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Emerging National Research Needs for Agricultural Air Quality

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Over the next 50 years, the Earth's human population is predicted to increase from the current 6.1 billion to more than 9 billion, creating a parallel increase in demand for agricultural commodities.

Satisfying the demand for food is already driving changes in crop and livestock production methods that may have profound environmental effects. Increased consumption of animal protein in developed and developing countries, for example, has resulted in concentrated production of poultry and livestock, which has led to concentrated emissions of pollutants from these production facilities and has created regulatory concerns for agriculture. Development of land for nonagricultural uses has placed more pressure on marginal agricultural lands and has caused environmental degradation including the emission of trace gases (e.g., carbon, sulfur, and nitrogen species) into the atmosphere.

Efforts to maximize benefits and reduce detrimental effects of agricultural production must transcend disciplinary, geographic, and political boundaries, and involve natural and social scientists, economists, engineers, business leaders, and decision makers.

Agricultural Pollutant Emissions and Fate

In the past 60 years, nitrogen fertilizers have had a beneficial effect on agriculture globally by increasing crop yields. However, the high loading of reactive nitrogen has led to deleterious effects on the environment, such as decreased visibility from increased aerosol production and elevated nitrogen concentrations in ground and surface waters [*Aneja et al.,* 2001]. Nitrogen compounds released into the atmosphere from anthropogenic or natural sources interact in atmospheric reactions (e.g., gas-to-particle conversion), are transported by winds, return to the surface by wet and dry deposition processes, and may have adverse effects on human health and the environment (Figure 1).

Emissions from animal and crop agriculture have now become a significant problem, both politically and environmentally, owing to increased food production and ever-growing pressures to develop agricultural land. These agricultural byproducts include odor emissions (e.g., organic acids), reactive nitrogen [e.g., ammonia (NH_3) and nitrogen oxides (NO_x)], particulate matter (e.g., particulates from tillage and burning), and gaseous sulfur compounds [e.g., hydrogen sulfide (H_2S)].

Globally, domestic animals are the largest source [32×10^{12} grams NH_3-N (ammonia-nitrogen) per year] of atmospheric NH_3, comprising approximately 40 percent of natural and anthropogenic emissions combined. Synthetic fertilizers and agricultural crops together contribute an additional 9×10^{12} grams NH_3-N per year (12 percent of total emissions) [*Schlesinger and Hartley,* 1992]. Thus, humans have more than doubled the flux of ammonia to the Earth's atmosphere and greatly increased the deposition of reactive nitrogen in regions downwind of agriculture.

Emissions of sulfur gases, volatile organic compounds, greenhouse gases, and particulate matter from agricultural sources are less quantified. Gaseous deposition, from both crop and animal operations, contributes to eutrophication and acidification of some downwind ecosystems [*Krupa,* 2003]. Greater removal of crop residues and efforts to incorporate crop remains into soil organic matter, coupled with legislation, have substantially decreased agricultural burning in the United States, but burning still represents a tremendous challenge in developing countries that do not have access to these technologies.

Public concerns about the potential environmental and health effects of air emissions from confined animal feeding operations (CAFOs) expand the impacts of food production beyond those associated with traditional agricultural practices. The increasing size and geographic concentration of CAFOs, and growing concerns about emissions from them, have led regulators and policy makers to focus on mitigating the harmful effects of CAFO emissions.

The geographic concentration of agricultural operations has brought with it related contamination of air, water, and soil that demands immediate attention. In addition, these concerns are compounded by the potential negative economic impacts of proposed regulations to curtail air pollution from agriculture: on agricultural economies and livelihoods and on the domestic and export markets for agricultural goods from the United States.

The cattle, hog, and poultry CAFOs and related dairy operations, for example, are a significant industry, with revenues that exceeded $120 billion for the United States in 2004 (http://www.ers.usda.gov/publications/Agoutlook/AOTables/). By comparison, revenues for crop production were ~$116 billion in 2004.

To mitigate air pollution from agriculture, scientists and policy makers must consider

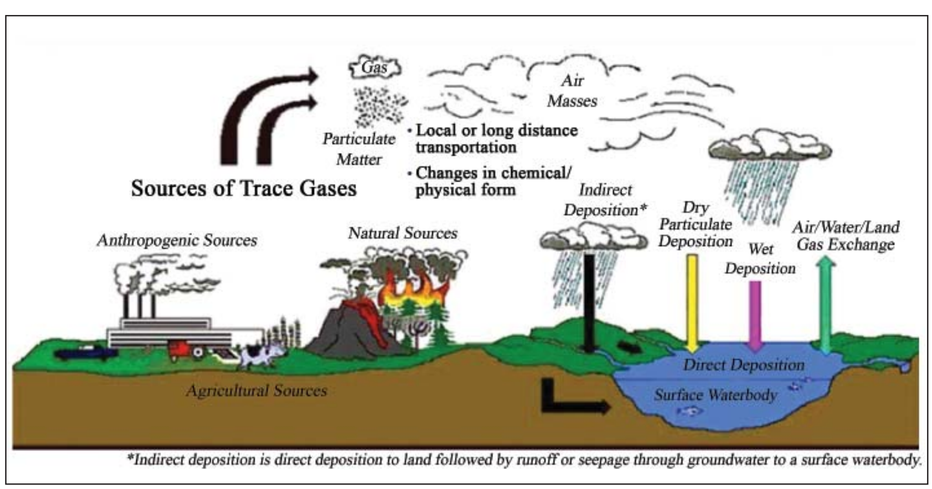

Fig. 1. Atmospheric emissions, transport, transformation, and deposition of trace gases.

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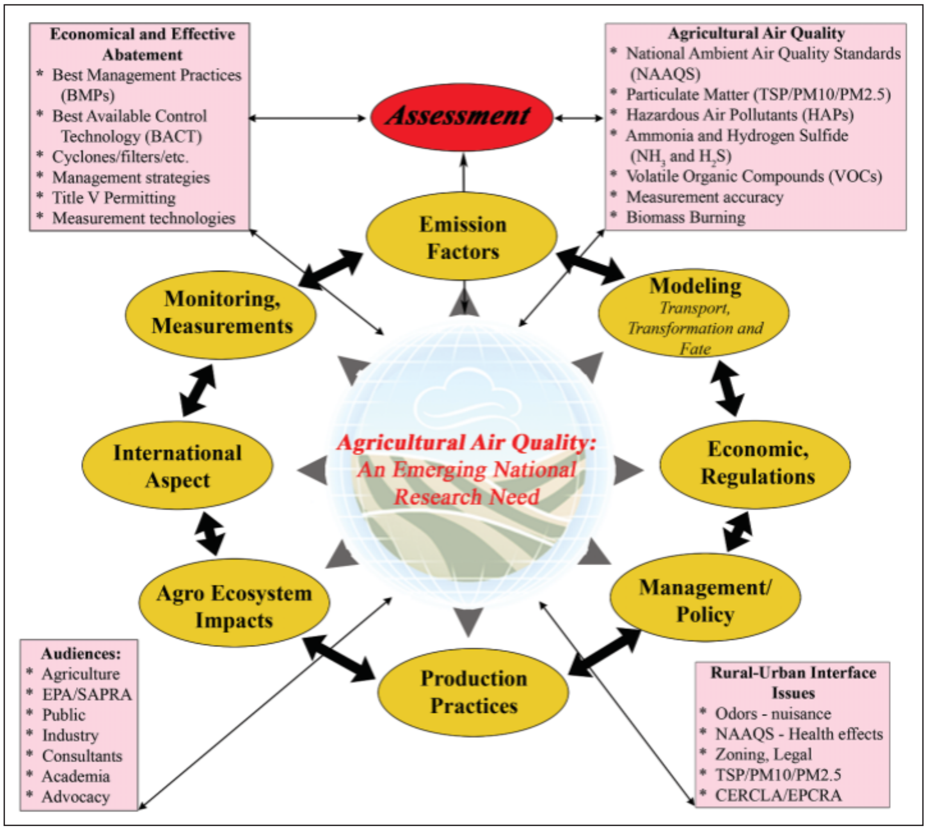

Fig. 2. Interactions and assessment of agricultural air quality.

emissions that occur at various stages and points in the entire food production system.

Agricultural Air Quality: A National Need

Agricultural air quality is an important emerging research area with significant multidisciplinary components. Agriculture, forest, and range production practices are increasingly subject to U.S. state and federal regulations intended to protect air resources. However, data on agricultural emissions of regulated pollutants or nuisance odors and fugitive dust often either do not exist or are insufficient to inform the development of appropriate policy.

Agricultural operations face regulatory challenges in the U.S. in permitting, enforcement, and compliance. Uncertainties are associated with U.S. federal operating permits (issued pursuant to Title V of the federal Clean Air Act) for pollutant sources and in emissions inventories for animal-feeding operations. Some uncertainties are associated with monitoring and measurement methodologies, unresolved standards for dispersion and transport models, the lack of accurate emission factors (average emission rate of a given pollutant for a given source relative to units of activity), and a need for process-based emissions model (mechanistic model of agricultural emission processes), and transport/transformation models [*National Research Council,* 2003].

These issues are further complicated by the need to consider abatement strategies, compliance costs, and emissions reductions associated with best management practices and best available control technologies, including how to innovate policy so that new technology is accepted by producers.

The demand for agricultural operations to comply with air pollution regulations is often perceived by agricultural producers as inappropriate and unfair, threatening the economic viability of rural and agricultural communities and regional economies, and perhaps the overall production of food by the U.S. agricultural economy. There is a clear need for scientific research that addresses agricultural air quality problems and informs the development of appropriate regulatory policies.

The lack of information—and the need for it—on emissions from animal operations and their effects was illustrated, for example, by a 20 July 2003 *Raleigh News and Observer* article about a company considering building a large CAFO about 10 miles from North Carolina's largest wildlife refuge. The article detailed immediate opposition to the project because of the potential for air quality problems in the refuge. Supporters of the project highlighted the potential for the CAFO to give a significant economic boost to an economically depressed region.

Without sufficient, reliable data, decisions about building a CAFO cannot always be based on sound scientific data, and the permit decision could be based primarily on considerations other than science. The information gap could exist anywhere a new CAFO is proposed. Addressing such information gaps requires research, outreach, and partnerships between academics, federal and state governments, industry, and public interest groups.

The U.S. Department of Agriculture (USDA) has recently taken several steps to respond to the growing public concerns and research needs related to agricultural air emissions. Examples include the 1997 formation of the Agricultural Air Quality Task Force, and requesting the U.S. National Academy of Sciences to evaluate the scientific basis of emissions estimates from CAFOs [*National Research Council,* 2003]. Building on these recommendations, the USDA has also created a new air quality research program in the National Research Initiative (http://www.csrees.usda.gov/airquality) explicitly focusing on agricultural air quality.

Fundamental Issues for Agricultural Air Quality

Figure 2 summarizes the major elements in agricultural air quality that need to be addressed by environmental managers and researchers. Accurate estimates of air emissions from CAFOs are needed to gauge their possible primary and secondary adverse impacts and the subsequent implementation of control measures. For example, the U.S. Environmental Protection Agency is under increasing pressure from litigation by environmental groups to address these emissions through the Clean Air Act and other federal laws and regulations, and to develop process-based studies for emission estimates.

However, limited data exist for estimating agricultural emissions of air pollutants, such as ammonia, or of public nuisances, such as odors and fugitive dust. Credible estimates of air emissions from CAFOs are also complicated by factors that affect the amounts and dispersion of emissions in the atmosphere. Such factors include the kinds and numbers of animals involved, their diets and housing, the management of their manure (feces and urine, which may also include litter or bedding materials), topography, climatic and weather conditions, and actions taken to mitigate emissions and their effects. Emissions estimates generated for one set of conditions or for one type of CAFO may not translate readily to others.

Much of the science related to agricultural air quality has grown out of the synthesis of specialized field measurements that were developed for urban air quality monitoring. The resulting Federal Reference Methods may inaccurately estimate emissions from agricultural sources.

Measurement protocols and instrumentation, including remote sensing to measure and characterize particulate matter and gases for CAFOs, within field/facility and at edge-of-field/facility boundaries, are important components of an integrated agricultural air quality discussion. Studies of fine (< 2.5 micron diameter) and coarse (2.5–10 micron diameter) particulate matter emissions and evaluations of techniques for monitoring and characterizing odors and aerosols are in demand by the scientific and regulatory communities.

Research is also needed on the fate and transport of gases and particulates, especially of particular nutrients or particulate matter that could become important air emission components. Field measurements and modeling analyses are needed to estimate deposition of nitrogen and sulfur compounds in the vicinity of CAFOs. Improved coupled multimedia (air, water, and soil) models are needed to predict movements and dispersion of air pollutants. Studies of methods for reducing emissions of gaseous and particulate air pollutants and for developing best management practices and best available control technologies are critical for technology transfer from research to application.

Agricultural air quality also can vary regionally, due to differing animal and crop production or farming activities and regional climates. Recently, several U.S. multistate and other large projects [e.g., Project OPEN (Odors, Pathogens, and Emissions of Nitrogen) in North Carolina, the National Air Emissions Monitoring Study, multistate air quality projects, and so forth] have been undertaken to bring together multidisciplinary experts to address regional variations.

Educational and Outreach Needs

Programs are also needed that reach out to citizens, regulators, the agricultural industry, and farm operators, and increase their understanding of issues related to air quality and public health. The success of these programs can be evaluated based on the implementation of farm best management practices for controlling emissions and improvements in regulations and enforcement programs.

Research on agricultural air quality also creates tremendous opportunities for the development of field-research classes in areas of current environmental concern. Students in such courses could visit research sites, help record observations, and incorporate data from ongoing research into reports, theses, and dissertations on different aspects of air quality issues. Environmental curriculum in primary and secondary education should show the relationships between human food production and its effects on the air and water pollution and biodiversity.

Assessing the Future of Agriculture and Air Quality

Insufficient scientific knowledge about nitrogen, volatile organic compounds, sulfur, and particulate matter emissions from intensively managed agriculture and the ultimate fate of these compounds are directly comparable to the situation in the 1980s with regard to agricultural nonpoint sources of nutrient contamination of water. There is just enough information for researchers and policy makers to recognize a serious problem, but not enough information for them to understand the extent of the problem or to make scientifically credible recommendations about potential solutions, which may ultimately influence air, soil, and water quality, human health, and the economy of agricultural regions.

Scientists, industry, policy makers, and regulators need to make optimal choices about issues confronting U.S. agriculture in order to maximize the benefits and reduce the detrimental effects of food production activities. Improvements are needed in agricultural air pollutant emission inventories, measurement and monitoring methodologies, modeling, and best management/production practices to mitigate air pollutant emissions from agricultural sources.

An upcoming meeting, called the Workshop on Agricultural Air Quality: State of the Science, will be held 5–8 June 2006 in Potomac, Md. (near Washington, D.C.). The meeting will address these issues and provide an opportunity for all concerned to share information. For further information, visit the Web site: http://www.esa.org/AirWorkshop

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The Holocene CO_2 Rise: Anthropogenic or Natural?

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In view of the wide attention received by the suggestion that the rise in atmospheric carbon dioxide (CO_2) over the last 8000 years is anthropogenic rather than natural in origin [*Ruddiman*, 2003], this claim should be carefully examined. The basis for the claim is that following each of the three preceding glacial terminations, the CO_2 content of the atmosphere peaked early on and then underwent a steady decline. By contrast, following the end of the last glacial period, while it also peaked early, the decline bottomed out around 8000 years ago, and since then the atmospheric CO_2 content has steadily risen.

By analogy with previous interglaciations, Ruddiman estimates that in the absence of human activity, the CO_2 content of the atmosphere would have dropped to 240 ppm. Instead it has risen to 280 ppm. In a recent article, *Ruddiman* [2005] proposes that this 40 ppm human-induced rise prevented the onset of another ice age.

However, a 40 ppm increase in atmospheric CO_2 content over an 8000-year time interval requires an enormous amount of deforestation: Not only must the atmosphere's CO_2 inventory be increased, but also the ocean's dissolved inorganic carbon inventory. Unlike the present fossil fuel-driven increase in which the ocean has taken up only about two-thirds of the amount that has accumulated in the atmosphere, under Ruddiman's scenario the amount taken up by the ocean would have exceeded that which accumulated in the atmosphere by at least a factor of five.

The difference has to do with the sluggish rate of ocean mixing. During the course of the Holocene, the extra CO_2 has had adequate time to equilibrate with the entire ocean, whereas the fossil fuel-derived CO_2 has been

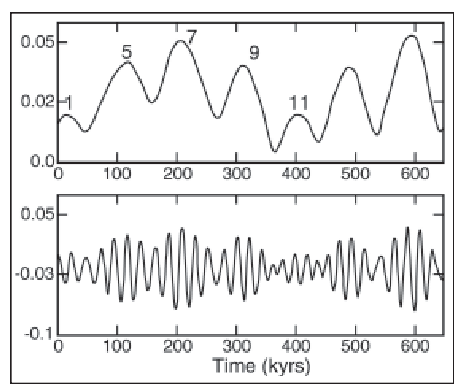

Fig. 1. (top) Magnitude of the eccentricity of the Earth's orbit over the last 650,000 years and (bottom) the consequent amplitude of the precession component of insolation seasonality. The times of the last five interglacials are shown. Note that during stage 11 and stage 1, the amplitude of the precession-related cycle in seasonality was much smaller than that during stages 5, 7, and 9.

able to equilibrate with only about 15 percent of the ocean's volume. The ocean uptake would likely have exceeded this factor of five because,