elevated concentrations of CO_2 and O_3. *Global Change Biology* 11:685-698.

- **Rising Tropospheric Ozone Concentration Reduces Soybean C Uptake**. Surface O_3 concentrations in the northern mid-latitudes have risen from an estimated pre-industrial 10ppb to an average regional concentration of almost 60ppb today. Mean July ozone levels are projected to increase over this century by 30ppb in the Midwest US, and by 50ppb in eastern China, two of the largest soybean production areas of the globe. Research was conducted that utilized an open-air treatment facility to determine how soybean responds to elevated O_3 exposure in the field. Elevated O_3 accelerated the loss of photosynthetic capacity in the late-season cohort of leaves, which are critical in providing assimilate to the developing seeds. However, there is significant variation in response to O_3 among soybean cultivars. This information will help predict the amount of crop yield loss that can be expected as ozone pollution increases.

  Morgan, P.B., C.J. Bernacchi, D.R. Ort, S.P. Long. 2004. An in vivo analysis of the effect of season-long open-air elevation of ozone to anticipated 2050 levels on photosynthesis in soybean. *Plant Physiology* 135: 2348-2357.

  Christ, M.M., E.A. Ainsworth, R.L. Nelson, U. Schurr, and A. Walter. 2006. Putative yield loss in field-grown soybean under elevated ozone can be avoided at the expense of leaf growth during early reproductive growth stages in favorable environmental conditions. *Journal of Experimental Botany* 57: 2267-2275.

Topic: Protect agricultural productivity from excessive ozone.
Goal: Search for the basis for developing ozone-tolerant crop varieties.

Summary: High concentrations of ascorbic acid (vitamin C) and other antioxidants were associated with ozone-tolerance in soybean and snapbean. Such associations along with assays of photosynthesis, foliar injury, and yield provided the basis for screening for ozone-tolerance for the purpose of developing new ozone-tolerant cultivars. Ozone-sensitive and -tolerant snap bean cultivars were developed for studying biological mechanisms of ozone injury and for use as bio-indicator plants of ozone damage. The basis for developing ozone-tolerant crop varieties will rely on insights to genetic, biochemical and physiological processes utilizing crop and model plant systems. Information was provided to the EPA for use in preparation of the 2007 OAQPS Staff Paper, Review of the National Air Quality Standards for Ozone: Policy Assessment of Scientific and Technical Information. Contributions to and reviews of EPA 2006 Air Quality Criteria for Ozone and Related Photochemcial Oxidants.

Selected Accomplishments

- **Screening soybean ancestors for potential sources of ozone tolerance genes**. Thirty soybean ancestors representing a majority of genes present in modern U.S. cultivars were screened for ozone sensitivity under greenhouse conditions using foliar injury as an assessment tool. The ancestral lines exhibited a wide range of ozone injury compared with established ozone-sensitive and tolerant soybean cultivars. Three ancestors exhibited minimal ozone injury following a 6-day exposure to 80 ppb ozone. If confirmed in yield tests, these ozone-tolerant ancestors represent sources of genes for development of new ozone tolerant cultivars so that productivity can be maintained under future climate scenarios where ambient ozone concentrations are expected to be much higher than today.

- **Snapbean genotypes suggest possible mechanisms for ozone sensitivity**. Growth of the three snap bean genotypes, S156, R123 and R331 showed that on a unit exposure basis, R331 was found to be as sensitive to ozone as S156 while R123 was substantially less sensitive, confirming previous data. Measurements of daily water loss, photosynthetic parameters and seed yield showed that even though S156 was sustaining greater levels of damage to its photosynthetic systems, the feedback control regulating stomatal conductance was compromised resulting in greater daily water loss even though photosynthetic rates and leaf area were substantially reduced. Additional data suggested that the S156 ozone-sensitive line has little ability to maintain Rubisco activity in response to ozone when

compared to the resistant line. Ozone-sensitivity is thus related to suppressed photoassimilation capacity and loss of stomatal control.

Flowers, M.D., E.L. Fiscus, K.O. Burkey, F.L. Booker, and J.-J. B. Dubois. 2007. Photosynthesis, chlorophyll fluorescence, and yield of snap bean (Phaseolus vulgaris L.) genotypes differing in sensitivity to ozone. *Environmental and Experimental Botany* (In press).

- **Maintenance of elevated amounts of the reduced form of vitamin C factors in soybean tolerance to ozone**. Exposure of plant leaves to ozone causes damage to photosynthesis and substantially reduces the yield of many crops. It was demonstrated that there was a correlation between the ozone tolerance of soybean cultivars and higher foliar levels of the reduced form of the antioxidant vitamin C. Higher redox status of vitamin C was accompanied by a greater tolerance of leaf photosynthesis and stomatal conductance to ozone. Ozone tolerant cultivars also had higher activities of foliar enzymes involved in the removal of strong oxidants. This study indicated that there is genetic variation in the soybean germplasm, in the activities of enzymes associated with the reduction of dehydroascorbate to ascorbate, as well as the enzymes associated with the scavenging of strong oxidants. These observations suggest possible breeding strategies for improving the tolerance of soybean cultivars to prolonged exposure to ozone.

  Britz S.J. and Robinson, J.M. 2001. Chronic ozone exposure and photosynthate partitioning into starch in soybean leaves. 2001. *International Journal of Plant Sciences* 162 (1): 111-117.

  Robinson, J.M., and Britz, S.J. 2001. Ascorbate-dehydroascorbate level and redox status in leaflets of field grown soybeans exposed to elevated ozone levels. 2001. *International Journal of Plant Sciences* 162: 119-125.

- **Leaf antioxidants and ozone tolerance**. Antioxidant compounds present in the leaf apoplast (the liquid layer surrounding leaf cells) have the potential to scavenge ozone entering the leaf and thus prevent foliar injury and reduce the impact of ozone on biomass production and seed yield. Using biochemical approaches, leaf apoplast antioxidant capacity was compared for crop plants (snap bean and soybean) and native vegetation (wildflowers in the Great Smoky Mountains National Park) known to exhibit differences in ozone sensitivity. Vitamin C and other unidentified compounds found in the leaf apoplast were associated with ozone tolerance. These compounds represent potential metabolic targets that could be manipulated to enhance the ozone tolerance of crops.

  Cheng, F.-Y., K.O. Burkey, J.M. Robinson, and F.L. Booker. 2007. Leaf extracellular ascorbate in relation to O3 tolerance of two soybean cultivars. *Environmental Pollution* 150:355-362

  Burkey, K.O., H.S. Neufeld, L. Souza, A.H. Chappelka, and A.W. Davison. 2006. Seasonal profiles of leaf ascorbic acid in ozone-sensitive wildflowers. *Environmental Pollution* 143:427-434.

  Burkey, K.O., G. Eason, and E.L. Fiscus. 2003. Factors that affect extracellular ascorbic acid content and redox status. *Physiologia Plantarum* 117:51-57.

- **Vitamin C in soybean leaves is maintained during severe drought stress**. Severe water stress, like elevated ozone exposure, can produce symptoms of oxidative damage in plant leaves. An investigation tested whether drought reduced the ability of leaves to maintain high levels of the antioxidant ascorbic acid, the reduced form of vitamin C. It was demonstrated that leaves of soybean and spinach maintained both high vitamin C levels and high redox status (the ratio of ascorbic acid to dehydroascorbate) during severe drought-induced water stress under high light. It was concluded that during water stress, enzymes of the ascorbate-glutathione cycle in leaf cells, as well as the photosynthetic electron transport in chloroplasts that generates reductant, were able to remain active enough to maintain the reduction and synthesis of vitamin C. This indicates that ozone exposure and drought stress are dissimilar in the way in which oxidative damage occurs, and improving the tolerance to the two stresses will require different strategies of crop genetic manipulation.

Robinson, J. M. and Bunce J. A 2000. Influence of drought-induced water stress on soybean and spinach leaf ascorbate-dehydroascorbate level and redox status. *International Journal of Plant Sciences*. 161: 271-279.

- **A snap bean bio-indicator system for assessment of ambient ozone effects on vegetation**. Bio-indicator plants provide an approach to direct assessment of the effects of ambient ozone on vegetation. Ozone-sensitive and -tolerant snap bean cultivars were developed, tested, and found to have the capacity to detect ozone effects at present-day levels of air pollution. Ozone dose response studies of sensitive and tolerant snap bean lines showed a sharp decline in yield of the sensitive line at ozone concentrations above 30 parts per billionppb, supporting the use of snap bean as an ozone bio-indicator system. These cultivars are now being used at research stations around the U.S. to assess the impact of ambient ozone in the absence of artificial exposure systems. Specifically, snap bean seed lines that exhibit differences in ozone sensitivity were provided to researchers at five universities for a multi-state project aimed at modeling impacts of ambient ozone on vegetation (http://www.ncsu.edu/project/usda-ne-1013/snap_bean_project.htm). Differentially ozone-sensitive snap bean seed lines were provided to the NASA GLOBE project for use in educational activities (http://www.globe.gov). UNECP ICP Vegetation program participants were provided ozone-sensitive and tolerant clover plants for biomonitoring and modeling of ambient ozone effects on vegetation in North America and Europe (http://icpvegetation.ceh.ac.uk/index.htm).

  Burkey, K.O., J.E. Miller, and E.L. Fiscus. 2005. Assessment of ambient ozone effects on vegetation using snap bean as a bio-indicator species. *Journal of Environmental Quality* 34:1081-1086.

  Flowers, M.D., E.L. Fiscus, K.O. Burkey, F.L. Booker, and J.-J. B. Dubois. 2007. Photosynthesis, chlorophyll fluorescence, and yield of snap bean (Phaseolus vulgaris L.) genotypes differing in sensitivity to ozone. *Environmental and Experimental Botany* (In press).

- **G-protein signaling pathway in plant response to ozone stress**. Arabidopsis mutants were used to obtain the first evidence that ozone responses in plants are mediated in part by a plasma membrane G protein signaling pathway. Using mutants developed by a collaborator it was shown that plants missing specific proteins in the G protein signaling pathway did not exhibit characteristic ozone symptoms (leaf epinasty) following chronic ozone exposure. G-protein null mutations, however, did not confer protection from ozone-induced biomass suppression. The implications are that ozone responses are meditated by multiple signaling pathways and that targeting the G-protein pathway alone may not be sufficient for improving crop response to ozone stress.

  Booker, F.L., K.O. Burkey, K. Overmyer, and A.M. Jones. 2004. Differential responses of G-protein Arabidopsis thaliana mutants to ozone. *New Phytologist* 162:633-641.

- **Influence of ozone on ribonuclease activity in wheat (Triticum aestivum) leaves**. Enzymes that degrade RNA (RNases) exert a major influence on gene expression during leaf development and in response to programmed cell death processes such as pathogen attack and wounding. Ozone often induces injury and accelerated senescence in many plants, but the biochemical mechanisms involved in these responses remain unclear. Exposure of a sensitive wheat cultivar to ozone caused a two-fold increase of RNase activity in flag leaves. RNase activity gels indicated the presence of three major RNases and two nucleases, and their expression was enhanced by the ozone treatment. Induction of these enzymes was also found during normal flag leaf senescence. However, phosphate concentrations in the leaf tissue samples suggested that ozone-induced injury and accelerated senescence was atypical of normal senescence processes. Thus, leaf senescence associated with ozone stress appears to be more complex than simply an acceleration of normal leaf senescence.

  Booker, F.L. Influence of ozone on ribonuclease activity in wheat (Triticum aestivum L.) leaves. 2004. *Physiologia Plantarum* 120:249-255.

Program Component V: Pesticides and Other Synthetic Organic Compounds

Topic: Mechanisms and processes influencing pesticide volatilization and transport.
Goals: Understand the biological, physical, and chemical mechanisms and processes that influence pesticide volatilization and transport. Understand transport processes. Quantify factors controlling the movement and availability of pesticides.

Summary: Pesticides may also be attached to particulates (i.e., colloids) from other agricultural or non-agricultural sources. New research on this topic has improved our understanding of pesticides' fate and dynamics in soil, water, and the atmosphere, and has provided the knowledge base for development of methodologies to protect human health and the atmosphere from adverse effects from pesticide use. The new methodologies include new information on the degradation of pesticidal compounds, new methods for estimating agricultural film permeability and elucidation of a new degradation mechanism between agricultural fumigants. The research also provides a better understanding of the conditions that promote volatilization and the importance of volatilization relative to other losses, such as leaching.

Selected Accomplishments

- **New information on the degradation of soil fumigants.** Soil fumigation using shank injection tends to create high fumigant concentration gradients along the soil profile from the injection points to the soil surface. A temperature gradient also exists along the soil profile. The effects of soil temperature, organic matter and fumigant concentration on degradation of methyl isothiocyanate (MITC) and 1,3-dichloropropene (1,3-D) was studied in Arlington sandy loam and a new model was proposed to describe the concentration-degradation rate relationship. At the same concentration, degradation rates of MITC and 1,3-D increased exponentially with temperature from 20 to 40°C and followed the Arrhenius equation ($r^2 > 0.81$). At the same temperature, degradation rates of both fumigants were inversely proportional to concentration and were well described by an inverse first-order equation ($r^2 > 0.89$). Initial concentration had a significant effect on degradation of these fumigants in the soil. Sterilized and non-sterilized soils were used to show that the primary degradation pathway was microbially-mediated biodegradation. Additions of organic matter also increased the degradation rate. Results from these studies indicate that pesticide fate models should include temperature and initial concentration in simulating dissipation of MITC and 1,3-D in the field.

Ma, Q.L., Gan, J., Papiernik, S.K., Becker, J.O. and Yates, S.R. 2001. Degradation of soil fumigants as affected by initial concentration and temperature. *Journal Environmental Quality* 30:1278-1286.

Dungan, R., Gan, J. and Yates, S.R. 2001. Effect of temperature, organic amendment rate, and moisture content on the degradation of 1,3-dichloropropene in soil. *Pesticide Management Science* 57:1107-1113.

Papiernik, S.K., Gan, J. and Yates, S.R. 2002. Characterization of propargyl bromide transformation in soil. *Pest Management Science* 58:1055-1062.

Dungan, R., Gan, J. and Yates, S.R. 2003. Accelerated degradation of methyl isothiocyanate in soil. *Water, Air, and Soil Pollution*. 142: 299–310.

Dungan, R.S., Yates S.R. 2003. Degradation of Fumigant Pesticides: 1,3-Dichloropropene, Methyl Isothiocyanate, Chloropicrin, and Methyl Bromide, *Vadose Zone Journal*. 2:279-286.

Guo, M., Papiernik, S.K., Zheng, W. and Yates, S.R. 2004. Effect of environmental factors on 1,3-dichloropropene hydrolysis in water and soil. *Journal Environmental Quality*. 33:612-618.

Dungan, R.S., Papiernik, S., Yates, S.R. 2005. Use of composted animal manures to reduce 1,3-dichloropropene emissions. *Journal of Environmental Science & Health Part B-Pesticides Food Contaminants and Agricultural Wastes.* 40:355-362.

- **Volatile losses of some commonly-used pesticides are similar in magnitude to losses in the soil due to leaching and degradation**. The process of volatilization is often not considered important for many agricultural pesticides. While pesticide drift is well understood and can be minimized by proper use of equipment and monitoring weather conditions during application, volatilization can continue for several weeks after application. In a multi-year study of metolachlor volatilization, soil moisture was a key factor governing flux rates leading to volatile losses ranging from 5 to 25%. In a separate volatilization study of multiple pesticides, rain events occurring during the first three days both enhanced volatile losses from the wet soil and led to downward movement of residues into the soil column. Emissions to the atmosphere led to losses ranging from 7.5% for atrazine up to >34% for endosulfan. Results of these studies indicate the importance of measuring all environmental compartments simultaneously in pesticide fate experiments. An interagency agreement with EPA was formed as part of the research.

Preuger, J.H., T.J. Gish, L.L. McConnell, L.G. McKee, J.L. Hatfield, and W.P. Kustas. 2005. Solar Radiation, Relative Humidity, and Soil Water Effects on Metolachlor Volatilization. *Environmental Science and Technology* 39(14):5219-5226.

Rice, C.P., C.B. Nochetto, and P. Zara. 2002. Volatilization of Trifluralin, Atrazine, Metolachlor, Chlorpyrifos, alpha-Endosulfan, and beta-Endosulfan from Freshly Tilled Soil. *Journal of Agricultural Food Chemistry* 50(14):4009-4017.

Hapeman, C. J., L.L. McConnell, C.P. Rice, A.M. Sadeghi, W.F. Schmidt, G.W. McCarty, J.L. Starr, P.J. Rice, J.T. Angier, and J.A. Harman-Fetcho. 2003. Current United States Department of Agriculture - Agricultural Research Service Research on Understanding Agrochemical Fate and Transport to Prevent and Mitigate Adverse Environmental Impacts. *Pest Management Science* 59:681-690.

Jayasundera, S., W.F. Schmidt, C.J. Hapeman, and A. Torrents. 2003. Examination of Molecular Interaction Sites of Acetanilides with Organic Matter Surrogates Using Nuclear Magnetic Resonance Techniques. *Journal of Agricultural and Food Chemistry* 51(13):3829 - 3835.

McConnell, L.L., C.P. Rice, and S.M. Chernyak. 2007. Atmospheric Deposition Flux Estimates for Chlorpyrifos and Trifluralin in the Chukchi Sea. In: 1993 Monograph, Results of the 5th Joint US-Russian Bering and Chukchi Sea Expedition, Editors: Grebmeier J. and Rice, C., U.S. Geological Survey (in press)

- **Sprayfield irrigation operations can release flame retardant chemicals into the atmosphere.** Polybrominated diphenyl ethers (PBDEs) are flame-retardant chemicals used as additives in many consumer products (i.e., foams, fabrics, and electronics). PBDE levels in the environment are increasing and PDBEs have been shown to cause neurotoxic effects in mice. They are frequently found in wastewater streams. Beneficial re-use of treated municipal wastewater in irrigation systems is used to recharge groundwater and to limit nutrient discharge from wastewater effluents into surface waters. Results from a multi-year experiment to measure organic contaminants in air on the Delmarva Peninsula revealed that spray irrigation is a significant source of PBDE release to the atmosphere. Analysis of vapor-particle partitioning behavior and air mass back-trajectory analysis was used to identify the source of elevated PBDE concentrations in Lewes, DE. Temporal trends indicated that aerial concentrations of PBDEs in this area are increasing at an exponential rate. The persistent nature of PBDEs and their potential for human toxicity makes these findings important for regulators and other decision-makers working in the area of wastewater management and water reuse.

Goel, A., L.L. McConnell, A. Torrents, J.R. Scudlark, and S. Simonich. 2006. Spray Irrigation of Treated Municipal Wastewater as a Potential Source of Atmospheric PBDEs. *Environmental Science and Technology* 40(7):2142-2148.

- **Fumigant mixtures containing metam sodium may fail to control plant-destroying pests**. Soil fumigants have the potential to cause pollution of the atmosphere and water supplies. These fumigants are becoming increasingly expensive to producers, and have a more limited spectrum of control than methyl bromide. This has caused growers to use mixtures of fumigants to control plant pests. Scientists found that a chemical reaction between mixtures of metam sodium and halogenated fumigants (i.e., methyl bromide, 1,3-dichloropropene, chloropicrin, and methyl iodide) quickly degrades the halogenated fumigant, reducing pest control efficacy, increasing fumigation cost, and increasing pollution. Experiments have been conducted to identify the reaction mechanisms between metam sodium and a halogenated fumigant so that a chemically stable fumigant mixture can be developed that is compatible with current fumigation practices and allows synergistic effects from combining different fumigants. The results have provided additional cost-effective options to growers and fumigators for preparing soils with pre-plant fumigation, and will help in the transition from methyl bromide fumigation to more sustainable management practices.

  Grant: Amvac Chemical Corporation; *"Investigating the factors that affect fumigant transport across agricultural films," PI: S.K. Papiernik (ARS)*, 2002-2004, $12,000.

  Zheng, W., Yates, S.R., Guo, M., Papiernik, S.K., and Kim, J.H. 2004. Transformation of chloropicrin and 1,3-dichloropropene by metam sodium in a combined application of fumigants. Journal of Agricultural & *Food Chemistry*. 52(10):3002-3009.

  Zheng, W., Yates, S.R., Papiernik, S.K. and Guo, M. 2004. Effect of Combined Application of Methyl Isothiocyanate and Chloropicrin on Their Transformation. *Journal Environmental Quality*. 33:2157-2164.

  Guo, M., Yates, S.R., Papiernik, S.K., and Zheng, W. 2005. Incompatibility of metam sodium with halogenated fumigants. *Pest Management Science*. 61:467-476.

  Zheng, W., Yates, S.R., and Papiernik, S.K. 2006. Conversion of metam sodium and emission of fumigant from soil columns, *Atmospheric Environment*. 40:7046–7056.

- **Volatilization is a significant loss process for pesticides in South Florida**. Agricultural production has been implicated in the decline of ecosystem health in Biscayne and Florida Bays of south Florida. A study was conducted to identify and to quantify the concentrations of currently-used pesticides present in air, rain, and surface waters. Results showed that much higher pesticide levels were in rain and air relative to surface water. These data support the hypothesis that frequent pesticide applications, combined with the low organic carbon and alkaline soils, frequent overhead irrigation, high temperature, and high rates of evapotranspiration and precipitation create ideal conditions to increase pesticide volatilization. Additional analyses indicated that a higher hazard potential to aquatic organisms occurs during harvest (March) than during planting (November) primarily from endosulfan use on vegetables. These data provide documentation of conditions prior to implementation of the Comprehensive Everglades Restoration Plan (CERP). These results will also be important to regulatory and policy personnel in developing strategies and practices to minimize pesticide losses. An interagency agreement with NOAA was formed as part of the research.

  Key, P., M. Fulton, J.A. Harman-Fetcho, and L.L. McConnell. 2003. Acetylcholinesterase Activity in Grass Shrimp and Aqueous Pesticide Levels from South Florida Drainage Canals. *Archives of Environmental Contamination and Toxicology* 45:371-377.

Harman Fetcho, J.A., C.J. Hapeman, L.L. McConnell, T.L. Potter, C.P. Rice, A.M. Sadeghi, R.D. Smith, K. Bialek Kalinski, K.A. Sefton, B.A. Schaffer, and R.W. Curry. 2005. Pesticide Occurrence in Selected South Florida Canals and Biscayne Bay during High Agricultural Activity. *Journal of Agricultural and Food Chemistry* 53:6040-6048.

- **A new approach to measuring the permeability of agricultural films used in soil fumigation.** Agricultural films are commonly used to seal the soil surface after fumigation. Both the material used and the manufacturing process significantly affects a membrane's ability to limit the escape of fumigant gases to the atmosphere. A new approach to measuring film permeability was developed that is more accurate and reproducible than earlier methods. The new method also allows information obtained by different researchers to be directly compared, and doesn't depend on the concentration gradient across the film. Knowledge of the film's permeability and other characteristics is crucial in developing management practices to minimize fumigant emissions to the atmosphere. Films offer one method for reducing fumigant emissions to the atmosphere, and thus, can be used to reduce bystander exposure to harmful chemicals and near-surface ozone (i.e., smog) levels.

Papiernik, S.K., Yates, S.R. and Gan, J. 2001. An approach for estimating the permeability of agricultural films. *Environmental Science and Technology* 35:1240-1246.

Papiernik, S.K., Ernst, F.F. and Yates, S.R.2002. An apparatus for measuring the gas permeability of films. *Journal of Environmental Quality* 31:358-361.

Papiernik, S.K. and Yates, S.R. 2002. Effect of environmental conditions on the permeability of high density polyethylene film to fumigant vapors. *Environmental Science and Technology* 36:1833-1838.

Allaire, S.A., Yates, S.R., Ernst, F. and Papiernik, S.K.2003. Gas phase sorption-desorption of propargyl bromide and 1,3-dichloropropene on plastic materials. *Journal Environmental Quality*. 32:1915-1921.

Topic: Spray Drift and Deposition of Pesticides and Other Synthetic Organic Compounds
Goals: Understand the impacts of spray drift and deposition and to determine how spray characteristics affect pesticide movement away from the target zone.

Summary: Another mechanism promoting the movement of pesticides from the target zone is spray drift. This mechanism differs from volatilization in that fine droplets, or aerosols, can move through the atmosphere and be deposited in sensitive ecosystems. During the transport process, the material may evaporate or adsorb to colloidal material, and thus be transported large distances from the source region. Research was conducted to develop information to better understand the conditions that promote spray drift and deposition of air-borne pesticide to land and water surfaces. This research has helped to improve the delivery of pesticide sprays through improved nozzle-spray systems and has resulted in a new method to estimate of spray drift. Research has also demonstrated the importance of long-range pesticide transport to surface water throughout the U.S.

Selected Accomplishments

- **A user-friendly computer program to predict spray drift potential from ground spray applications.** One of the most serious problems that pesticide applicators face is spray drift, which results in airborne droplets of pesticide reaching unintended targets. Complaints regarding spray drift are routinely brought to state departments of agriculture, and some cases even wind up in court. A user-friendly computer program was developed and released for pesticide spray applicators to estimate drift potentials before applying sprays, or making changes to spray practices and equipment to keep drift potential at a minimum level. This program has been used world-wide by researchers, educators, sprayer manufacturers and other agencies since it was released. The program has also been used in courts to adjudicate lawsuits on drift damages to neighboring crops.

Zhu, H., R. D. Fox, H. E. Ozkan. 2005. DRIFTSIM—Predicting Drift Distances of Spray Droplets. The program in CD was released to The Ohio State University Extension for distribution.

Zhu, H., R.D. Fox, and H.E. Ozkan. 2005. A Windows Version of DRIFTSIM for Estimating Drift Distances of Droplets. ASAE Paper No. 051145. (American Society Agricultural Engineers, St. Joseph, MI 49085).

- **Investigation of spray characteristics and drift reduction potential for conventional and air induction hydraulic nozzles**. During the past ten years, air induction nozzles were recommended by nozzle manufacturers and researchers to reduce spray drift. However, the engineering aspects of air induction nozzles have not been thoroughly studied for drift reduction. To obtain desired spray performances, air induction nozzles require much higher energy than conventional nozzles. Also, the price of air induction nozzles is 2-3 times higher than conventional nozzles. It is unclear to farmers and spray applicators whether it is practical and economical to use air induction nozzles. Our study demonstrated that spray performances and drift reduction potential of air induction nozzles could be achieved by conventional nozzles with an equal orifice size operated at low pressure. Therefore, spray applicators can use conventional nozzles with lower cost, lower energy and less equipment maintenance to obtain desired spray performances.

  Zhu, H., R C Derksen, H Guler, C R Krause, and H E Ozkan. 2005. Investigation of nursery canopy and ground deposition with three spray techniques. *Aspects of Applied Biology 77*. International Advances in Pesticide Application 2006 , Robinson College, Cambridge, UK. Pp. 489-496.

  Guler, H., H. Zhu, H. E. Ozkan, R.C. Derksen, and C.R. Krause. 2006. Wind Tunnel Evaluation of Drift Reduction Potential and Spray Characteristics with Drift Retardants at High Operating Pressure. *Journal of ASTM International (JAI)* Vol 3 (5): 1-9.

  Guler, H., H. Zhu, H.E. Ozkan; R.C. Derksen; Y.Yu and C.R. Krause. 2006. Spray Characteristics and Wind Tunnel Evaluation of Drift Reduction Potential with Air Induction and Conventional Flat Fan Nozzle. ASABE Paper No. 061111. (American Society of Agricultural and Biological Engineers, St. Joseph, MI 49085).

  Guler, H., H. Zhu (corresponding author), H. E. Ozkan, R.C. Derksen, Y. Yu, C.R. Krause. 2006. Spray Characteristics and Drift Reduction Potential with Air Induction and Conventional Flat Fan Nozzles. *Trans. ASABE*. Vol 50(3): 745-754.

- **Rainfall contributes 10-20% of the pesticide load to Chesapeake Bay.** The Chesapeake Bay has a large surface area to mean water volume ratio and receives 75-100cm of precipitation annually. Precipitation samples were collected in the Choptank River watershed (a tributary of the Chesapeake Bay) over four years and analyzed for 19 agricultural pesticides. Although chlorothalonil was the single biggest contributor to pesticide flux (33-46%), pesticide wet deposition was dominated by herbicides (46-61%) with the greatest fluxes occurring during the time of herbicide application on corn and soybeans. The extent of wet deposition of herbicides was dependent on the timing of precipitation relative to herbicide application, while insecticide and fungicide deposition was governed by the total amount of rainfall in the agricultural season. Comparison with published riverine flux data indicates that wet deposition can account for 10-20% of the annual loadings of pesticides to the Bay. These data were sought by the US EPA Chesapeake Bay Program Office for modeling pesticide inputs to the Bay.

  Goel, A., L.L. McConnell, and A. Torrents. 2005. Wet Deposition of Current Use Pesticides at a Rural Location on the Delmarva Peninsula: Impact of Rainfall Patterns and Agricultural Activity. *Journal of Agriculture and Food Chemistry* 53:7915-7924.

  Goel, A., L.L. McConnell, and A. Torrents. Determination of Vapor Pressure Temperature Relationships of Current Use Pesticides and Transformation Products. *Journal of Environmental Science and Health, Part A* (In press).

  Kuang, Z., L.L. McConnell, A. Torrents, D. Merritt, and S. Tobash. 2003. Atmospheric Deposition of Pesticides to an Agricultural Watershed of the Chesapeake Bay. *Journal of Environmental Quality* 32:1611-1622.

- **Snowfall is the most important transport process affecting pesticide exposure to amphibians in the Sierra Nevada Mountains.** Amphibian species in the Sierra Nevada Mountains have undergone drastic population declines over the past several decades; several species are listed as threatened. Pesticides have been implicated in their disappearance. Studies were conducted to characterize pesticide movement to this alpine ecosystem. In a sentinel amphibian species, a link was discovered between pesticide residues present in the vernal ponds due to atmospheric deposition and acetylcholinesterase inhibition, a biological indicator for pesticide exposure. The highest risk occurs when heavy snowfall continues into the spring months, coinciding with increased pesticide application activities in the Central Valley and the beginning of the amphibian reproduction cycle. This work provides important information to California extension and regulatory personnel on the effectiveness of practices to reduce insecticide volatilization. These data are part of a US EPA risk assessment for pesticides on amphibians in the Sierra Nevada Mountains.

  Fellers, G.M., L.L McConnell, D. Pratt, and S. Datta. 2004. Pesticides in Mountain Yellow-Legged Frogs (Rana muscosa) from the Sierra Nevada Mountains of California, USA. *Environmental Toxicology and Chemistry* 23:2170-2177.

- **Investigation of spray deposition and off-target loss with different spray techniques in nurseries.** Because many nurseries operate in small areas close to residential districts and urban or suburban areas, pesticide contamination in the environment threatens the quality of life and safety of nearby residents. Spray deposits at various elevations within crabapple trees, on the ground and in the air were investigated with an air blast sprayer equipped with conventional hollow cone nozzles, low drift nozzles, and conventional hollow cone nozzles with a drift retardant. Current settings of air blast sprayers provided too much spray deposition inside tree canopies. Excessive sprays were lost to the ground and air. Proper settings and application rates from the air blast sprayers were recommended for nursery applications. Leading nursery growers are testing the recommended method to reduce both pesticide and water use by half. This research will result not only in a reduction in the amount of pesticides used in the nursery industry, but also in a reduction of labor costs and adversary environmental pollutions due to pesticide applications.

  Krause, C.R., H. Zhu, R.D. Fox, R.D. Brazee, R.C. Derksen, L.E. Horst, and R.H. Zondag. 2003. Detection and Quantification of Nursery Spray Penetration and Off-Target Loss with Electron Beam and Conductivity Analysis. *Trans. ASAE*. 47(2): 375-384.

  Zhu, H., R.C. Derksen, C. R. Krause, R.D. Fox, R.D. Brazee and H.E. Ozkan. 2005. Effect of solution pH conditions on fluorescence of spray deposition tracers. *Applied Engineering in Agriculture* 21(3):325-329.

  Zhu, H., R.C. Derksen, C.R. Krause, R.D. Brazee, R.H. Zondag, R.D. Fox, M.E. Reding and H.E. Ozkan. 2005. Spray deposition and off-target loss in nursery tree crops with conventional nozzle, air induction nozzle and drift retardant. ASAE Paper No. 051007. (American Society Agricultural Engineers, St. Joseph, MI 49085).

  Zhu, H., R. C. Derksen, H. Guler and C. R. Krause. 2006. Foliar deposition and off-target loss with different spray techniques in nursery application. *Trans. ASAE*. 49(2): 325-334.

- **Volatilized pesticides captured by riparian buffers can enter streams directly during rain events.** Forest canopies are known to remove chemicals readily from the air. These chemicals can be washed off the exposed surfaces of the tree (leaves and bark) and transported directly to forest floor during rain events. Pesticide residues were measured on the leaves of a highly instrumented riparian buffer region and in through-fall (rain passing through the leaf canopy directly to forest litter), stem flow (channeling of rainwater down the leaves, stem, and trunk), rain outside the riparian area, and runoff from adjacent fields. Results indicated that pesticide concentrations were much higher in the rain water after it passed through the tree canopy, particularly when rain events occurred within weeks of pesticide applications, and that pesticides entered riparian streams directly. This information is

needed by policymakers and natural resource managers considering the benefits of riparian areas for erosion control and reduced nutrient loadings. These data and additional data are required to build atmospheric contributions into the USDA-ARS Riparian Ecosystem Management Model (REMM).

Angier, J.T., G.W. McCarty, C.P. Rice, and K. Bialek, 2002, Influence of a Riparian Wetland on Nitrate and Herbicides Exported from an Agricultural Field. *Journal of Agricultural and Food Chemistry* 50(15): 4424-4429.

- **Temporal trends in the transport of herbicides across the air-water interface of the Choptank River in response to agricultural activity in the watershed.** The Choptank River watershed, located on the Delmarva Peninsula of the Chesapeake Bay, is dominated by agricultural land use. Weekly/biweekly air and monthly water samples at 8 riverine sites over a year were analyzed for pesticide residues. Air concentrations in the watershed increased more rapidly than water concentrations in response to herbicide applications in the early spring, creating a gradient between the two environmental compartments. Thus it appears that the air acted as a source of herbicides to the river during this period through the process of diffusive gas exchange across the air-water interface. Later in the season, as water concentrations increased, the air and water concentrations were closer to equilibrium and the net flux movement of herbicides was limited. These data and similar data from other tributaries have been used by the EPA-Chesapeake Bay Program Office in their toxics inventory to characterize segments of the Chesapeake Bay watershed. An interagency agreements with NOAA, EPA, and Maryland Department of Environment was setup as part of the research.

Kuang, Z., L.L. McConnell, A. Torrents, D. Merritt, and S. Tobash. 2003. Atmospheric Deposition of Pesticides to an Agricultural Watershed of the Chesapeake Bay. *Journal of Environmental Quality* 32:1611-1622.

Liu, B., L.L. McConnell, and A. Torrents. 2002. Herbicide and Insecticide Loading from the Susquehanna River to the Northern Chesapeake Bay. *Journal of Agricultural and Food Chemistry* 50:4385-4392.

Hapeman, C.J., C.P. Dionigi, P.V. Zimba, and L.L. McConnell. 2002. Agrochemical and Nutrient Impacts on Estuaries and Other Aquatic Systems. *Journal of Agricultural and Food Chemistry* 50: 4382-4384.

McConnell, L.L., J.A. Harman-Fetcho, and J.D. Hagy, III. 2004. Measured Concentrations of Herbicides and Model Predictions of Atrazine Fate in the Patuxent River Estuary. *Journal of Environmental Quality* 33: 694-604.

McConnell, L. L., C.P. Rice, C.J. Hapeman, L. Drakeford, J.A. Harman-Fetcho, K. Bialek, M.H. Fulton, A.K. Leight, and G. Allen. Agricultural Pesticides and Selected Degradation Products in Five Tidal Regions and the Mainstem of Chesapeake Bay. *Environmental Toxicology and Chemistry* (In press).

Topic: Model Development and Testing.

Goals: Develop new predictive algorithms to quantify pesticide transformation in the environment, develop easy-to-use models that can accurately describe movement and transformation of pesticides and other synthetic organic chemicals in the atmosphere and soil-water systems, and develop new and more accurate methods to couple soil-based processes to atmospheric-based processes.

Summary: Many National Programs have active research on the design and development of predictive methods that are appropriate for studying the fate and transport of volatile pesticides in the environment. In an effort to utilize resources efficiently, cooperative efforts have been established to adapt and use these models to protect natural resources from pesticide contamination. Selected research specific to pesticides and not reported elsewhere is given below. This research has improved our understanding of the dynamics of pesticides in the application zone and their transfer to the atmosphere. This research has shown that field-scale pesticide volatilization can be accurately predicted using simulation models that couple soil and atmospheric transport processes. Further investigations have shown that total pesticide loadings to the atmosphere can be accurately predicted with fairly simplified models; predicting emission rates, on the other hand, require more complex approaches.

- **Accurate prediction of herbicide volatilization from bare soil is possible**. Scientists at the U.S. Salinity Laboratory used a new soil diffusion model to predict the fate and transport of a pre-emergent herbicide (i.e., triallate) after application to bare soil and found good agreement in the hourly emission rate after the first day and that the measured total emission (31%) was nearly the same as the predicted values (21-37%). Past research has shown that pesticide movement in soils is affected by many interrelated factors such as the pesticide application methods, soil and environmental conditions, and water management practices. A prospective simulation over a period of 100 days showed that applying triallate to the soil surface would ultimately lead to emissions of 80% but incorporating triallate to depth of 10cm would reduce emissions to less than 5%. After 100 days, incorporation leads to soil concentrations of 41%, compared to 6% when surface applied. Soil incorporation therefore improves both efficacy and environmental protection. Models are valuable tools that can help improve one's understanding of physical processes, help to promote environmental protection, and can be used to make more efficient use of materials used in crop production.

  Yates, S.R., Wang, D., Papiernik, S.K. and Gan, J. 2002. Predicting pesticide volatilization from soils, *Environmetrics* 13:569–578.

  Yates, S.R. 2006. Measuring herbicide volatilization from bare soils. *Environmental Science and Technology*. 40:3223 -3228.

  Yates, S.R. 2006. Simulating herbicide volatilization from bare soil affected by limited solubility in water. *Environmental Science and Technology*. 40:6963-6968.

- **Protecting the fruit and vegetable industries from the loss of soil fumigants**. Ground-level ozone, a primary ingredient of smog, is a severe pollution problem in California and other parts of the United States; new methods are needed to reduce VOC emissions from agricultural fumigants and pesticides. Many approaches have recently been developed to reduce fumigant emissions to the atmosphere, but insufficient experimental information is available to support regulation that would allow producers to incorporate these methods into their production systems. To obtain this information using conventional approaches would take many years, cost many millions of dollars, and would not provide complete and consistent information to regulators. This project's goal is to develop new, simple, low-cost, and accurate methods that can be used in place of currently mandated approaches to obtain fumigant emissions estimates. The methodology will be applied to current fumigation practices and should provide state and federal regulators with urgently needed information that can be used to quickly and effectively regulate new emission-reduction methods, thus providing the fruit and vegetable industries with more options to reduce emissions and for developing efficient production systems.

  Grant: California Strawberry Commission, "*Development and testing of simplified and cost-effective methodology to evaluate emission reduction from fumigation during strawberry production"*, PI: S.R. Yates (ARS), 2006-2007, $96,500.

Topic: Technologies for control of emissions.
Goals: Develop alternative methods to reduce emissions from agricultural sources

Summary: Growers in many parts of the Nation face new regulations regarding the use of pesticides in crop production. New regulations promulgated by EPA's Ambient Air Quality Standards have increased the pressure on growers to limit the emissions of volatile organic chemicals into the atmosphere, including both the pesticide itself and formulation material. Many research activities have been devoted to emission reduction, including some research efforts identified in National Program 308 (Methyl Bromide Alternatives). The importance of these studies is demonstrated by grants provided by various governmental and industry organizations. This research identified a variety of strategies to control

unwanted pesticide emissions to the atmosphere, including organic and/or fertilizer amendments, use of surface water seals, using irrigation systems to apply chemicals, and new spray systems that reduce pesticide losses. Total grant funding from non-ARS sources for this research exceeds $1.5 M

- **Development of an organic amendment method to reduce fumigant emissions**. Scientists conducted laboratory and large-scale field experiments to determine the effectiveness of adding organic material (municipal green waste at 300 tons/acre) to the soil surface prior to soil fumigation, in reducing Telone II (1,3-dichloropropene) emissions to the atmosphere. The total measured emissions ranged from 3-7% and compared very well with laboratory values. For non-amended soil, the total emissions were approximately 33%. Repeatedly applying irrigation water to the natural and amended field soil reduced emissions by approximately 50% and is clearly an effective method to reduce fumigant levels in the atmosphere. Adding organic material to the surface soil decreased emissions by greater than 75%. Added organic material also improved soil tilth, and provided a source of nutrients and an ecologically sound means of disposal for municipalities. This research demonstrates that adding organic material and/or sealing the soil surface with repeated water application are economical and effective emission-reduction methodologies. As regulations on atmospheric emissions become more severe, this research provides growers with alternatives to meeting state-imposed emission targets.

  Grant: California Air Resources Board Project, “Reducing Emissions of VOC from Agricultural Fumigation", S.R. Yates (USDA) and J. Gan (UC-Riverside), 2004-2008, $200,000

  Yates, S.R., Gan, J., Papiernik, S.K., Dungan, R. and Wang, D. 2002. Reducing fumigant emissions after soil application, *Phytopathology* 92:1344-1348.

  Yates, S.R, Gan, J. and Papiernik, S.K. 2003. Environmental fate of methyl bromide as a soil fumigant. *Reviews of Environmental Contamination and Toxicology*. 177:45-122.

  Ashworth, D.J., and Yates, S.R. 2007. Surface irrigation reduces the emission of volatile 1,3-D from agricultural soils, *Environmental Science and Technology*. 41:2231-2236.

- **Irrigation and pesticide management practices to reduce pesticide contamination of the atmosphere and water supplies**. The use of soil fumigants has the potential to cause pollution of the atmosphere and water supplies. Due to the pending phase-out of methyl bromide, new chemicals are needed that are environmentally safe. Experiments were conducted to determine whether drip applications of fumigants produce lower atmospheric emissions compared to shank injection. The results indicate that (1) the configuration of the drip system (i.e., emitter spacing, number of lines) had little impact on emissions, (2) tarping the soil surface with standard high-density polyethylene reduced the maximum flux but did not affect cumulative emissions, and (3) the use of impermeable plastic can drastically reduce emissions from the covered beds but a large proportion of the total flux will escape from the uncovered furrows. These experiments provide detailed information on the performance of subsurface drip application of fumigants, and will provide valuable guidance for reducing emissions for this fumigant application method.

  Wang, D., Yates, S.R., Ernst, F.F. and Knuteson, J. 2001. Volatilization of 1,3-dichloropropene under different applications methods. *Water, Air and Soil Pollution* 127:109-123.

  Papiernik, S.K., Yates, S.R., Dungan, R.S., Lesch, S.M., Zheng, W., Guo, M.X. 2004. Effect of surface tarp on emissions and distribution of drip-applied fumigants. *Environmental Science & Technology*. 38:4254-4262.

  Papiernik, S. K., R. S. Dungan, W. Zheng, M. Guo, S. M. Lesch, and S. R. Yates. 2004. Effect of application variables on emissions and distribution of fumigants applied via subsurface drip irrigation. *Environmental Science & Technology*. 38:5489-5496.

Guo, M., Zheng, W., Papiernik, S.K., and Yates, S.R. 2004. Distribution and leaching of methyl iodide in soil following emulated shank and drip application. *Journal Environmental Quality*. 33:2149-2156.

Allaire, S.E., Yates, S.R. and Ernst, F.F. 2004. Effect of soil moisture and irrigation on propargyl bromide volatilization and movement in soil. *Vadose Zone J*. 3: 656-667.

Allaire, S.E., Yates, S.R., Zhang, Q., and Ernst, F.F. 2005. The potential efficiency of irrigation management and propargyl bromide in controlling three soil pests: *Tylenchulus semipenetrans*, *Fusarium oxysporum* and *Echinochloa crus-galli*. *Pest Management Science* 61:799-808.

- **Techniques for reducing pesticide use and reducing off-target emissions to the air**. Food and ornamental production is threatened by Food Quality Protection Act (FQPA) and by regulatory constraints that limit available pest management tools.. Experiments were conducted on research farms, commercial nursery production systems, and in greenhouses to evaluate methodologies for applying pest management materials to improve the efficacy of these materials and mitigate off-target spray movement. Air-assist spraying, electrostatic charged spraying and large droplet applications have been shown to be effective in different pest management situations. In vegetable insect and disease management trials, new application methodologies compared favorably with the traditional small droplet application. Studies also found that lower rates of fungicides and insecticides could provide acceptable pest control and reduce spray drift. Tree spraying studies demonstrated that tower spraying techniques could keep more material in the target area and reduce off-target spray drift. Research trials also demonstrated that alternatives to traditional pesticides, such as entomopathogenic nematodes (EPNs), can be applied through conventional application equipment without significantly reducing viability of the nematodes. These results demonstrate that it is possible to apply some biological pest management alternatives without major investments in new application technologies.

Mueller, D.S., A.E. Dorrance, R.C. Derksen, H.E. Ozkan, J.E. Kurle, C.R. Grau, J.M. Gaska, G.L. Hartman, C.A. Bradley, and W.L. Pedersen. 2002. Efficacy of fungicides on *Sclerotinia slerotiorum* and potential control of *Sclerotinaia* stem rot on soybean. *Plant Disease*. v86. p. 26-31

Fife, J.P., Derksen, R.C., Ozkan, H.E., Grewal, P.S. 2003. Effects of pressure differentials on the viability and infectivity of entomopathogenic nematodes. *Biological Control*. 2003. v. 27. p. 65-72.

Fox, R.D. and R.C. Derksen. 2003. Airflow Measurement. *Encyclopedia of Agricultural, Food, and Biological Engineering*. Marcel Dekker, Inc.: New York, 21-24.

Ramalingam, N., P.P. Ling, R.C. Derksen. 2003. Dynamic segmentation for automatic spray deposits analysis on uneven leaf surfaces. *Transactions of the ASAE*. 46(3). P. 893-900.

Derksen, R.C., Krause, C.R., R.D. Fox, and R.D. Brazee. 2004. Spray delivery to nursery trees by air curtain and axial fan orchard sprayers to nursery trees. *Journal of Environmental Horticulture*. 22(1):17-22.

Ebert, T.A., R.C. Derksen, R.A. Downer, and C.R. Krause. 2004. Comparing greenhouse sprayers: the dose transfer process. *Journal of Pesticide Science*. 60:507-513.

Ebert, T.A., and R.C. Derksen. 2004. A geometric model of mortality and crop protection for insects feeding on discrete toxicant deposits. *Journal of Economic Entomology*. 97(2):155-162.

Fife, J.P., R.C. Derksen, H.E. Ozkan, P.S. Grewal, J.J. Chalmers, and C.R. Krause. 2004. Evaluation of a contraction flow field on hydrodynamic damage to entomopathogenic nematodes – a biological pest control agent. *Biotechnology and Bioengineering*. 86(1):96-107.

Fox, R.D., R.C. Derksen, H. Zhu, R.A. Downer, and R.D. Brazee. 2004. Airborne spray collection efficiency of nylon screens. *Transactions of the ASAE*. 20(2):147-152.

Krause, C.R., H. Zhu, R.D. Fox, R.D. Brazee, R.C. Derksen, L.E. Horst, and R.H. Zondag. 2004. Detection and quantification of nursery spray penetration and off-target loss with electron beam and conductivity analysis. *Transactions of the ASAE*. 47(2): 375-384.

Fife, J.P., Ozkan, H.E., Derksen, R.C., Grewal, P.S., and Krause, C.R. 2005. Viability of a biological pest control agent through hydraulic nozzles. *Transactions of the ASAE*. 48(1):45-54.

Ramalingam, N., Ling, P.P., and Derksen, R.C. 2005. Background reflectance compensation and its effect on multispectral leaf surface moisture assessment. *Transactions of the ASAE.* 48(1):375-383.

Derksen, R.C., Krause, C.R., Fox, R.D., Brazee, R.D., and Zondag, R. 2006. Effect of Application Variables on Spray Deposition, Coverage, and Ground Losses in Nursery Tree Applications. *Journal of Environmental Horticulture.* 24(1):45-52.

Derksen, R.C., H. Zhu, H.E. Ozkan, A.E. Dorrance, and C.R. Krause. 2006. Effects of air-assisted and conventional spray delivery systems on management of soybean diseases. Aspects of Applied Biology 77. I*nternational Advances in Pesticide Applications 2006*, Robinson College, Cambridge, UK. Pp. 415-422.

Fife, J.P., H.E. Ozkan, R.C. Derksen, and P.S. Grewal. 2006. Using computational fluid dynamics to predict damage of a biological pesticide during passage through a hydraulic nozzle. *Biosystems Engineering.* Vol. 93(4):387-396.

Fife, J.P., Ozkan, H.E., Derksen, R.C., and Grewal, P.S. 2007. Effects of pumping on entomopathogenic nematodes and temperature increase within a spray system. *Applied Engineering in Agriculture.* Vol. 23(4).

- **A new approach to reducing fumigant emissions using common fertilizers and nitrification inhibitors.** Research was conducted that shows that commonly–used fertilizers and nitrification inhibitors can rapidly degrade and detoxify soil fumigants. Applying these materials as a thin layer at the soil surface, immediately after fumigant application, can significantly reduce atmospheric emissions. In addition, use of these agrochemicals can detoxify soil and water supplies contaminated with fumigant chemicals. The fumigants tested include methyl bromide, methyl iodide, chloropicrin, and 1,3-dichloropropene. The methodology was also found to be effective in degrading acetanilide herbicides such as alachlor. As an example, the fertilizer ammonium thiosulfate (ATS) was shown to reduce the cumulative emission of methyl bromide from 61% to less than 10% when added to soil in a 4:1 (ATS:methyl bromide) molar ratio. Similar reductions in 1,3-dichloropropene emission have been observed and the application of ATS had no effect on crop yields. The methodology has been shown effective in reducing fumigant emissions in outdoor field trials and is currently being adopted and tested by other researchers studying fumigation practices. Since ATS is an inexpensive fertilizer, this approach has great promises for field application as a risk-mitigation practice.

Gan, J., Wang, Q., Yates, S.R., Koskinen, W.C. and Jury, W.A. 2002. Dehalogenation of Chloroacetanilide Herbicides by Thiosulfate Salts. *Proceedings of National Academy of Sciences of The United States of America* 99:5189-5194.

Wang, Q., Gan, J., Papiernik, S.K. and Yates, S.R. 2001. Isomeric Effects of Thiosulfate Transformation and Detoxification of 1,3-Dichloropropene. *Environmental Toxicology and Chemistry* 20:960-964.

Zheng, W., Papiernik, S.K., Guo, M. and Yates, S.R. 2003. Accelerated degradation of methyl iodide by agrochemicals. *Journal of Agricultural and Food Chemistry*. 51:673-679.

Zheng, W., Papiernik, S.K., Guo, M. and Yates, S.R. 2004. Remediation of methyl iodide in aqueous solution and amended soils with thiourea. *Environmental Science and Technology.* 38:1188-1194.

Zheng, W., Yates, S. R., Papiernik, S. K. and Guo, M.2004. Transformation of herbicide propachlor by an agrochemical thiourea. *Environmental Science & Technology*. 38:6855-6860.

Zheng, W., Papiernik, S.K., Guo, M., Dungan, R.S., and Yates, S.R. 2005. Construction of a reactive surface barrier to reduce fumigant 1,3-Dichloropropene emissions. *Environmental Toxicology and Chemistry*. 24:1867-1874.

Bondarenko, S., Zheng, W., Yates, S.R., and Gan, J. 2006. Dehalogenation of halogenated fumigants by polysulfide salts. *Journal of Agricultural & Food Chemistry.* 54:5503-5508.

Zheng, W., Yates, S.R., Papiernik, S.K. and Wang, Q.Q. 2006. Reducing 1,3-dichloropropene emissions from soil columns amended with thiourea. *Environmental Science and Technology.* 40:2402-2407.

Zheng, W., Yates, S.R., Papiernik, S.K., Guo, M., and Gan, J. 2006. Dechlorination of chloropicrin and 1,3-dichloropropene by hydrogen sulfide species: Redox and nucleophilic substitution reactions. *Journal of Agricultural & Food Chemistry*. 54:2280-2287.

- **Hormones in feedyard wastewater shallow lakes (playas).** The hormone content of feedyard wastewater has not been studied extensively. A radioimmunoassay technique was used to measure the concentrations of three endogenous hormones (estradiol, testosterone, and cortisol) in runoff retention ponds at seven large feedyards on the Southern High Plains. In general, hormone concentrations in feedyard playas were higher than in non-feedyard playas. The biodegradation of these hormones in retention ponds, their dilution by rainfall, and their potential impact on wildlife or cattle exposed to aerosolized wastewater need to be determined.

- **Regression modeling as a means to explain variability in pesticide air concentrations in the Chesapeake Bay region**. The Delmarva Peninsula, within the Chesapeake Bay watershed, is a region of intense agricultural activity where 44% of the land area is under agriculture and approximately 3000 tons of pesticides are used annually. Results from weekly air samples (n=129, 2000-2003) indicated that pesticide concentrations exhibited a log-normal distribution. The median concentrations ranged from 75 pg/m^3 for alpha-endosulfan to 700 pg/m^3 for chlorothalonil. A multiple linear regression model incorporating temperature and time explained 32-43% of the variability in concentrations. The addition of an agricultural cycle to the model improved predictions, especially for alpha-endosulfan, however, wind speed and wind direction did not have a statistically significant influence on concentrations. Results indicate that temperature, time, and agricultural cycle are the main drivers for the occurrence of current use pesticides in the atmosphere of the Delmarva Peninsula. This information is critical to understanding the required inputs in atmospheric pesticide modeling and for development of strategies to controlling atmospheric pesticide transport.

- **Development of a water seal method to reduce fumigant emissions.** Laboratory and large-scale field experiments were conducted to determine if repeated sprinkling of irrigation water onto the soil surface after soil fumigation reduces Telone II (1,3-dichloropropene) emissions to the atmosphere. Large-scale demonstration experiments to measure volatilization are rare because they are extremely expensive, difficult, and require large investments in time and personnel. The peak Telone emission rate occurred 3 days after application and the total measured emission ranged from 10-17%. Under standard fumigation practices, the total emission was approximately 33%. Repeatedly applying irrigation water to the field therefore reduced emission by approximately 50%. Applying sprinkler irrigation is a relatively cost-effective method to reduce fumigant emissions. This research demonstrates that sealing the soil surface with repeated water application is an economical and effective emission-reduction methodology. As regulations on atmospheric emissions become more severe, this research provides growers with alternatives to meeting state-imposed emission targets.

Summary

Agricultural air quality is emerging as a topic of increasing concern to citizens, producers and policy-makers. The NP 203 accomplishment report highlights ARS contributions to this relatively young science. The goals of ARS air quality research are to provide information for informed decision-making by producers and policy makers, and to provide tools to solve air quality problems. To meet these goals ARS research on air quality research has taken the approach of:

- collecting data on particulate and gaseous emissions from agricultural sources with attention to variability through time and space,
- assessing the adequacy of existing measurement technologies for measuring emissions from agricultural sources and developing new technologies where needed,
- developing process models that provide tools for further research, and that can serve as a basis for the development of decision support systems and emission control technologies,
- developing-and documenting the effectiveness of emission control devices and management strategies that reduce emissions, and
- developing-tools for agriculture to cope with the detrimental effects of air quality on production.

Notable examples of specific outcomes from these efforts include:

- additions to the state of knowledge on particulate and gaseous emission characteristics from production systems and processing facilities,
- identification and documentation of errors in agricultural emissions data encountered when using sampling devices designed for urban settings,
- development of new air quality measurement and assessment technologies that more accurately measure emissions from agricultural sources, thus enabling more realistic assessments of agricultural contributions to air quality,
- development of physically-based models of emission processes that can be used to assess the effects of management actions and climate on emission processes and quantities,
- development of management practices, control technologies and systems, and new approaches for application of agrochemicals that reduce emissions, thus reducing the impact of agriculture on environmental quality and increasing the efficiency and profitability of production, and
- identification, development and distribution of genetic material for developing crops with increased resistance to the effects of air pollution on yield that maintain nutritional quality.

The research accomplishments reported by this document provide the foundations for the next five year cycle of agricultural air quality research by ARS. Future research is expected to continue collecting basic data on emissions, developing new measurement technologies, developing improved management practices and control technologies to reduce emissions, and developing decision support tools to assist producers, advisors and regulators.

The NP 203 Air Quality and NP 204 Global Change programs will merge with the NP 202 Soils program to form the NP 212 Soil and Air Resources Program during 2008. This will enable the ARS focus on agricultural air quality to include greenhouse gas emissions as it is necessary to address questions about the impact of agriculture on regional and global air quality. ARS is well positioned to address these questions and to provide solutions to agricultural air quality issues. The ARS air quality research program has a vision of agriculture that is free of air quality concerns. This report documents ARS efforts to pursue this vision and make it a reality.

Appendix A: Current Research Projects Contributing to ARS Air Quality Research

Research Projects Associated with National Program 203
Note: C=contributing to NP203

Location and Principal Investigator	NP Code	Project Number and Title
Charles L. Walthall Beltsville, MD	203 206 (C)	0500-00080-001-00D AIR QUALITY ASSOCIATED WITH AGRICULTURAL OPERATIONS (SDL)
John Meisinger Beltsville, MD	206 203 (C)	1265-12000-032-00D MANAGING THE FATE AND TRANSPORT OF NITROGEN, CARBON, AND AMMONIA IN ANIMAL MANURES TO IMPROVE ENVIRONMENTAL QUALITY
Cathleen Hapeman Beltsville, MD	203 211 (C)	1265-12220-004-00D AIR QUALITY IN THE CHESAPEAKE BAY REGION AS INFLUENCED BY AGRICULTURAL LAND USE CHANGES
Laura McConnell	206 203 (C)	1265-12630-001-00D DEVELOPING TOOLS TO PREDICT ATMOSPHERIC FATE OF VOC & ODORANT EMISSIONS FROM AG OPERATIONS
Daniel Shelton Beltsville, MD	206 203 (C) 211 (C)	1265-63000-001-00D PREVALENCE AND DIVERSITY OF MANURE-ASSOCIATED PATHOGENS IN AIR AND WATER
James Bunce Beltsville, MD	204 203 (C) 302 (C)	1275-11210-001-00D CROP AND WEED RESPONSES TO INCREASING ATMOSPHERIC CARBON DIOXIDE

Clarence Rotz University Park, PA	203 207(C)	1902-11130-001-00D MANAGING DAIRY FARMS FOR ENVIRONMENTAL STEWARDSHIP AND PROFIT
Dennis Flanagan West Lafayette, IN	211 203(C)	3602-12000-012-00D COMMON MODULAR WIND AND WATER EROSION MODELING FOR CONSERVATION PLANNING
Richard Derksen Wooster, OH	205 203 (C)	3607-21000-009-00D IMPROVING CROP PROTECTION TECHNOLOGY FOR HORTICULTURE CROPS
Heping Zhu Wooster, OH	305 203 (C)	3607-21620-006-00D BIOLOGICAL, MICROCLIMATE, AND TRANSPORT PROCESSSES AFFECTING PEST CONTROL APPLICATION TECHNOLOGY
John Prueger Ames, IA	206 203 (C)	3625-11630-002-00D EMISSION AND DISPERSION OF AIR QUALITY CONSTITUENTS FROM AGRICULTURAL SYSTEMS
Scott Yates Riverside, CA	203 211 (C)	5310-12130-008-00D MINIMIZING AIR & WATER CONTAMINATION FROM AGRICULTURAL PESTICIDES
Brenton Sharratt Pullman, WA	203	5348-11000-004-00D STRATEGIES FOR PREDICTING AND CONTROLLING PM10 EMISSIONS FROM AGRICULTURAL SOILS WITHIN THE COLUMBIA PLATEAU

Edward Skidmore Manhattan, KS	203 202 (C)	5430-11120-008-00D PARTICULATE EMISSIONS FROM WIND EROSION: PROCESSES, ASSESSMENT, AND CONTROL
Daniel Miller Lincoln, NE	206 203 (C)	5440-12000-060-00D ENVIRONMENTALLY SOUND MANURE MANAGEMENT FOR REDUCTION OF HEALTH-RELATED MICROORGANISMS AND ODOR
Teddy Zoebeck Lubbock, TX	202 203 (C)	6208-12000-009-00D SOIL MANAGEMENT FOR SUSTAINABLE AGRICULTURAL SYSTEMS THAT PREVENT WIND EROSION AND ENHANCE THE ENVIRONMENT
Michael Buser Lubbock, TX	203	6208-66000-001-00D AIR QUALITY ISSUES RELATED TO AGRICULTURAL OPERATIONS AND PROCESSES
Noel Cole Bushland, TX	206 201 (C) 203 (C)	6209-31630-002-00D MINIMIZING THE ENVIRONMENTAL IMPACT OF LIVESTOCK MANURES USING INTEGRATED MANAGEMENT REGIMENS
Philip Moore, Jr. Fayetteville, AR	206 201 (C) 203 (C)	6226-63000-001-00D POULTRY MANURE MANAGEMENT STRATEGIES TO REDUCE NON-POINT SOURCE PHOSPHORUS POLLUTION
Sidney Hughs Las Cruces, NM	306 203 (C)	6235-41000-006-00D GINNING AND PROCESSING RESEARCH TO ENHANCE QUALITY, PROFITABILITY, AND TEXTILE UTILITY OF WESTERN COTTONS

Karamat Sistani Bowling Green, KY	206 201 (C) 203 (C)	6445-12630-003-00D EFFICIENT MANAGEMENT AND USE OF ANIMAL MANURE TO PROTECT HUMAN HEALTH AND ENVIRONMENTAL QUALITY
Michael Jenkins Athens, GA	206 108 (C) 203 (C)	6612-32630-001-00D SURVIVAL AND TRANSPORT OF PATHOGENS FROM ANIMAL PRODUCTION SYSTEMS WITHIN LANDSCAPES OF THE SOUTHEASTERN USA
Kent Burkey Raleigh, NC	204 203 (C)	6645-11000-007-00D ECOLOGICAL, PHYSIOLOGICAL AND GENETIC ASPECTS OF GLOBAL CLIMATE CHANGE IMPACTS IN FIELD CROP SYSTEMS

Guide to National Programs

108: Food Safety (Plant and Animal Products)
201/211: Water Availability and Watershed Management
202: Soil Resource Management
203: Air Quality
204: Global Change
205: Pastures, Forages, and Rangeland Systems
206: Manure and Byproduct Utilization
302: Plant Biological and Molecular Processes
305: Crop Production
306: Quality and Utilization of Agricultural Products