

[National Programs Air Quality](#)

Action Plan:

Introduction

Background

'Air quality' refers to the combination of the physical-chemical-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 liquids (such as water droplets or vapor). We use the term 'air quality' to refer 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 affects and is affected by human, plant, and animal activities, including life functions. The sweep of winds and the exchange of gases, liquids, and solids between air masses and land and water surfaces affect air quality.

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 colorful sunsets that follow periods of intense volcanic activity.

Agriculture is a necessary human activity that interacts with air; it 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.

The Agricultural Research Service (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 develop solutions. Similarly, it believes that air pollution impacts on agriculture can be resolved through research and development.

Program Components

Particulate Emissions. This component addresses particulates regulated under the NAAQS, including fugitive dust in the PM-10 and PM-2.5 categories (10 micrometer and 2.5 micrometer, respectively). Dust emissions result from wind erosion, on-farm operations, agricultural industry, and smoke from agricultural burning. The research seeks to elucidate the biological, physical, and chemical mechanisms by which particulates are generated, how they are transported and suspended in the air and their patterns of movement and deposition. The research goal is to support development of technology to reduce or prevent agricultural particulate emissions.

Ammonia and Ammonium Emissions. The central regulatory issue is agriculturally-emitted ammonia as a major source of secondary, PM-2.5 particulates as a result of its interactions with other atmospheric compounds. The focus of this component is on understanding ammonia emissions and their role in forming secondary particulates, developing methods to measure emissions, establishing emission factors for various agricultural activities, and suppressing ammonia and ammonium emissions beyond farm boundaries.

Malodorous Compounds. Although not regulated, offensive odors from animal production operations are a major nuisance and may have health impacts. Basic and applied research will be done to identify odor-producing agents and to understand the biological and chemical processes that produce odors, emit them to the atmosphere, and govern their distribution and movement off-farm. This will permit the development of mitigating measures for application at the emitting source.

Ozone Impacts. High concentrations of ozone in the lower atmosphere result in reduction of crop yields by up to 20%. Carbon dioxide may have a mitigating effect on these losses. ARS research assesses the effects of ozone and the interaction of ozone and carbon dioxide upon crop production and searches for the basis for developing ozone-tolerant crop varieties.

Pesticides and Other Synthetic Organic Compounds. 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. The research objectives are to understand the biological, physical, and chemical mechanisms that influence pesticide volatilization and transport, to understand transport processes, to understand the impacts of deposition, and develop means to reduce emissions.

Vision

Agricultural enterprises throughout the Nation free from air quality concerns

Mission

Through research, to understand the processes of air pollution emissions 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 agricultural air pollution emissions and predicting and mitigating the impacts of air quality upon agriculture.

Planning Process and Plan Development

In 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 in 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. This document is the first result. It discusses issues from the California meeting, Task Force recommendations, and contacts with EPA. Using this document, ARS will continue to develop and implement a research program in agricultural air quality on the highest priority problems. This research plan and any modifications will be available on the Internet.

Based on customer issues raised at the workshop, ARS research in agricultural air quality has been organized into five categories, which will be called 'components' of the ARS Air Quality National Program:

- Particulate Emissions
- Ammonia and Ammonium Emissions
- Malodorous Compounds
- Ozone Impacts
- Pesticides and Other Synthetic Organic Chemicals

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

Air quality is intimately associated with most aspects of agricultural operations and is therefore also associated with other ARS national programs. Odors are most commonly agricultural issues in the context of animal production. The Malodorous Compounds component of this national program is closely related to a similar component of the Manure and Byproducts Utilization National Program.

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 also may 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. ARS resources do not permit addressing all of the goals listed. Those that will be addressed will be of the highest priority and will appear in the research plans developed for the ensuing five years. Others must await additional funding, resolution of the problems that will be addressed during the next five years, or resolution by other agencies or institutions.

Table 1 lists the ARS locations across the U.S. that are presently contributing to research in the Air Quality National Program. ARS scientists strive to take advantage of this geographical, disciplinary, and issue-oriented diversity by collaborating across locations.

Table 1. ARS Research Locations Contributing to the Air Quality National Program

Program Components						
State	Locations	Particulate Emissions	Ammonia & Ammonium Emissions	Malodorous Compounds	Ozone Impacts	Pesticides & Other Synthetic Organic Compounds
AR	Fayetteville		X	X		
CA	Albany				X	
CA	Riverside	X				X
CO	Akron	X				
GA	Athens	X		X		
GA	Tifton			X		

GA	Watkinsville		X			
IA	Ames	X	X	X		X
KS	Manhattan	X				
MD	Beltsville	X	X	X	X	X
MN	St. Paul					X
NC	Raleigh				X	
ND	Mandan	X				
NE	Clay Center		X	X		
NE	Lincoln	X	X	X		
NM	Mesilla Park	X				
SC	Florence			X		
TX	Bushland	X		X		
TX	College Station		X			X
TX	Lubbock	X				
WA	Pullman	X				

Action Plan:

Component I: Particulate Emissions

Introduction

Background

Excessive levels of particulate matter in the air adversely affect human health and welfare. Particulate matter smaller than 10 micrometers is regulated as a human health hazard with both 24-hour and average annual limits. Primary particulates in fugitive dust originating from agricultural burning, wind erosion, agricultural operations, agricultural industry, and biological sources are high priority national problems.

Even before open field burning became a traditional agricultural practice, it was practiced by Native Americans. Centuries ago, Indians living on the tall-grass prairie set fires near their villages. They knew that after a fire, nutritious shoots of new grass would appear, and bison would come to graze. Ranchers today still set fire to their grazing lands in the spring. Fire prevents unwanted weeds, shrubs, and trees from crowding out grasses that nourish livestock. Farmers also use fire effectively to remove excess crop residues and control weeds and diseases. However, in some cases, agricultural burning has deleterious effects. Smoke from agricultural burning can cause various visibility and health problems, and loss of organic matter can degrade soil resources.

Wind erosion continues as a national problem. It physically removes from the field the most fertile portion of the soil. Some soil from damaged land enters suspension and becomes part of the atmospheric dust load. Dust obscures visibility and can cause automobile accidents, pollutes the air, fouls machinery, and imperils animal and human health. Blowing soil also fills road and irrigation ditches, buries fences, reduces seedling survival and growth, lowers marketability of vegetable crops, increases susceptibility of plants to diseases, and contributes to transmission of some plant pathogens. Deposition of wind-blown sediments in drainage pathways and on water bodies significantly deteriorates water quality. Wind erosion continues as a threat to environmental quality and agricultural sustainability.

Accomplishing the mission of the Particulate Emissions component of the Air Quality National Program by addressing the goals under the five problem areas will provide 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.

Beneficiaries from this technology include land managers and their consultants, environmental health rule makers and regulators, environmental and global change policy makers, conservation planners, and all who wear clothes, eat food, drink water, and breathe air.

Vision

Sustainable agricultural systems that prevent emission of particulates harmful to human health and the environment

Mission

Develop agricultural technologies and practices that minimize contamination of the air by particulates generated during production and processing of food and fiber and provide science-based technology for sound policy and regulatory decisions.

Table 2. ARS Research Locations Contributing to Component I of the Air Quality National Program-- Particulate Emissions

Component Problem Areas						
State	Locations	Agricultural Burning Alternatives	Particulate Emissions from Wind Erosion	Agricultural Operations	Particulate Emissions from Agricultural Industry	Emission & Transport of Airborne Pathogens
CA	Riverside					X
CO	Akron		X			
GA	Athens					X
IA	Ames					X
KS	Manhattan	X	X	X		
MD	Beltsville					X
ND	Mandan		X			
NE	Lincoln					X
NM	Mesilla Park				X	
TX	Lubbock		X	X	X	X
TX	Bushland		X		X	X

WA	Pullman	X	X	X		X
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Agricultural Burning Alternatives

Problem Statement

Rationale. Open-field burning of plant material has been a long-standing traditional agricultural practice by farmers and foresters. The reasons are highly variable. Most often it is an efficient method to remove plant materials such as remaining crop residues after harvest or remaining tree limbs, etc., from timber harvest. Burning often is used to reduce infestations of insects, weeds, or disease. While efficient in terms of cost and time, the negative impacts of burning often are overlooked or accepted as minimal. Significant examples are the degradation of air quality by smoke particles and the loss of organic material for soil enhancement. Smoke from agricultural burning can be a significant health issue for humans sensitive to those chemicals and pollutants, particularly people with breathing and asthmatic conditions.

What is known. Burning of agricultural materials releases a variety of products into the atmosphere. The combustion process is well documented as one of combining oxygen with carbon materials producing carbon monoxide, carbon dioxide, and water plus a wide variety of volatile (dispersable into the atmosphere) chemicals depending on the material being burned. Additionally, the smoke plume contains particulates of partially combusted materials as soot, which become airborne and are transported downwind. Some unburned residues usually remain at the site of the fire as ashes to be returned to the soil or blown away. Thus, the smoke plume is a variety of particulates and gases that move vertically and downwind in a transportation and dispersion process. The on-site burning impact is to remove a large portion of the organic material being burned while denying the soil an opportunity to enhance its organic matter and incorporate important chemicals such as nitrogen and phosphorous. The off-site impacts can be health related if there are populations downwind with sensitivity to the smoke constituents and general air quality degradation of regional haze.

Gaps. The quantity and composition of particular agricultural burning are difficult to measure and document. These depend on such variables as the organic material quantity, composition, arrangement, and moisture content; wind; and fire characteristics. The proportions that become combusted or suspended as soot or ashes depend on many of these same parameters and are highly variable, making them difficult to predict. The off-site impacts on health and air quality degradation are not readily known and are difficult to estimate. The variation in human sensitivity to combustion products makes this aspect particularly difficult to assess and manage. General air quality and regional haze depend highly on atmospheric conditions such as wind and pressure patterns, precipitation, and interaction with radiation.

Goals

- Develop viable alternatives to agricultural burning;
- Develop burning strategies that reduce emissions and downwind impacts;
- Develop capability to predict composition and quantities of emissions from agricultural burning; and
- Identify and minimize those burning components that significantly impact downwind inhabitants.

Approach

Reasonable tasks directed toward accomplishing these goals will include a specialized research capability to perform agricultural burning experiments; coordination with the U.S. Forest Service, since they have a history of research on burning; careful analysis of each application of agricultural burning for its need and impact on agricultural production operations, followed by seeking alternatives to burning; development and testing a variety of burning techniques that minimize emissions and downwind impacts; and close coordination with the medical profession to evaluate components and concentrations of burning emissions that cause the most impairment on impacted people. This work also should proceed in coordination with the National Oceanic and Atmospheric Administration (NOAA) for their knowledge and expertise in atmospheric interactions with burning emissions and with agricultural producers for concepts and evaluations of alternative practices to burning.

Outcomes

While burning of plant materials has particular benefits to agricultural and forest operations such as disease and weed control, it has larger, far-reaching negative impacts upon regional air quality and human health. Thus, research should achieve an understanding such that burning be used minimally and in specialized cases. Through alternative practices and careful management, burning should be utilized for those agricultural and forester operations for which there are no other logical mechanical or biological options. Utilizing burning as the most economical of several options should not be an acceptable criterion for general applications.

Impact

Improved air quality for health and visibility while maintaining an economical and productive agriculture.

Linkages to Other ARS National Programs

- Global Change
- Integrated Agricultural Systems
- Rangeland, Pasture, and Forages
- Soil Resource Management
- Water Quality and Management

Particulate Emissions from Wind Erosion

Problem Statement

Rationale. Wind erosion and agricultural dust emissions continue as national and global concerns. Millions of acres of U.S. cropland suffer soil loss from wind erosion each year. During wind erosion events, fine soil fractions enter suspension and contribute to the atmospheric dust load. Fine dust grains may be transported great distances and represent the component of top-soil that is truly lost from a wind-eroding region. Dust emissions from agricultural sources can significantly degrade air quality and negatively impact human and animal health. Elevated dust levels can obscure visibility and foul machinery and thereby disrupt transportation systems. Deposition of transported dust on crops hinders processing and decreases yield and value. Deposition of wind-blown dust in water bodies can degrade water quality. Knowledge of the basic physical processes that lead to agricultural dust emissions is key to the design of measures to reduce or eliminate the problem. The need for a sound scientific approach to the wind erosion problem increases as the world's population grows.

What is known. Past studies have drawn attention to the association between suspended particulate matter in ambient air and human health problems. In arid and semiarid agricultural regions, wind erosion is an important source of particulate matter. Elevated particulate matter levels often are associated with regional-scale wind erosion events caused by the combination of strong winds and exposed soil surfaces. Management practices influence the rate of dust emissions in many ways. Properly managing surface crop residues, planting cover crops, or returning fields to their original vegetative condition can provide a protective vegetative blanket that shields the soil from wind forces. In addition, surface roughness produced by tillage can slow near-surface winds and thereby shelter loose erodible material with less erodible clods. The main factors influencing wind erosion, identified as soil aggregate status, surface roughness, surface wetness, wind speed, vegetation, and distance across an erodible surface have been formulated into empirical equations and process-based prediction systems with varying degrees of success.

Gaps. The fundamental wind erosion process of dust emissions from wind-eroding surfaces is imperfectly understood. Knowledge gaps hinder the development of improved measures to better manage arid and semiarid agricultural fields so that crop production can continue with minimal impacts on air quality. Research is needed to determine the effects of management decisions on dust emission rates and ambient dust levels and to quantify the potential benefits of modified management practices. There is a need for better techniques to measure dust emission rates, ambient dust concentrations, and rates of dust deposition. There also is a need for physically-based mathematical descriptions of dust emissions, transport, and deposition. Improved analysis is needed of the chemical and biological content of particulate matter and the relation of dust grains to their respective sources. Long-term records need to be obtained for impacted regions to determine if evolving land-use practices are improving or degrading air quality.

Goals

- Develop appropriate, cost effective control technologies that benefit both producers and consumers;
- Develop effective solutions that do not create collateral problems;
- Define plant and soil surface properties that impact wind erosion processes and identify properties that reduce the magnitude and frequency of dust emissions;
- Develop physically-based mathematical descriptions of dust emissions, transport, and deposition that can be incorporated into decision-making tools such as computer models;
- Define the linkage between meteorological conditions and regional dust levels;
- Improve sampling techniques and obtain long-term records that establish dust trends in arid and semiarid agricultural regions and relate changing ambient dust levels to changing land-use practices; and
- Determine the potential effects of dust emissions and elevated dust levels on global climate change.

Approach

Realization of these goals will require a fundamental understanding of basic wind erosion and related processes and mathematical expressions that accurately describe dust emissions, transport, and deposition in agricultural settings. This effort will require physical experiments and improved techniques to measure wind erosion processes and related dust emissions. Appropriate controls and technologies to quantify potential benefits will need to be developed and tested.

Outcomes

- Reliable mathematical descriptions and computer models will be developed that predict dust emissions, transport, and deposition from wind-eroding agricultural fields.
- Recommendations will be formulated for improved management practices and control technologies that conserve soil resources and limit air quality degradation.
- Long-term records of wind erosion activity and ambient dust levels within arid and semiarid agricultural regions will be obtained that provide the data necessary to assess the effects of evolving land-use practices.

Impact

Air quality control decisions by agricultural producers, land managers, and policymakers from local to national levels will be based on state-of-the-art air quality control decision aids.

Linkages to Other ARS National Programs

- Global Change
- Integrated Agricultural Systems
- Rangeland, Pasture, and Forages
- Soil Resource Management
- Water Quality and Management

Agricultural Operations

Problem Statement

Rationale. Many agricultural field and processing operations, by the nature of their activities, produce airborne dust and particulates. Typical examples are tillage operations in dry soil, harvest operations using threshing and blowing to separate grain and residue, or agricultural chemical spraying. These dust and chemical particulates often remain in the field or quite local, depending on atmospheric conditions, but they also can be transported long distances as part of the regional air mass. With a wide variety of emission materials and conditions, the off-site impacts also are highly variable. Some emissions contribute to local particulate concentrations and chemical drift and deposition, while others impact regional air quality, causing downwind health and nuisance concerns.

What is known. Particulate emissions from agricultural operations often are visible and identifiable. It is well known that tillage of dry soil causes dust emissions, and recent research in the western U.S. has shown these sources to contain particulate matter (PM) less than 10 and 2.5 micrometers, particulates that are invisible to the human eye. PM-10 and PM-2.5 emissions have been associated with human health concerns, and as a result, Particulate Matter standards regulating PM-10 emissions have been implemented and are pending for PM-2.5.

Harvesting operations emit considerable organic dusts as well as mineral dust particulates. Chemical spraying or dusting operations have been shown to generate a range of liquid or dry particulates intended for deposit in the vicinity of the target plants or animals, but some drift away to become air contaminants. On occasion, these have negatively impacted nontarget species. Agricultural materials processing, traffic within fields and working areas, and animal activities all have the potential to generate airborne particulates.

Gaps. Many agricultural operations potentially involve airborne particulate emissions. However, there is a serious lack of quantification and speciation of these particulates as, for example, in the quantity and characterization of dust during tillage operations. Many variables are involved, such as the type of tillage implement, soil characteristics and current wetness, and tillage speed. Methodology to evaluate and quantify these emissions is not fully developed because the emissions occur as a plume above and behind a moving implement and quickly disperse into the local air mass. The impact may be minimal under windy conditions, but given stagnant air in an inhabited area, the impact may be significant. Assessment is very difficult. Similar differences and impacts are associated with other operations such as harvesting, processing, and concentrated animal facilities.

Goals

- Develop quantification methods to assess particulate emissions from a wide variety of farming operations;
- Relate local particulate emissions to local and regional air quality in a wide variety of atmospheric conditions sufficiently accurately to assess environmental and health-related impacts; and
- Develop practical and economical control strategies for operations with high emissions in priority situations offering potential for emission reductions.

Approach

This problem requires a three-pronged approach: (1) Conduct a series of experiments to determine particulate emissions from offensive agricultural operations. Emphasis will be given to those operations that are either obvious emitters causing off-site impacts or those in which regulations are being imposed without adequate scientific knowledge about quantification or remedial measures. (2) Assess the transport and dispersion of emitted particulates from agricultural operations to define downwind concentrations related to health and environmental impacts. (3) Carefully examine each major agricultural operation emitting particulates and determine alternative methods and control strategies to reduce, change the timing or location of, or redirect these emissions.

Outcome

A science base will be developed to evaluate the relative magnitudes of each emitting source for use in minimizing on- and off-site impacts.

Impact

Improved local and regional air quality with profitable and viable agricultural operations.

Linkages to Other ARS National Programs

- Integrated Agricultural Systems
- Soil Resource Management
- Water Quality and Management

Particulate Emissions from Agricultural Industry

Problem Statement

Rationale. Concerns about particulate emissions from agricultural industries ranging from concentrated animal feeding operations to processing and handling facilities such as cotton gins, feed mills, grain transfer and handling operations, textile mills, and others accompany growing environmental concerns about the quality of air we breath. Understanding how these emissions are generated, transported, and controlled is of primary interest to agricultural industries. With ever increasing regulatory stringency in relation to the character and quantity of emissions, agricultural industry needs reliable emission factors by which they can better understand the amount of particulate emission generated by certain processes in their operation. Without this understanding, reduction of emissions will have limited success.

What is known. Concerns are growing in the industrial, governmental, and public sectors in regard to the quality of air we breath. We know that one of the primary pollutants of concern is particulate matter. We know that agricultural industry is a source of particulate emissions. Particulate emissions of primary concern are those termed PM-10 and PM-2.5 since these emissions have been deemed to have significant potential to impact the health and well-being of humans and animals. Particulates of these sizes can pass by a human's nasal air filtering system and can be difficult for the body to dislodge from the respiratory tract. Current emission factors used by regulatory agencies for certain agricultural industry operations have not differentiated the particle sizes, and therefore yield egregious errors that may not apply to all processes of that type throughout agricultural industry.

Gaps. Even though agricultural industry emits particulate matter, its effect on overall air quality is not known. For example, the time of year when air quality is a problem in a particular location does not always coincide with the time when agricultural processing operations are active. Thus, the character and quantity of particulate emissions from various operations in agricultural industry are not well documented. A more thorough understanding is needed of the portion of these particulate emissions that are PM-10 and/or PM-2.5 to understand how particulates are transported and deposited once emitted. This understanding is vital to provide data that will contribute to (1) more accurate emissions factors of the processes commonly regulated by environmental agencies, (2) more accurate assessment of impacts to off-site receptors, and (3) a better understanding of the types of particulate emissions to help select effective control methods. In addition to a more comprehensive understanding of the character and quantity of particulate emissions, improvements are needed in abatement technologies and devices that will reduce emissions as effectively as possible. Control technologies need to aim at optimum efficiency in reducing particulates emitted into the atmosphere at minimum cost to the industry.

Goals

- Further quantify the portion of particulate emissions from agricultural industry that are PM-10 and those that are PM-2.5;
- Develop scientifically sound emission factors for PM-10 and PM-2.5 primary particulates emitted from agricultural industries;
- Investigate the generation, transport, and deposition of particulate emissions;
- Further develop cost-effective control technologies to reduce the quantity of particulate emissions from agricultural industries; and
- Determine the composition of PM-10 and PM-2.5 (e.g., is it composed of a particle with an ammonia nuclei?).

Approach

A multidisciplinary approach will be used to further differentiate the quantity of PM-10 and PM-2.5 being emitted from agricultural processing industries and use that information to formulate reliable emission factors. Methods and procedures will be developed and employed to investigate the generation, transport, and deposition of particulate emissions from concentrated animal feeding operations and agricultural processing facilities. Efforts will be ongoing to improve current methods of controlling particulate emissions either at the source of generation or prior to the point of emission. If improvements to current control methods are inadequate, new technologies and methods will be developed to further abate particulate emissions from agricultural industries.

Outcomes

- Reliable particulate emission factors will be developed for both PM-10 and PM-2.5 for various agricultural processes.
- Reliable, repeatable methods will be developed to measure and evaluate sizes of particulates emitted from agricultural processes.
- A database will be created to support scientifically sound decisions concerning the generation, transportation, and deposition of particulates from agricultural industry.
- Documentation will be provided detailing possible improvements to existing particulate abatement equipment and quantifying the amount of reductions that can be gained by those improvements.
- New control technologies will be developed where needed to reduce PM-10 and PM-2.5 particulate emissions.
- Conditions that create PM-10 and PM-2.5 occurrences will be predictable (e.g., weather, humidity, crop variety processed).

Impact

Maximum and cost-effective reduction of particulate emissions by agricultural industry.

Linkages to Other ARS National Programs

- Crop Production
- New Uses, Quality, and Marketability of Plant and Animal Products
- Manure and Byproduct Utilization

Emission and Transport of Airborne Pathogens

Problem Statement

Rationale. Release of airborne pathogens from livestock production facilities and their movement across the landscape cause concern among the public about the potential human health impacts of livestock operations. Increasing numbers of reports associating sickness with proximity to large livestock operations suggest that understanding the particles shed from livestock operations needs to be quickly addressed. The movement of airborne pathogens across the landscape is similar to that of other particulate matter; however, effects on health raise a new level of concern.

What is known. Pathogens can be transmitted through the air. They often behave as small particles and are subject to the same transport processes as other small particles. Approximately 2 - 4% of the dust particulate matter emitted by beef cattle feedyards is classified as PM-2.5. The pathogens in feedyard air may be released from animals through respiration and also from buildings or feeding areas where manure and urine are deposited.

Gaps. The information base on airborne pathogens is limited. The complete profile of these pathogens can not be characterized because of a general lack of information about the types of pathogens associated with livestock and their potential to become airborne, either on their own or riding on dust particles. There are a number of major gaps in the knowledge about the presence and transport of airborne pathogens. There is a need to

- Identify and describe the types of pathogens found in livestock operations that could become airborne;
- Evaluate the pathogenicity of airborne pathogens in livestock operations;
- Determine the composition of dust particles to understand if potential health problems are due to small-sized dust particles inhaled into the lungs, to included or attached pathogens, or to dust chemical and physical composition; and
- Develop management practices to reduce the occurrence of airborne pathogens.

Goals

Goals of this research are phased to address this problem area from a progression of studies that would first identify presence and then determine transport and impacts. Specific goals for this effort are to

- Identify potential airborne pathogens present in different species of livestock operations and production systems;
- Determine the source of the pathogens for different livestock species;
- Determine the pathogenicity of these pathogens once shed from the animal and present in the air;
- Evaluate the source strength of airborne pathogens from buildings and feeding areas;
- Evaluate the potential movement of airborne pathogens from buildings and feeding areas;
- Quantify the movement patterns downwind across the complex landscape that characterize livestock operations; and
- Develop and evaluate potential control measures to reduce source strength or transport from the source.

Approach

A series of phased studies to address this problem will first identify the problem; next, determine the impacts and risks; and then select or develop appropriate management options. These studies will require the development of interdisciplinary teams across livestock species to understand the pathogen, livestock management practices, building and feeding operations, atmospheric transport, and human health impacts. Addressing these goals will require experimental and theoretical approaches to understanding the potential differences of management within a species and across climates and species. This work should include collaboration with EPA; NOAA; Food and Drug Administration (FDA); Cooperative State Research, Education, and Extension Service (CSREES); the Department of Defense (DOD); Center for Disease Control (CDC); and universities and land grant institutions.

Outcomes

The presence of pathogens in different livestock operations will be defined, and their potential impact on human health, if posed, will be determined.

Impact

An environment with minimal risk to human and livestock health from airborne pathogens generated by livestock operations.

Linkages to Other ARS National Programs

- Food Animal Production
- Food Safety
- Manure and Byproduct Utilization

Action Plan:

Component II: Ammonia and Ammonium Emissions

Introduction

Background

Under standard conditions, ammonia is a colorless gas with a pungent odor detectable at 3 to 5 parts per million but easily discernible at concentrations above 50 parts per million. It is ubiquitous in the soil, atmosphere, and waters of the earth with most of the ammonia coming from anthropogenic (human-related) activity. It is highly reactive and remains in the atmosphere only a short time. It reacts quickly with water, forming ammonium. In the air, it can dissolve in precipitation and fall to the earth as ammonium. Because ammonia gas is so reactive, after being released, its concentration is localized because of absorption by both plants and/or water and neutralization to aerosols. However, ammonia rarely is depleted in the atmosphere because all plants have a point below which they emit gaseous ammonia; at concentrations above this point (ammonia compensation point), plants will absorb ammonia.

The possible combined effect of ammonia absorption and ammonium aerosol deposition can be both beneficial and harmful. In fertilized cropping systems, the plant community may absorb significant quantities of nitrogen from the atmosphere. The release of ammonia into areas of natural terrestrial and aquatic ecosystems may cause a significant shift in the nutrient economy. This destabilizing effect in the existing plant community may result in replacement by species that use more nitrogen. Ecosystem soils may become more acidified, with possible long-term nutrient imbalances of calcium, potassium, and magnesium. Ammonia emissions also potentially cause some nitrous oxide loss into the atmosphere.

The largest source of ammonia emissions is the use of synthetic or biologically-fixed nitrogen (atmospheric nitrogen that has been incorporated into a nitrogen-containing compound by plants). The major global anthropogenic sources are from domestic and wild animal wastes (40%), fertilizer use (17%), oceans (8%), biomass burning (6%), agricultural crops (4%), humans and pets (3%), and natural ecosystems (3%). About half of the global emissions come from Asia, and about 70% of the total is related to food production. However, the regions with highest geographically-localized emission rates are found in Europe, the Indian subcontinent, China, and parts of the U.S. The largest potential concentrated sources are animal feeding operations because they often are located in relatively small geographical areas to provide increased efficiency, improved economics, and a better industry support system. These facilities use waste management systems that release ammonia to the environment.

The calculation of ammonia emissions from domestic animal production is based on an average nitrogen excretion for different categories. However, emissions can be quite different depending on housing types, feedstuffs and nutritional management systems, waste handling methods, application techniques, and type of crops upon which wastes are applied. Indeed, emission calculations do not take into account partial processing of the wastes during housing and/or waste storage (lagoons or holding tanks), assuming all nitrogen losses as atmospheric ammonia emissions and leaching into the soil from the storage liners. Data on domestic animal ammonia emissions in the U.S. are limited, and early ammonia emissions inventories were based on European country-specific emissions from animal wastes. Better emissions information is needed from U.S. production systems, which are very different from European conditions, including climatic, management systems, housing, and waste recycling and/or disposal systems. Furthermore, reduction of nitrogen losses is economically significant, providing strong motivation from the animal and crop producer's viewpoint to promote reduction or prevention of these losses.

Vision

Productive animal and cropping systems that minimize ammonia-containing nitrogen emissions to the atmosphere

Mission

Develop systems to reduce ammonia emissions from cropping and animal production systems while improving productivity

Table 3. ARS Research Locations Contributing to Component II of the Air Quality National Program—Ammonia and Ammonium Emissions

Component Problem Areas			
State	Locations	Systems to Contain Nitrogen Compounds Within Farm Boundaries	Measurement of Atmospheric Ammonia Exchanges under Field Conditions
AR	Fayetteville	X	X
GA	Watkinsville	X	X
IA	Ames	X	X
MD	Beltsville	X	X
NE	Clay Center	X	

NE	Lincoln	X	
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Systems to Contain Nitrogen Compounds Within Farm Boundaries

Problem Statement

Rationale. Nitrogen compounds are imported onto farms through animal feed or fertilizer. This nitrogen is essential for efficient animal and crop production. Life cycle analysis systems approaches are needed to link nitrogen imports tightly to production, thus limiting the potential nitrogen losses to surrounding ecosystems. These approaches need to include entire farm management plans that maximize nitrogen use efficiency and limit excess nitrogen output. Excess nitrogen can degrade water quality through leaching and runoff of nitrate or air quality through volatilization of ammonia.

What is known. Substantial research has been conducted on ammonia volatilization resulting from application of synthetic fertilizer and animal manure. In general, factors such as soil pH, soil moisture content, air temperature, and method of application affect the quantity of ammonia lost to the atmosphere. Method of application probably is the most critical factor. Injection or immediate incorporation of the fertilizer into the soil greatly reduces ammonia volatilization compared to surface applications. Most of the studies, however, were conducted in the laboratory or with static chambers in the field and may not accurately measure net ammonia under field conditions or accurately emulate true field conditions. Neither do the studies account for spatial variability in ammonia emission rates or possible ammonia uptake by plants.

Fewer studies have been done on ammonia emissions from animal facilities, feed lots, or waste storage facilities, and most were done in Europe under conditions that may not be applicable to the U.S. In addition, recent studies with swine lagoons in the Southeast indicate that more nitrogen may be lost as environmentally harmless nitrogen gas rather than ammonia.

Further, nitrogen conversion needs to be enhanced in many nutritional management and animal nutrient processing and cycling technologies to reduce the amount of nitrogen lost as liquid and solid wastes. Reducing amino acid content in feed is one example of a technology that reduces ammonia in the waste stream.

Gaps. We have limited ability to recommend whole-farm management systems that economically reduce ammonia emissions. Changes in one component, e.g., feed quality, may greatly affect ammonia volatilization rates from waste storage facilities or land application. Thus, whole-farm ammonia absorption and desorption, including domestic animals and cropping systems, need to be considered. Specific gaps include

- Net changes in ammonia emissions from crops after animal waste applications, including the effect of crop management practices, the ability of the crop to utilize both atmospheric ammonia and applied nutrients, and the type and quality of waste applied;
- The role of riparian and buffer zones in amelioration of ammonia and ammonium aerosol transport before leaving the farm site;
- Methods to maximize the fertilizer value of nitrogen stored in animal waste products; and
- Nutritional management strategies to reduce volatile nitrogen emissions.

Goals

- Develop productive management practices that maximize nitrogen use efficiency through a tighter coupling between animal and crop production;
- Reduce nitrogen imports onto the farm through improved feeds;
- Develop techniques to convert nitrogen compounds in waste to nitrogen gas or conserve the nitrogen in the waste as a valuable source of nitrogen for crop production;
- Quantify the role of on-farm buffer and riparian zones in reducing atmospheric ammonia transport across farm boundaries; and
- Develop nutritional management strategies to redirect nitrogen from urine and reduce animal nitrogen emissions.

Approach

A multidisciplinary research effort is needed to develop whole farm management plans that reduce ammonia emissions from farms. Researchers should include soil scientists, animal nutritionists, engineers, and modelers. A basic understanding of the processes involved in nitrogen transport and ammonia emissions will be needed to develop models for whole-farm nitrogen management.

Outcomes

- Management systems will be developed that improve animal and farm-level nitrogen utilization and contain atmospheric ammonia within farm boundaries.
- Models will be developed that allow producers to predict potential ammonia losses resulting from changes in any component within their production system.

Impact

Increased efficiency in nitrogen utilization and decreased ammonia emissions.

Linkages to Other ARS National Programs

- Food Animal Production
- Global Change
- Integrated Agricultural Systems
- Manure and Byproduct Utilization
- Water Quality and Management

Measurement of Atmospheric Ammonia Exchanges under Field Conditions

Problem Statement

Rationale. There are major uncertainties regarding the exchange of atmospheric ammonia with ecosystems because quantitative emission and deposition fluctuations are poorly defined. Ammonia emissions have not been quantified to the extent of emissions of sulfur compounds, nitrogen oxides, and nonmethane hydrocarbons. Emission inventories are commonly prescribed as the emissions per animal, allowing no flexibility for more complex classifications or combinations of different systems, management practices, animal sizes, types, classifications, stages of growth and production, level of production, level of technology adaption, and waste treatment. Because of the lack of emissions information in the U.S., emissions and emission factors from Europe have been modified and used for emission inventories. These factors are variable and inappropriate for animal feeding and management systems in the U.S. and for use in many parts of the U.S., such as the humid south or the semiarid Great Plains. Consequently, as concentrated animal feeding operations continue to increase, better emissions inventories are needed to evaluate effects of emissions on local and regional soils, groundwater, and atmospheric environments and to develop means to reduce emissions and conserve the nitrogen resource. Further, because of acid gases, possible atmospheric ammonia depletion below plants=ammonia compensation point (the atmospheric concentration below which plants give off ammonia to the atmosphere and above which plants absorb ammonia from the atmosphere) may result in long-range nitrogen depletion from natural systems

What is known. Ammonia is the most abundant alkaline component in the atmosphere that neutralizes acid gases of sulfur and nitrogen oxides. Consequently, with large amounts of acid gases from fossil fuel combustion, ammonium is a major component of atmospheric aerosols. Ammonia and ammonium aerosols have different residence times in the atmosphere and may affect ecosystems in many different localities. When ammonia and ammonium are deposited on soils, the effect may have a destabilizing effect on existing plant communities. The decomposition of domestic livestock waste is the largest contributor of ammonia to the atmosphere.

Gaps. As noted earlier, little information about ammonia emissions from domestic animal systems is available for developing an ammonia emissions inventory for this country, and our ability is limited to recommend whole-farm management systems that economically reduce ammonia emissions. New techniques to obtain emission factors from concentrated animal feeding operations are essential to quantify ammonia exchange processes, integrate emission reduction techniques, promote more efficient nitrogen use, and limit excess nitrogen leakage to the environment. Because of the large amounts of acid gases produced by automobiles and industry, possible atmospheric ammonia depletion below plants=ammonia compensation point may result in long-range nitrogen depletion from natural systems. Gaps in our knowledge that preclude field, farm, and regional assessment of ammonia and ammonium aerosols include, but are not limited to the following:

- Ability to assess ammonia emissions from animal housing, waste storage and application systems, and crops;
- Exchange processes and how they are affected by management and climate variability;
- The effect of crop management and its ability to utilize both atmospheric emissions and application of stored nutrients;
- Limited knowledge of the rapidity of ammonia conversion to ammonium aerosols and their transport from the farm site;
- Whole-farm ammonia absorption and desorption, including domestic animals and cropping systems;
- The role of riparian zones in amelioration of ammonia and ammonium aerosol transport from the farm site;
- The relationship of ammonia emissions to nitrogen oxides and sulfur oxides to form particulates that may travel relatively large distances; and
- A lack of understanding of the effects of reduced atmospheric ammonia on natural ecosystems, given the large amounts of acid gases produced by automobiles and industry.

Goals

To preserve environmental quality while enhancing crop and animal productivity, specific goals of this research are to

- Develop productive management practices that minimize ammonia emissions, including animal nutritional management technology, nutritional technology, more specific nutrient formulation, fertilizer management, and a tighter link between livestock and crop production;
- Quantify ammonia emissions from animal housing, waste management and storage, and waste application techniques, and develop abatement and conservation technologies;
- Provide information and technologies to improve national ammonia and ammonium inventories;
- Quantify the role of buffer and riparian zones on atmospheric ammonia exchange; and
- Quantify the deposition and localized impact of increased ammonia concentrations from nearby concentrated animal feeding operations.

Approach

Multidisciplinary research is needed to assess impacts of management on nitrogen budgets (input vs. output) at the concentrated operation, field, farm, regional, and national scales. These efforts will require input from agronomic, engineering, natural and physical, and atmospheric scientists who utilize a variety of methods to measure, assess, and mitigate ammonia gas exchange relationships. These methods, which include different measurement techniques as well as synthetic and analytical methods such as modeling, will need to be evaluated at the appropriate temporal and spatial scales. Further development of fundamental understanding will allow integration of measurement and modeling to guide improved management techniques that conserve nitrogen and limit ammonia and ammonium emissions.

Outcomes

- Improved measurement techniques will be developed to obtain ammonia concentrations and fluctuations.
- Fundamental understanding of atmospheric ammonia and ammonium aerosols and interactions with the environment will be improved.
- Crop and animal production management systems will be developed that improve nitrogen utilization and limit ammonia emissions.

- Seasonal and annual ammonia emissions from farming practices will be more predictable.
- National inventories of ammonia emissions will be improved.

Impact

Decreased ammonia and ammonium aerosol emissions without adverse effects on productivity and production economics.

Linkages to Other ARS National Programs

- Food Animal Production
- Global Change
- Manure and Byproduct Utilization

Action Plan:

Component III: Malodorous Compounds

Introduction

Background

Emissions from livestock operations cover a wide range of compounds. The largest public concern is the generation and transport of malodorous compounds across the landscape. Policy issues focus more on transport and deposition of ammonia, methane, nitrous oxide, and particulates. Humans can detect as odors a large number and mixture of volatile organic compounds or even single compounds, e.g., ammonia or hydrogen sulfide. These volatile organic compounds and gases may potentially interact with particulates in the atmosphere to change their dispersion characteristics and reaction in the human nose.

Odors result from the digestive process of microorganisms in manure. Odorous compounds commonly associated with livestock facilities include ammonia, volatile organic compounds including amines and fatty acids, and sulfur-containing compounds. In addition, significant quantities of gases can be released as by-products of engineering processes designed to dispose of manure or reduce odors. Odors, however, are only a small part of the overall emission profile; other gases of environmental and ecological concern, e.g., ammonia, methane, nitrous oxide, and hydrogen sulfide, are released as part of the overall digestion process.

Particulates generally are a consequence of interactions of animals with their environment. In concentrated housing facilities, bedding, manure, litter, and animal byproducts such as feathers; and the activities of mixing and distributing feed; can generate particulates. Animal activity within housing, during transport, or due to other husbandry efforts can cause particulates to become airborne. In external housing facilities, animal movement on dry soil and manure can produce significant dust problems. Aerosols can be generated any time in the presence of a water source and air movement. Numerous farm management procedures generate aerosols, including misting or spraying to cool animals, manure separation techniques, spray irrigation, and spraying to control dust. PM-10 standards and the pending regulation of PM-2.5 increase the urgency to address the sources and amounts of particulate emissions.

Little is known about the interaction of ammonia with other nitrogen or sulfur species in the atmosphere that would suggest a difference among locations (urban environments with large production of these compounds compared to rural environments with relatively low concentrations). Ammonia as a compound or as a precursor of PM-2.5 is of concern both environmentally and ecologically, and understanding the role of livestock production systems on ammonia emission and dispersion is critical to regulating and managing air quality in the context of confined animal feeding operations (CAFOs).

Odors can impact the well-being of workers and animals. Perceptions of odors by neighbors and government regulation of odor emissions can have serious economic consequences for farmers. Greenhouse gases contribute to global warming and the reduction of stratospheric ozone. Unfortunately, most of the greenhouse gases released from livestock facilities are a necessary consequence of production. The major exceptions are methane production related to storage and use of manures and gas production from manure processing systems.

Particulates can cause respiratory problems in humans and animals, either directly or by carrying pathogens, endotoxins, or allergens. Pathogen distribution via particulates can be a source of disease. Health problems of workers and animals in concentrated housing situations are a particular concern.

Given our lack of understanding of the emission and dispersion of gases and particulates, we can not reliably predict the environmental impact of current animal production systems. Given further our lack of understanding of the human perception of odors and our inadequate ability to quantify odor emissions, it is difficult to assess the dispersion pathways over complex terrain and to develop gaseous and particulate emission control practices.

The objectives of the Manure and Byproduct Utilization National Program are to (1) address the measurement of compounds associated with animal production and manure storage; (2) elucidate the mechanisms responsible for the formation of these gases; (3) determine the rates of emission; (4) evaluate the role of environmental conditions on emission generation and transport; (5) define impacts of emissions; and (6) develop cost-effective methods to control emissions. The Air Quality National Program focuses on determining emission rates from different systems and practices of livestock production, manure storage and handling, and manure application and dispersion of these emissions across the landscape. The linkages between these two programs are critical to the needs of the public. Additionally, collaborative linkages will be important with EPA, NOAA, FDA, CSREES, Natural Resource Conservation Service (NRCS), U.S. Forest Service (FS), DOD, Department of Energy (DOE), universities and land grant institutions, and the equipment industry.

Vision

Livestock production systems with no atmospheric impact

Mission

Develop practices and technologies for animal production systems that minimize gaseous and particulate emissions and human health impacts and provide information for science-based policy and regulation decisions

Table 4. ARS Research Locations Contributing to Component III of the Air Quality National Program--Malodorous Compounds

Component Problem Areas			
State	Locations	Emission Rates of Manure-Related Systems	Transport Processes of Odors and Particulates
AR	Fayetteville	X	
GA	Athens	X	
GA	Tifton	X	
IA	Ames	X	X
MD	Beltsville	X	
NE	Clay Center	X	
NE	Lincoln	X	
SC	Florence	X	
TX	Bushland	X	

Emission Rates of Manure-Related Systems**Problem Statement**

Rationale. Emission of gases and particulates from all phases of livestock production and manure handling, storage, processing, and application is poorly understood; and perception of emission rates varies among the public. A range of compounds are released from production systems, and these compounds vary among production units and across time. Thus, it has been difficult for producers or the public to compare production systems or evaluate the efficacy of control techniques. Uncovered manure storage systems are coming under greater scrutiny for their environmental impact and release of ammonia, methane, nitrous oxide, and volatile organic compounds into the atmosphere.

What is known. Current information on emission rates shows a large variation across time and among types of manure storage and handling systems. However, the literature often presents only snapshots of production systems and a limited number of gases.

Gaps. The information base upon which to make decisions about new methods is inadequate. Studies on emission rates from different livestock systems are limited, and there is no comprehensive database across a range of systems. Knowing rates of emission is necessary to understand how management practices or alternative manure-handling processes could reduce impacts of these emissions on the environment and neighbors. Major gaps that need to be addressed are

- Emission rates of volatile organic compounds, ammonia, methane, nitrous oxide, and hydrogen sulfide from different building, manure-handling, and storage systems;
- Emission rates of particulates passing through the air above manure storage systems; and
- Comparison of emission rates from different livestock systems and management practices, e.g., animal stocking rates, age, diet, siting, or general hygiene of the buildings.

Goals

Specific goals of this research are to

- Quantify emission rates from livestock production buildings for ammonia, methane, nitrous oxide, hydrogen sulfide, volatile organic compounds, and particulates;
- Quantify emission rates of ammonia, methane, nitrous oxide, hydrogen sulfide, volatile organic compounds, and particulates from manure-handling, storage, processing, and application systems;
- Identify the composition of particulates and interactions of gaseous compounds with particulates;
- Quantify emission rates related to environmental and management factors to develop a tool to predict emission rates from a range of livestock production and manure-handling systems; and
- Correlate emissions with management practices to identify best management practices for producers.

Approach

A multidisciplinary research program will be developed to quantify emission rates across a range of livestock production and manure-handling and application systems across the U.S. Quantifying emission rates will require a novel experimental approach to measure spatial and temporal changes in different gases across different systems. Data will be needed that represent the range of animal age within a facility along with variations in management systems.

Outcomes

- Differences among systems will be defined, and variations in emission rates will be quantified.
- Scientific evidence of linkages between management practices and facility design and operation will be available to producers.
- Policymakers will be better able to make scientifically-based decisions.

Impact

An economically and environmentally sustainable role for modern livestock production systems.

Linkages to Other ARS National Programs

- Food Animal Production
- Food Safety
- Integrated Agricultural Systems
- Manure and Byproduct Utilization
- Soil Resource Management
- Water Quality and Management

Transport Processes of Odors and Particulates

Problem Statement

Rationale. Variations among environmental conditions have not been addressed in either gaseous or particulate emission and transport from livestock production facilities. Preliminary results from a comparison of lagoons in Iowa, Oklahoma, and North Carolina suggest that environmental conditions exert the strongest effect on transport mechanisms of different gases away from livestock production and manure-handling or application systems. Understanding transport processes of particulate and gas emission is necessary for evaluating management practices that reduce emissions. Understanding the microbial ecology and the dynamics of emissions for different populations will be critical to the success of this effort.

What is known. Qualitative observations show that air quality around livestock facilities and manure storage changes within a day, from day-to-day, and throughout the year. Manure storage systems interact with the atmosphere differently depending upon the surrounding land surface and design of the manure storage system. Complicated exchange processes between manure storage facilities and the atmosphere have not been fully quantified. Observations on ammonia reveal that ammonia as a gas is transported only short distances while ammonia attached to water droplets can be transported large distances. Turbulence structure at the surface of a lagoon depends upon the wind direction, vegetation around the lagoon, overall layout of the site, topography, and prevailing atmospheric conditions. Particulates released by livestock production units vary greatly with production practices and management and affect release of odors from facilities. However, this information has not been assembled into a comprehensive understanding of the transport of gases and particulates from livestock production, manure storage and handling, and manure application areas.

Gaps. Eliminating specific gaps are crucial to improving our understanding of the transport processes associated with livestock production and manure systems:

- Transport of gases and particulates from livestock facilities and manure storage will require understanding the turbulence induced by an

- uneven landscape around livestock facilities.
- Air movement patterns and the ability of the air to transport gases and particulates for long distances require atmospheric models that are beyond the present simple dispersion models.
- New approaches are needed to quantify atmospheric transport and dispersion over nonuniform landscapes.
- Models for defining site characteristics need to be developed and incorporated into site assessment tools to help producers and facility managers reduce emissions.

Goals

- Develop transport models that can quantify movement patterns and transport capacity of air moving away from livestock and manure facilities;
- Determine the environmental impacts on transport and dispersion of gases and particulates from livestock production, manure-handling, and manure application sites;
- Quantify the interactions of environmental parameters on transport and dispersion processes;
- Quantify the interactions of gas and particulate emissions as factors influencing atmospheric transport and dispersion;
- Evaluate the efficacy of dispersion models for a range of livestock production and manure handling and storage facilities and manure application sites; and
- Develop transport models based on digital elevation models that can be incorporated into GIS-based systems for ready application by producers to manage and site new facilities.

Approach

Addressing this problem will require the development of experimental and theoretical approaches to quantifying emission rates and then coupling these emissions with transport factors. Existing atmospheric models potentially could be used; however, these need to be applied to the topographic setting and arrangement of livestock production, manure-handling, and manure application sites. Dispersion models capable of incorporating digital terrain models along with meteorological data and site characteristics have been evaluated. These applications need to be extended to a larger range of livestock production sites and across species.

Outcomes

- Siting and management of livestock production facilities with an emphasis on atmospheric transport processes will significantly improve air quality; these models will provide an assessment for local and long-range transport.
- The immediate benefit would be enabling producers to make management changes in facilities that would increase neighbor acceptance.

Impact

Realistic atmospheric transport models for livestock production systems.

Linkages to Other ARS National Programs

- Food Animal Production
- Food Safety
- Integrated Agricultural Systems
- Manure and Byproduct Utilization
- Soil Resource Management
- Water Quality and Management

Action Plan:

Component IV: Ozone Impacts

Introduction

Background

The air pollutant ozone is toxic to plants and occurs at sufficiently high concentrations in many parts of the country to cause visible symptoms of injury and to suppress the growth of many common crops. Ozone is a secondary pollutant that forms from nitrogen oxides and hydrocarbons that originate mostly in populated and industrialized areas, but can be transported hundreds of miles before reacting to form ozone. Some of the most productive agricultural areas in the U.S. are exposed to elevated ozone, and concentrations in rural areas are projected to increase. Data on emissions of precursors and their reaction in the atmosphere to form ozone and its subsequent transport in the atmosphere, as well as measurement of ambient ozone concentrations nationally, are readily available from other agencies such as EPA and NOAA.

Tropospheric ozone, that is, ozone occurring in that part of the atmosphere that is within 7 to 10 miles of the earth's surface, disrupts processes that can significantly suppress photosynthesis of many plant species. It can cause significant yield losses in common crops such as soybean, cotton, and wheat. Estimates indicate ozone-induced yield losses at current concentrations ranging from negligible to approximately 20% or more in some areas, depending on the crop species and environmental conditions during plant growth and exposure.

Plants grown in elevated ozone exhibit extensive biochemical and physiological differences from plants grown at lower concentrations. For example, ozone induces common wound and defense responses. In some cases, compounds are increased that may protect the plants from further ozone-induced injury. Changes in the chemical composition of ozone-stressed plants may affect plant-pest interactions and nutrient cycling from decomposing plant debris as well. Exposure of plants to ozone can alter the extent of infestation by insect pests. Thus, biochemical changes induced in plants by these gases may have impacts on crop systems beyond direct effects on growth. Estimates of the impact of greenhouse gases on agriculture will be inaccurate unless such effects on noncrop organisms and their interactions with crop plants are considered.

Plant response to ozone is controlled genetically. Species and genotypes (cultivars, clones) within a species may exhibit a range of responses. Capitalizing on this genetic variability is one possible way to minimize the negative impacts of ozone on crop production. To incorporate these traits efficiently into crops that are otherwise desirable agronomically, the biochemical and physiological attributes that confer these traits must be determined. Collections of plants exist (e.g., snap bean genotypes and white clover clones) that exhibit a wide range in response to ozone; these will be useful as model systems for such studies. This research will contribute to development of genotypes with improved performance under ozone polluted conditions.

Effects of ozone on plant growth and biochemistry are well-documented, but impacts of this gas on crop production systems in the future currently cannot be predicted with a high degree of confidence. Uncertainties are due to the complexity of interactions among plants, gas concentrations, environmental conditions, and noncrop organisms. Studies of these interactions are at an early stage, but an improved understanding of the effects of the gases in combination and in interaction with other factors in crop systems is required before the net effect on agricultural commodities in the U.S. can be defined.

This research meets a national need for developing agricultural management strategies to respond to atmospheric change. Ozone concentrations in the atmosphere will continue to increase in the foreseeable future. Cost-effective approaches to mitigate negative effects of this gas are not currently available, and economically feasible management options need to be identified. These options are most likely to be identified by developing a thorough understanding of the plant physiological mechanisms of response, establishing the genetic/biochemical basis of stress resistance, and determining the relevant interactions of the gas effects with environment and noncrop organisms. Ozone toxicity resembles oxidative stresses caused by other environmental phenomena of importance to agriculture, such as chilling, high light intensity, herbicides, pathogens, and other pollutants. Thus, the knowledge gained from this work will have a broader application than for ozone pollution alone.

This research will show the degree of impact on agricultural production to be expected from changes in air quality and thus will indicate the level of response needed to ameliorate the effects. The agricultural community, including federal and state extension personnel, the Economic Research Service (ERS), growers, cooperating scientists, and the scientific community are users of the research results. Plant production industries are recognizing increasingly that atmospheric contaminants affect their products. Results of this research will continue to benefit regulatory and action agencies and policymakers. The Federal Clean Air Act (Sections 108 and 109) requires the periodic evaluation of data on air quality effects on public welfare (Secondary Standard) for setting National Ambient Air Quality Standards. This research will respond to that mandate by providing the best available information on ozone effects on crops.

This research also will be a major source of information used by EPA to develop the criteria document 'Air Quality Criteria for Ozone and Related Photochemical Oxidants.' This document is required to evaluate and set the National Ambient Air Quality Standards for protection of public health and welfare from adverse effects of photochemical oxidants. Recent meetings with EPA staff indicated a continuing need for expanded and updated data for ozone effects on crops. Furthermore, the research will contribute to the information base needed to assess national and international policies for control of anthropogenic emissions.

Vision

Quality crop production free of limitations caused by tropospheric ozone

Mission

Identify ozone-tolerant crop species and varieties, response mechanisms to select or develop tolerant varieties, and production methods that minimize ozone-induced limitations on crop production and quality; and develop science-based information required for sound policy and regulatory decisions.

Table 5. ARS Research Locations Contributing to Component IV of the Air Quality National Program--Ozone Impacts

Component Problem Areas					
State	Locations	Effects of Ozone on Yield & Product Quality	Mechanisms of Ozone Response	Ozone-Tolerant Crop Plants	Effects of Ozone on Pests & Parasites
MD	Beltsville		X	X	
NC	Raleigh	X	X	X	X

Effects of Ozone on Yield and Product Quality

Problem Statement

Rationale. Because of the wide-ranging movement of ozone precursors from urbanized areas and their subsequent combination to form ozone, the problem of ozone impacts on crops is not limited to urbanized areas or to any particular part of the country. Some of the most productive agricultural areas in the eastern and midwestern parts of the U.S. are exposed to elevated ozone, in addition to the well known ozone problems in California and elsewhere. Tropospheric ozone concentrations have increased appreciably over the past 50 years. Concentrations in many areas of the U.S. are now approximately twice as high as would exist without the influence of human activities, and ozone concentrations in rural areas are projected to increase. The adverse effect of ozone on agriculture has national and international ramifications because it directly increases production costs of food and fiber, which are passed on to the consumer. In addition, tropospheric ozone adversely affects food quality and nutrition, environmental quality, biodiversity, and the atmosphere as a natural resource.

What is known. Visible symptoms of ozone injury to plants vary in severity among species, but may consist of decreased chlorophyll, increased pigmentation, and areas of dead plant tissue. Unfortunately, these symptoms often are not distinguishable from symptoms caused by pathogens, nutrient deficiencies, or other stresses. Often, the only visible feature of ozone stress is more rapid senescence (tissue death) toward the end of the life cycle, especially with annual plants, which is noticeable only when directly compared to nonstressed plants. Field experiments with open-top chambers have shown that ambient ozone concentrations suppress the growth and yield of major crops in productive agricultural areas of the country. Agronomic crops such as soybean, cotton, peanut, and some wheat cultivars are generally sensitive to ozone. Corn and sorghum are less sensitive although there is variability in ozone sensitivity among cultivars of the same crop. Estimates of ozone-induced yield losses nationally are variable, but limited data indicate that ozone causes substantial economic losses through reduction of crop yields. The extent of loss varies not only with the ozone sensitivity of individual crops, but also highly depends on environmental conditions during plant growth and exposure. For example, plants tend to be more sensitive to injury when grown and exposed under conditions of high humidity; whereas they are less sensitive under drought and elevated atmospheric carbon dioxide. In general, detrimental effects of ozone are on crop yield although minor changes in product quality have been reported. Visible injury and suppressed growth also diminish the economic value of some horticultural and ornamental crops.

Gaps. Although limited data are available from field studies concerning ozone effects on yield and/or quality of major crops (e.g., soybean, corn, cotton, peanut, rice, wheat, sorghum), not all economically important crops have been tested. For those crops that have been studied, too few cultivars or varieties were evaluated to estimate risks to production with confidence. Furthermore, there are insufficient data on those cultivars currently used in production agriculture, and too little is known about their genetic variability in ozone sensitivity. There is a serious shortage of data on horticultural crops (food and ornamentals), which often are ozone sensitive and are very important economically. In addition, experiments to date have not been conducted under a sufficient range of climates to understand the effects of variable environmental factors on the quantification of ozone impacts. Effects of environmental variables such as temperature, relative humidity, rainfall, solar radiation, and soil properties are particularly important with the rise in atmospheric carbon dioxide concentrations and the associated changes in global climate that may occur. Ozone exposure patterns vary to some extent both geographically and year-to-year. The degree to which these variations affect plant response are not well understood. The capability to extrapolate data across years and climates is currently limited, and data are needed to develop plant growth process models and statistical models for extrapolation and prediction. Techniques and tools for experimentation and assessment need further development.

Goals

- Determine impacts of ozone on yield and quality of major crops, including variation among cultivars within species;
- Determine environmental influences on crop response to ozone; and
- Improve ability to predict ozone effects on crop production under future climate/management scenarios

Approach

This research should emphasize experiments in field plots with plants grown from germination through maturity while exposed to appropriate ozone concentrations and exposure regimes. Experiments in greenhouses and growth chambers should be conducted with supplemental light that approximates the quality and intensity of full sunlight. Typically, open-top field chambers or similar facilities will be used to control and manipulate ozone concentrations around test plants. This approach permits the experimental pollutant-exposure treatments to be defined, allowing dose-response analysis within and across years. Use of existing ambient ozone gradients, open-air treatments (similar to those used in free-air carbon dioxide enrichment studies) or chemical ozone protectants should be considered when there are distinct experimental advantages.

Plant response to ozone varies across locations and years, and therefore gas exposure concentrations should encompass a wide range. Ozone exposure regimes should be similar to those found in ambient air (i.e., simulate daily peaks and episodic nature of ambient ozone concentrations). Plant cultivars, soil variables, or other factors can be included as additional variables, as appropriate. Environmental data such as temperature, rainfall, humidity, and irradiation should be routinely recorded throughout the experiments. Prominent cultivars of economically important agronomic and horticultural species should be used unless the specific research needs dictate otherwise. Emphasis for each crop species should be on cultivars or genotypes that represent current and, as much as known, future farming practices.

Statistical dose-response models will be developed to estimate effects of ranges of ozone concentrations on yield. The experimental data, however, will represent only a small fraction of the air pollutant/climate scenarios that may be encountered. Therefore when possible, associated physiological and growth data should be used to develop mechanistic simulation models of crop growth and yield that incorporate response to ozone stress.

Outcomes

- Data will be available to determine the economic costs of ozone pollution to crop production.
- The future effects of ozone on crop production in a changing climate will be predictable.
- A scientific basis will be provided to choose among management options to limit ozone impacts on crop production.

Impact

Informed decisions by agricultural producers and regulatory and policymakers to minimize ozone impacts on agricultural production, agribusiness, and the public.

Linkages to Other ARS National Programs

- Global Change
- Integrated Agricultural Systems
- Plant Diseases

Mechanisms of Ozone Response

Problem Statement

Rationale. In many crops, current tropospheric ozone levels inhibit photosynthesis, alter plant structure and development, and suppress biomass and yield. Such effects are mediated by numerous metabolic pathways through which plants produce energy and carry on other activities. However, these pathways remain either unknown or only partially described. This is partly due to the current state of plant science research, which is just beginning to integrate plant biology from the molecular to the organismal level. Extension of these research efforts toward defining the mechanisms of ozone toxicity are required to understand the adverse effects of ozone on plants. Biological impairment by ozone needs further clarification if we are to provide the information needed to counteract its adverse effects.

What is known. The mechanisms of ozone action involve both toxicity and responses that counteract, perpetuate, or even exacerbate effects of ozone exposure. In addition, some plant responses to ozone might have no role at all in counteracting ozone stress.

Plants take up ozone primarily through their leaves, a process largely influenced by physiological and environmental factors (carbon dioxide concentration, humidity, light, temperature, nutrient and water availability). The complex processes of metabolism following ozone uptake are thought to include decreasing the amount of carbon available for plant growth by suppressing photosynthesis and by stimulating the need for carbon in maintenance and repair processes. In addition, translocation of carbohydrates from leaves to shoot and roots is inhibited by ozone injury. In this respect, carbohydrate metabolism and allocation are important links between carbon dioxide fixation and biomass production. Analysis of carbohydrate pools and plant structure can be a valuable tool in identifying the sensitive steps in plant metabolism that reveal the mechanisms of ozone injury.

In concert with plant responses to ozone injury per se, a number of genetic responses are induced by exposure to ozone. The responses described so far involve photosynthesis, antioxidant and secondary metabolism, pathogen-defense responses, and senescence-related processes. Some of these responses correspond to defense reactions to oxidative stress. In addition, ozone induces several genetic pathways associated with senescence processes, and there are indications that ozone provokes programmed cell death.

Gaps. A comprehensive understanding of ozone impairment of plant growth and development is lacking. This includes physiological and environmental factors controlling ozone uptake. An integrated understanding of direct and indirect effects of ozone on plant mechanisms and processes, including photosynthesis, ion regulation, carbohydrate, lipid and nitrogen metabolism, water relations, phloem loading, and biomass allocation needs to be developed from the molecular to the organismal level. The significance of ozone-induced changes in antioxidant metabolism, pathogen defense responses, and secondary metabolism needs to be assessed. How senescence processes, especially ethylene production, are induced and interact with ozone needs to be investigated. Many recent studies on photosynthesis, carbohydrate metabolism, and molecular biology have been done with woody plants and model plant systems. These findings should be addressed for applicability to herbaceous crop plants.

Goals

- Improve understanding of physiological processes and environmental factors controlling ozone uptake in crop plants;
- Determine effects of ozone on carbohydrate and nitrogen metabolic pathways;
- Expand our knowledge of genes induced by ozone and their adaptive significance;
- Characterize ozone-induced senescence processes and programmed cell death; and
- Link genetic markers to adaptive physiological traits for ozone resistance.

Approach

A multidisciplinary approach will be used to assess direct and indirect effects of ozone on the quality and quantity of seed and forage crops. Treatment facilities include indoor and outdoor controlled environment chambers, greenhouse chambers, and open-top field chambers. Experiments using model plants and crop plants will be conducted. Experts in molecular biology, plant physiology, and biochemistry will cooperate to measure and assess plant responses to ozone.

Outcomes

- Mechanisms of ozone toxicity will be defined for various crop plants and cropping systems and the information used to counteract adverse effects of ozone exposure.
- Biochemical and molecular markers will be identified that detect ozone stress when visible symptoms are absent or inconclusive.

Impact

A sustainable crop production system that minimizes adverse effects of tropospheric ozone pollution.

Linkages to Other ARS National Programs

- Global Change
- Plant Biological and Molecular Processes
- Plant Microbial and Insect Genetic Resources, Genomics, and Genetic Improvement

Ozone-Tolerant Crops

Problem Statement

Rationale. Tropospheric ozone concentrations can inhibit plant growth and yield in many agricultural regions. One management strategy is to utilize ozone-tolerant varieties that perform well in high ozone environments, yet maintain yield and quality in years when ozone impact is minimal. To implement such a strategy, information is needed on the range of ozone sensitivity within cultivars of major crops. For certain crops, available cultivars may not express sufficient ozone tolerance to maintain high levels of productivity under current or future ozone levels. Therefore, new varieties are needed with enhanced ozone tolerance.

What is known. Plants are known to exhibit a range of ozone sensitivity in terms of visible injury and yield reduction, including significant variation among genotypes or clones of the same species. Presumably, genetic variation represents differences in capacity to express one or more tolerance mechanisms. Studies to date have identified three aspects of plant physiology that determine the impact of ozone stress on plant growth. First, ozone entry into the plant is primarily via leaf stomata, so stomatal processes that limit ozone uptake could ameliorate the effect of ozone stress. However, reduced stomatal conductance also could negatively affect plant growth through reduction of carbon dioxide and water vapor gas exchange, although tolerance to drought might be improved. Second, ozone injury can be minimized or prevented by metabolic pathways that detoxify ozone and the reactive oxygen species formed from ozone. Finally, once ozone injury has been initiated, metabolic responses are induced that replace damaged cellular constituents (e.g., lipids and proteins) or alter whole plant development patterns (e.g., accelerated senescence). There also is evidence that plant responses to ozone share common features with responses to other environmental stresses (e.g., pathogen infection, chilling, drought stress), so that new knowledge about plant tolerance to other stress factors may provide insights into ozone tolerance and vice versa.

Gaps. Although current knowledge can suggest future research efforts, no definitive ozone tolerance mechanisms have been characterized. Specific mechanisms must be identified, and an understanding is needed of how multiple mechanisms combine to produce the ozone tolerance associated with a particular genotype. The distinctions between injury prevention versus repair processes need to be clarified. Initiation of ozone injury induces a localized or general response that may permanently alter the growth and yield potential of the plant, so mechanisms that prevent injury may have greater impact than mechanisms related to cellular repair.

Evidence suggests that a range of ozone sensitivity exists within each species, but information on ozone-sensitive and tolerant cultivars is not available for each major crop. Knowledge and methodology must be developed to allow rapid selection of ozone-tolerant varieties from available germplasm.

Goals

- Identify specific aspects of physiology and metabolism that distinguish ozone-sensitive and ozone-tolerant plants;
- Formulate strategies based on genetic manipulation of key metabolic pathways that will increase yield potential under elevated ozone environments; and
- Identify ozone-sensitive and -tolerant cultivars within existing germplasm of major crop species.

Approach

Controlled environment facilities and open-top chambers will be used to conduct mechanistic studies and to screen available germplasm under a range of ozone concentrations. Ozone-sensitive and ozone-tolerant genotypes from the same species will be compared to identify biochemical and physiological characteristics that contribute to ozone tolerance. Mutants of model plants will be utilized as a tool to provide insights into tolerance mechanisms not yet recognized. Plants with known tolerance to pathogens or to stresses such as chilling and drought will be tested for cross-tolerance against ozone as an alternative approach for mechanism identification. Specific enzymes or physiological markers with the potential to affect ozone tolerance will be identified and this information used to produce plants for further testing and to develop new methods for rapidly screening germplasm.

Outcomes

- Fundamental knowledge of ozone tolerance will be developed that can be used to produce plants with enhanced performance under elevated ozone environments.
- The potential impact of ozone on crop production and quality will be demonstrated to growers, extension agents, and others.
- Ranking of modern cultivars for ozone-sensitivity will allow growers in areas of high ozone to select ozone-tolerant varieties that are compatible with current farming practices.

Impact

Crop productivity and quality maintained or improved in agricultural areas subjected to elevated tropospheric ozone.

Linkages to Other ARS National Programs

- Global Change
- Integrated Agricultural Systems

- Plant Biological and Molecular Processes

Effects of Ozone on Pests and Parasites

Problem Statement

Rationale. Relationships between plants and their pests and pathogens are delicately balanced. Plants possess intricate defense mechanisms, whereas pests and pathogens possess elaborate strategies to cope with plant defenses. Any factor that upsets normal plant metabolism can affect plant defenses and threaten overall plant health. For the first time in human history, anthropogenic emissions have resulted in tropospheric ozone concentrations high enough to disrupt plant metabolism and cause the ozone-induced injuries noted earlier, which result in suppressed growth and yield. It is not surprising that this relatively sudden change in earth's air quality also has affected interactions between plants, pests, and pathogens. Research to unravel effects of tropospheric ozone on pests and pathogens of agricultural crops has been fragmented and sporadic. Plant stress caused by ozone can increase, decrease, or have no effect on pests and pathogens, but mechanisms to explain these responses are unknown. Ozone-induced increases in pest and pathogen populations would further suppress crop yield and increase pesticide use. Increased use of pesticides would threaten environmental quality. Data are required to estimate the environmental and economic impact of such changes.

What is known. Reports of stimulatory responses of insects feeding on plants exposed to air pollutants predominate over reports of inhibitory responses. Early investigations in Europe showed that growth rate and degree of infestation of various aphid species often were greater on plants in nonfiltered urban air than in charcoal-filtered air although two aphid species were inhibited by nonfiltered air. Specific atmospheric components responsible for effects attributed to nonfiltered air in European reports were not identified, but evidence from later experiments with specific pollutants indicates that ozone is a prime candidate. Various stimulatory responses (increased feeding, faster development, better survival) have been reported for larvae of several leaf-chewing insects when host plants were exposed to ozone. Populations of the two-spotted spider mite on white clover and peanut increased faster on plants exposed to ambient concentrations of ozone than on plants exposed to lower concentrations of ozone. Increased fecundity and shorter development time caused this increase in mite populations.

Our present knowledge of pollutant effects on plant disease stems largely from short-term experiments performed mostly in the greenhouse or laboratory, dealing with only one stage in the parasite cycle. Studies with diseases caused by fungi have predominated over diseases caused by other organisms. Foliar diseases have been studied more than diseases of other plant organs.

It is generally agreed that effects of ozone on pests and pathogens are mediated mostly through effects on host plant physiology. Effects on plant concentrations of carbohydrates, nitrogen compounds, or metabolites that may be directly involved in plant defense often have been cited as possible indirect mechanisms.

Gaps. Effects of tropospheric ozone have been studied for only a small percentage of important pests and diseases. Most research has involved short-term exposure to one or two relatively high pollutant concentrations to measure effects on individual life stages. Studies employing long-term exposure to a wide range of pollutant concentrations allowing measures of changes in multiple life stages and population dynamics are rare. Most research has been performed in greenhouse or environmentally controlled exposure systems. Few studies have been performed in systems under near-ambient environmental conditions. Changes in host plants that may account for observed effects on pests or disease include changes in host suitability as a food source and increases or decreases in metabolites that may be involved in defense mechanisms or host attractiveness. However, pollutant-induced changes in specific host nutrients or specific metabolites have not been proven as cause for pest or disease response. Recent reports show that carbon dioxide enrichment can prevent ozone stress in many crops. Other soil-related and climatic factors also can alter plant response to ozone. Effects of carbon dioxide enrichment and other environmental factors on pest or pathogen response to ozone have not been adequately addressed.

Goals

- Determine effects of chronic ozone exposure of plants on multiple life stages and population dynamics for representative agricultural pests and pathogens;
- Identify ozone-induced changes in plant chemistry that control pest infestation; and
- Estimate effects of observed responses on crop yield and pesticide use.

Approach

Experimental ozone exposures will be performed in controlled environments, greenhouses, or open-top field chambers. Exposures will be chronic, mimic real-world exposure dynamics, and span the range of concentrations that occur in the troposphere at various locations throughout the world. Exposures will be performed before, during, and after pests or disease organisms are introduced to host plants. Temperature, rainfall, humidity, and solar radiation will be routinely recorded throughout the experiments to examine possible influence of these factors on measured responses.

Economically important pests and parasites will be selected for study, and host plants with variable degrees of tolerance to ozone will be used when possible. Measurements of individual and multiple life stages will be made to allow estimates of long-term effects on population dynamics. Measures of ozone effects on plant biochemistry will be made to identify mechanisms of pest and parasite responses. Effects of carbon dioxide enrichment and other factors such as temperature or soil nutrition on pest or pathogen response to ozone will be included as experimental variables when appropriate to increase extrapolation of results to a wider range of environments

Outcomes

- Estimates will be developed for risks to crop production from ozone-induced effects on pests and diseases.
- Ozone-induced changes in pesticide use caused by ozone impact on pests and disease will be assessed.

Impact

Minimal adverse effects on crops caused by ozone influence on plant pests and diseases and

improved regulatory and policy decisions to minimize ozone effects on agriculture

Linkages to Other ARS National Programs

- Global Change
- Integrated Agricultural Systems
- Plant Biological and Molecular Processes
- Plant Diseases
- Plant Microbial and Insect Genetic Resources, Genomics, and Genetic Improvement

Action Plan:

Component V: Pesticides and Other Synthetic Organic Chemicals

Introduction

Background

Pesticides have been used for decades to control agricultural pests and to ensure an adequate quantity and quality of food for the Nation. A pesticide's toxicity is responsible for its effectiveness in controlling pests but may cause undesirable side-effects when the chemical moves from its intended location. Pesticide movement to the atmosphere depends upon complex interactions between the properties of the individual chemicals, the weather, the properties of the soil or plant tissue on which they are adsorbed, the way they are applied, and the management of the field or crop. Pesticides potentially can contaminate soil, water, and air. To protect our natural resources, research on pesticide movement and transformation must integrate the effects from all environmental systems.

The occurrence of pesticides in the atmosphere and water is an important national issue. Studies have documented that some of the pesticides found in the atmosphere and water have resulted from agricultural applications. Dissipation and accumulation of pesticide residues can limit the efficacy of some pesticide materials. Pesticides and transformation products in the atmosphere can be a major health concern and cause plant damage far from their sites of application. For example, methyl bromide, a widely-used soil fumigant, has been implicated in damage to the stratospheric ozone layer. It has been estimated that as much as 40-60% of the applied material may ultimately reach the atmosphere.

Many pesticides are volatile, and even those with low volatility can be transported in the atmosphere as residues bound to dust particles or as aerosols. Both the active ingredient and formulation constituents can become air contaminants. Volatile components and residues bound to dusts may rise high into the atmosphere, travel long distances, and be deposited far from the point of origin through various deposition processes. Raindrops have been shown to have pesticide components.

Sources of Emissions. Pesticides are applied to the soil or to a crop. Many techniques can be used to apply a pesticide depending on type of formulation, timing of application, the pest to be controlled, and other soil environmental management considerations. The pesticide can be injected into the soil as a fumigant or into irrigation water; or it can be sprayed onto the soil surface. Crops can be sprayed, for example, with boom sprayers or tunnel sprayers or by aerial application, or they can be treated with systemic pesticides. Seeds are sometimes treated with pesticides prior to planting. Pesticides also can be incorporated into other materials so that release of the active ingredient occurs over a longer period of time.

During aerial pesticide application, some part of applied material is lost to the atmosphere in the form of fine droplets moving off-target through the air stream by a process called spray drift. Spraying pesticides through spray nozzles produces a spectrum of droplet diameters. The smallest droplets will remain airborne and become lost as spray drift. Larger droplets can be transported by the wind and deposited some distance outside the target area. As droplets are transported, their diameter decreases through evaporation. As they become smaller, they remain airborne longer and can be transported over regional, continental, or intercontinental distances.

Pesticides of moderate-to-high volatility sprayed above the soil surface form droplets that rapidly enter the gaseous phase and can be transported in the atmosphere. A portion of the pesticide that reaches the soil or plant surface also may evaporate over time and move into the atmosphere through a process of volatilization. Once in the atmosphere, a volatile pesticide can travel long distances. Loss during application through spray drift depends largely on application method, properties of the formulation, and environmental conditions. Volatilization losses from soil or plants depend largely on soil and environmental conditions, chemical properties of the pesticide, and agricultural management after application.

Once a pesticide is in the atmosphere its movement and transformation are controlled by various atmospheric and chemical processes. Pesticides can degrade in the atmosphere during photosynthesis or in reaction with other atmospheric constituents. Some processes are particularly important in determining the ultimate concentration and transport distance from the point of application, which affects the risk of contaminating sensitive ecosystems.

Alternatives to Pesticides. Alternatives to use of pesticides to control agricultural pests include biological control, genetically altered organisms, and various cultural and environmental practices (e.g., exposure to the sun, flooding, and crop rotations). Many issues need to be addressed before cultural and environmental practices will be suitable for replacing pesticides. For example, exposure to the sun can provide good pest control near the soil surface, but control diminishes with depth, and the effectiveness of the treatment is often variable.

Genetic engineering poses unique possibilities to end or limit the use of pesticides but also may involve unexplored risks to agricultural and ecological systems. Releasing genetically engineered organisms into the environment could devastate native organisms in a similar manner as the introduction of nonnative species.

A pesticide's behavior in the environment is fairly well known and, with proper management, may involve smaller overall risks to agricultural and

ecological systems than the use of biologically engineered organisms. Cultural and environmental practices offer ways to reduce pesticide use; however, these systems likely will require occasional treatment with pesticides. Therefore, improved pesticide management methods are needed to reduce emissions and off-target contamination to ensure that pesticides are used safely.

Source Reduction. Significant pesticide contamination is possible when pesticides are applied inappropriately, inefficiently, or when accidentally spilled. Large quantities of applied pesticides may be lost from aerial spraying during windy conditions, and pesticides may drift onto adjacent fields or nearby ecosystems. Such conditions can cause significant atmospheric contamination.

Soil fumigants are a special category of pesticides that are highly mobile in the soil-water-air environment. Because of environmental and health concerns, several fumigants have been banned during the last decade. Recently, methyl bromide emissions to the atmosphere have been found to deplete stratospheric ozone, and the use of methyl bromide is scheduled to be phased out in the U.S. by 2005. There is a general lack of knowledge of the mechanisms underlying the environmental behavior of these volatile pesticides.

Volatile pesticides are released to the atmosphere during and after application. Large pulses of pesticides may be released from areas of heavy agricultural activity for three to four days after application, causing increased pesticide concentrations in the entire region. Lower concentrations persist throughout the remainder of the year as the pesticide material is cycled within the plant-air-soil-water environment.

Potential impacts of pesticide loss to the atmosphere are (1) decline in air and water quality; (2) loss of beneficial insects and plants through off-site drift; (3) regional and long-range transport and degradation of soil, plant, and surface water quality; (4) accumulation and transfer of pesticide residues to sensitive wildlife and potential disruption of the food chain; and (5) degradation of the global atmosphere and loss of natural protective zones such as stratospheric ozone.

Vision

An environment and society free of adverse effects from agricultural pesticides

Mission

Develop agricultural production systems that minimize unwanted emission and transport of pesticides

Table 6. ARS Research Locations Contributing to Component V of the Air Quality National Program B Pesticides and Other Synthetic Organic Chemicals

Component Problem Areas				
State	Location	Measurement, Mechanisms, & Processes	Model Development & Testing	Source (Emission) Reduction & Improved Pesticide Management
CA	Riverside	X	X	X
IA	Ames	X		
MD	Beltsville	X		
MN	St. Paul		X	
TX	College Station	X		

Measurement, Mechanisms, and Processes

Problem Statement

Rationale. Pesticides and other synthetic organic chemicals used in agricultural production can move into the atmosphere where their presence raises concerns about harmful impacts on aquatic and terrestrial ecosystems and human health. Pesticides and other synthetic organic chemicals are biologically active by design, but some pesticides also are classified as potential carcinogens or endocrine disruptors. To evaluate the risks of using pesticides or synthetic organic chemicals in agriculture, accurate methods are needed to measure environmental concentrations in air, water, and soil. Further, transport of pesticides from target locations to the atmosphere is affected by many factors, processes, and mechanisms. A better understanding of interrelated factors affecting movement and transformation is needed to develop management practices that use pesticides effectively and control emissions into the atmosphere.

What is known. Pesticides are important tools in plant and animal production systems that provide an abundant and nutritious food supply. The potential for pesticide contamination of air, water, and soil depends upon all the processes, mechanisms, and factors that affect pesticide movement and degradation. Pesticides use continuously exposes nontarget organisms, including humans, to low concentrations of these chemicals. Biological and chemical degradation processes produce new chemicals that also may be volatile and biologically active, and their toxicity may vary from that of the parent chemical. A large amount of information has been obtained on various pesticide properties important for environmental movement and transformation studies. This information is available in various databases.

Pesticide movement to the atmosphere is known to depend on environmental conditions, properties of pesticides, and target media (e.g., soil, plant material, water). Pesticide movement further depends on water movement and various interactions with soil material, e.g. adsorption, degradation. Changes in soil, water, and pesticide management practices greatly affect pesticide transport to the atmosphere. Newer irrigation techniques greatly increase water use efficiency and minimize loss of water by deep percolation. Minimizing deep percolation by using irrigation best management practices reduces the movement of pesticides toward groundwater but may have the unintended effect of increasing contamination of the atmosphere. In rain-fed areas, water application (e.g., rainfall) patterns are unpredictable. Under these conditions, rainfall timing and amount are highly variable in space and time and significantly affect pesticide movement and transformation. This uncertainty complicates the effectiveness and optimal management of pesticides.

Gaps. We currently have a limited understanding of the processes, factors, and relationships that control pesticide transport from soil, water, and plants into the atmosphere. This information is required to develop and refine mechanism and process descriptions for use in models to predict pesticide transport and to help develop management practices that reduce or prevent groundwater contamination. Specific gaps include

- The best techniques for rapid, cost-effective monitoring and analysis of pesticides, pesticides bound to dust particles, and new and emerging chemicals in soil, water and air; including knowledge of the limitations and operational requirements of measurement systems;
- Knowledge of current pesticide loading to air, water, and soil systems and persistence of pesticides in the atmosphere;
- An understanding of reactions of pesticides and synthetic organic chemicals in the atmosphere, including aspects that directly affect nontarget contamination;
- The best methods to apply pesticides accurately, effectively, efficiently, and economically, including information on the performance of new pesticide formulations and delivery systems;
- Additional information on the emission rates and total loss of agricultural pesticides to the atmosphere during and after application to soil and on emissions from spray drift related to various application systems;
- A better understanding of processes and mechanisms important in wet and dry deposition and partitioning between air-water-particulates in the atmosphere;
- Research that allows information gathered at one scale (e.g., laboratory) to be accurately used at other spatial and temporal scales (e.g., watershed);
- Effects of preferential flow and macropores on pesticide volatilization; and
- Effects of new irrigation methods on pesticide transport to the atmosphere.

Goals

- Develop simple, accurate, inexpensive methods to measure volatile concentrations and pesticide residues bound to particulate matter in the atmosphere, and develop analytical methods for new pesticides and transformation products;
- Develop simple, accurate, inexpensive methods to estimate pesticide emissions, deposition, and off-site transport;
- Monitor air, soil, and water for the presence of pesticides and transformation products;
- Quantify factors that control movement and availability of synthetic organic chemicals relative to their transport, degradation, and persistence in air and soil-water environments; and
- Understand the integrative roles of sorption, transformation, partitioning, energy, preferential flow, and the influence of microbial communities in soil and the root zone area as they affect transport of pesticides to the atmosphere.

Approach

Develop a multidisciplinary research program consisting of laboratory, field, and regional-scale research. New sampling devices and analytical methods to measure the presence of pesticides in air, water, and soil will require novel approaches. Existing laboratory and field methods to determine emission rates will be evaluated and new methods developed that are more accurate and economical. Experiments will be conducted to provide quantitative information on processes affecting chemical movement, binding, transformation, and bioavailability of synthetic organic chemicals. Relationships between soil, water, chemical, and environmental conditions and pesticide emissions and deposition will be developed. Methods that relate laboratory parameter values to appropriate field-scale parameters will be a priority. This research will be coordinated with research on pesticide transport in soils in the Water Quality and Management National Program.

Outcomes

- Tools and methods will be developed to quantify the occurrence of pesticides and synthetic organic chemicals within the soil, air, water continuum and the transfer between environmental systems.
- The occurrence of volatile pesticides and other synthetic organic chemicals, including newly developed pesticides, in the atmosphere will be reduced.
- 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 will protect public health and sensitive ecosystems from pesticide contamination.

Impact

Reduced risks to human health, reduced contamination of remote and sensitive ecosystems, and a sustainable agricultural production system that uses pesticides and other synthetic organic chemicals in a benign manner.

Linkages to Other ARS National Programs

- Integrated Agricultural Systems
- Methyl Bromide Alternatives
- Manure and Byproduct Utilization
- Rangeland, Pasture, and Forages
- Water Quality and Management

Model Development and Testing

Problem Statement

Rationale. Behavior of a pesticide in the environment is the result of many complex processes, mechanisms, and interactions that affect movement and transformation. Mathematical models provide a conceptual framework to study behavior of pesticides and the importance of various processes to their environmental transmission. Models provide a quantitative approach for determining the influence of various factors and processes known to affect pesticide movement and transformation. They also provide a quantitative methodology for use in developing management methods to mitigate harmful effects that may occur from use of pesticides and other synthetic organic chemicals. Much research has been devoted to developing complex simulation algorithms with the hope that they can be used to determine best management practices; however, obtaining data to support use of these models is very difficult and will probably remain a research activity for the near future.

The appropriate complexity of a model depends on its application. Simple models are appropriate for determining vulnerability of the atmosphere to contamination so that land-use managers can predict effects on the environment from various management decisions. These assessment methods also should provide information on the uncertainty in assessment methods (i.e., models) and the supporting data to allow land-use managers to determine the reliability of management decision-making tools. There is a great need to test models under conditions matching the complexity of the simulation, especially if the models are to be used as predictive or management tools.

What is known. Much progress has been made in understanding processes affecting pesticide fate and the movement of water and chemicals in the environment as well as in developing mathematical models to describe and simulate their movement. Recent research has shown that the behavior of volatile organic compounds in soil is controlled primarily by their physical and chemical properties.

Total exposure to pesticide concentrations varies across and within a landscape and depends on the spatial-temporal scale and regional environmental conditions. Total exposure to a pesticide is an integration of all the effects (e.g., transport and transformation) to which the pesticide is subjected from processes and mechanisms that occur at all scales. For the entire spatial and temporal domain, neither these effects nor their occurrence can be described or predicted with certainty. Thus, complete information is never available, and intensity of exposure can be described only in probabilistic terms.

Under certain conditions, models can accurately simulate the potential for pesticide contamination as related to soil-atmosphere conditions and pesticide management practices. Simulation can provide a focus for the research objectives of laboratory and field experiments and help identify redundant or superficial experiments. Likewise, results of field experiments can be used to test and enhance the model. Models have been especially useful for ranking relative effects, such as various management options. As the simulation accuracy improves, the predictive capability of a model becomes a valuable tool in management-decision processes. To achieve this goal, however, requires a comprehensive demonstration that the model accurately estimates the potential for a pesticide to contaminate air, water, and soil systems.

Gaps. Many gaps in our understanding of the volatilization, transport, and dissipation processes restrict our ability to simulate pesticide movement and transformation. For example, although many scientists recognize that changes in atmospheric pressure above a soil strongly affect the transport of organic chemicals between the atmosphere and soil, there is little agreement on how to characterize this process or how to incorporate this effect into models. Little information and few methods exist to simulate pesticide adsorption to particulate material and subsequent atmospheric transport and deposition. There also is increasing pressure to develop improved management systems that use chemicals efficiently; provide adequate yields of pesticide-free crops; and reduce or eliminate air, soil, and water contamination. In all cases, it is important to recognize the intended use of the models so that appropriate results are obtained while optimizing pesticide management. Specific research gaps include the following:

- A better understanding is needed of the environmental conditions that affect pesticide movement and transformation from heterogeneous soil to the atmosphere.
- Better methods are needed to predict pesticide emissions and off-site transport.
- Little research has been completed to improve methods for characterizing pesticide volatilization under the general conditions encountered with production agriculture.
- It is unclear how pesticide emissions are affected by the large and relatively continuous voids that may be present in structured soils.
- Comprehensive environmental models are needed that will simulate proposed changes in pesticide management to identify changes in pesticide behavior in soil, water (surface and ground), and air and implications for adverse impacts on other environmental systems.
- Models and methods are needed to develop buffer zones and to aid in determining the risk of exposure from pesticides in air.
- Screening methods are needed to determine the environmental and human health impact of pesticides as affected by application and use pattern.
- Regional and continental scale models are needed to predict effects of long-range transport.
- Improved methods are needed to obtain model parameters; discrepancies between model parameters (theoretical and pure) and estimates

derived in laboratory experiments need to be identified and resolved.

Goals

- Develop new and efficient predictive algorithms to quantify at field, farm, and regional scales processes that control pesticide transformation in the environment and discharges into the atmosphere;
- 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;
- Develop new and more accurate methods to couple soil-based processes to atmospheric-based processes; and
- Develop data bases of pesticide properties, soil and hydraulic parameters, and typical environmental conditions that can be used for modeling situations;

Approach

Develop and test models of atmospheric transport that incorporate appropriate models of soil volatilization and/or deposition processes. Improvements in simulating gas exchange between soil and atmosphere will require extensive research. Use monitoring data, geographic information systems (GIS), soil and crop data, terrain analysis, and simulation modeling to define processes that control pesticide and synthetic organic chemical movement and loadings to air and water resources for agricultural regions. Conduct field-scale monitoring and transport studies to determine atmospheric concentration and volatilization rate of pesticides. Determine the effects of specific field management practices, such as tillage systems or application technology, together with effects of off-site practices such as use of buffer strips or riparian zones, on loadings of synthetic organic chemicals into the atmosphere and to surface or ground water. Use this information to test models and to develop specific practices that improve air quality without degrading surface or ground water quality.

Outcomes

- Quantitative tools, methods, procedures, and databases will be developed to simulate movement and transformation of pesticides and synthetic organic chemicals within the air, water, and soil continuum.
- Factors affecting movement and transformation of volatile pesticides and synthetic organic chemicals in the atmosphere will be controlled, and the presence of volatile pesticides and other synthetic organic chemicals in the atmosphere will be reduced.
- Models will improve management methods and provide the basis for development of risk assessment methods.
- Improved models will protect the atmosphere and sensitive nontargeted ecosystems from pesticide contamination, benefitting the environment of both urban and agricultural areas.

Impact

Optimum pesticide efficacy with no nontarget transmission.

Linkages to Other ARS National Programs

- Integrated Agricultural Systems
- Methyl Bromide Alternatives
- Manure and Byproduct Utilization
- Rangeland, Pasture, and Forages
- Water Quality and Management

Source (Emission) Reduction and Improved Pesticide Management

Problem Statement

Rationale. A sustainable agricultural system requires a balance between environmental stewardship and economic vitality and equality for producers. Source reduction is an integral component to sustainable agriculture, since in general, reducing pesticide emissions benefits both the environment and a producer's profitability. Since pesticide emission is the movement of pesticide from target to other locations, management strategies that help to keep pesticides at the target location will reduce emissions. When a larger fraction of the pesticide remains at the target location, the total amount needed to achieve adequate pest control is often reduced. The producer profits economically by reducing pesticide consumption; and the environment benefits with reduced pesticide to target, and more importantly, to nontarget areas.

Improved pesticide management can make pesticides safer to use. Methods used to apply pesticides, timing of applications, and farm management practices before and after pesticide application can significantly affect pesticide emissions to the atmosphere and residues in soil. Research has demonstrated that most of the negative environmental aspects resulting from pesticide use can be controlled by adopting better management practices. In many cases, these practices will not reduce profitability.

What is known. Field measurements have established volatilization and spray drift as primary pathways for the loss of many pesticides and other synthetic organic chemicals from soil. Volatilization of chemicals from soils can be estimated from a consideration of physical and chemical factors controlling their concentration at the soil surface. When an organic chemical is mixed into soil, volatilization involves partitioning into the vapor phase, movement to the soil surface, and vaporization into the atmosphere. The factors affecting their rate of volatilization are known, including reported increases in volatility of about three-to-four times for each increase of 18 degrees in temperature. Pesticides also move to the soil surface by both mass flow in water and gaseous diffusion.

Pesticide movement in soil is strongly affected by soil water content, water movement, soil structure, and soil management practices. For pesticides with low effective vapor pressures, water movement is important in transporting pesticides through the root zone. For highly volatile pesticides, vapor diffusion is a dominant transport mechanism unless soil pores are nearly saturated. If a soil is saturated with water, gaseous diffusion or

advection will be completely eliminated. Pesticides are known to be transported attached to dust particles and as aerosols.

Gaps. Research in this problem area will build on research results from Problem Areas A and B, above. New pesticide management plans need to be developed by obtaining and integrating the following information:

- Relationships between volatilization, soil water regimes, amendments, and pesticide management have not been determined.
- Various nonchemical pest control methods have been suggested, but none have gained wide acceptance; therefore, guidance for current approaches, and new nonchemical (or hybrid) approaches are needed to provide a wider range of nonchemical alternatives.
- Anecdotal evidence suggests that residues from disposal of pesticides, pesticide rinsing processes, and spills can be a serious environmental problem; information concerning the extent of the problem and corrective methods is needed; .
- Improved pesticide spraying systems are needed to improve the management of pesticide emissions; improvements should include uniform sized droplets, lower volumes, and increased spread of spray droplets.
- Accurate, effective, efficient methods for applying pesticides using aircraft and boom spraying systems are needed; new pesticide formulations and delivery systems are needed that minimize environmental contamination.
- Methods for detecting spray drift and comparisons between various pesticide application systems are needed.
- Safe, simple, economical methods are needed to reduce pesticide loss to the atmosphere after soil application.
- New methods are needed to enhance pesticide degradation and adsorption to reduce movement away from the target location into the atmosphere or water supplies.
- Information is needed on the effectiveness of cultural practices as a method to control agricultural pests; integrative methods are needed that utilize the beneficial aspects of nonchemical control, especially to reduce pesticide use or increase pesticide efficiency.
- Continued research is needed on the effect of encapsulation of pesticides on volatile losses to the atmosphere.

Goals

- Develop management practices that reduce losses of pesticides and synthetic organic chemicals into air, water, and soil resources and/or mitigate their impact through soil-water management, use of amendments, application technology, drainage, biofilters, and riparian areas;
- Develop and test irrigation and pesticide management practices to reduce pesticide contamination of the atmosphere and water supplies;
- Develop precision-farming systems to control agricultural pests that limit the amount of pesticide used during farming operations and optimize the timing and placement of application;
- Develop information on the effectiveness of cultural practices as a method for controlling agricultural pests, and develop integrative methods that utilize any beneficial aspect of nonchemical control, especially to reduce pesticide use;
- Develop new and improved methods to apply pesticides to the target zone that are cost-effective, accurate, and efficient and that minimize pesticide loss from target areas; and
- Develop safe, effective, economical methods to dispose of pesticides, pesticide rinsing residues, and spills to prevent residues from being transported into the atmosphere.

Approach

A holistic or systems approach will involve a multidisciplinary team to lead it. This approach also requires the cooperation of a variety of research teams focusing on specific aspects of the system. For example, relationships will be developed between volatilization, soil-water regimes, environmental conditions, and soil amendments and pesticide movement from the target zone. The impact of irrigation methods on pesticide movement through the root zone to the atmosphere and water supplies will be determined. This information will be used to develop optimal methods and timing relationships to minimize pesticide emissions.

Experiments will be conducted to develop and test methods for safe and effective disposal of pesticides. Research will be conducted to evaluate the effectiveness and efficiency of methods to apply pesticides as sprays. This research will include the development and evaluation of new pesticide formulations and delivery systems.

Safe, simple and economical management methods will be developed to reduce pesticide loss to the atmosphere after application. The effectiveness of methods to enhance pesticide degradation and adsorption to limit movement away from the target location will be evaluated. Studies will be conducted to investigate and demonstrate use of precision-farming systems to control precisely the location and amount of pesticide application. Management strategies that incorporate use of various cultural practices will be developed to control agricultural pests and minimize use of chemicals for that purpose. Research will be continued on methods to encapsulate pesticides and the effect on atmospheric emissions in the form of vapors, aerosols, and dusts. Methods and guidelines will be developed to determine the risk of pesticide exposure.

Outcomes

- A series of best management practices will be developed that improve pest-control targeting, reduce pesticide loading to the environment, and improve pesticide efficacy.
- Risk assessment methods and criteria will be developed to provide quantitative measures of nontarget effects and the benefits that result from adoption of best management practices.
- This research will result in methods that will help to produce a stable and healthy environment, protect sensitive ecosystems from pesticide contamination, and continue long-term production of an abundant and nutritious food supply.

Impact

A sustainable agricultural system that protects environmental health and produces economic vitality.

Linkages to Other ARS National Programs

- Integrated Agricultural Systems
- Methyl Bromide Alternatives

- Manure and Byproduct Utilization
- Rangeland, Pasture, and Forages
- Water Quality and Management

Last Modified: 10/06/2000