

Effects of Intensively Managed AGRICULTURE on the Atmospheric Environment

Viney P. Aneja, William H. Schlesinger and Saurabh P. Aneja

Viney P. Aneja is with the Department of Marine, Earth, and Atmospheric Sciences at North Carolina State University and **William H. Schlesinger** and **Saurabh P. Aneja** are with the Nicholas School of Environment at Duke University. E-mail: vpaneja@ncsu.edu

Agricultural activities in the United States in general and North Carolina in particular are important to a number of environmental transport related issues. These include multi-media issues including waste management, water quality, local and regional air quality problems such as odor, particulate matter (PM) exposure, eutrophication and acidification, and toxics as well as substantial greenhouse gas emissions (GHG). Here we examine atmospheric emissions and transport from agriculture. The most important agricultural pollutant emissions in terms of contributions to U.S. totals are ammonia (~90%), reduced sulfur (unquantified), PM_{2.5} (~16%), PM₁₀ (~18%), methane (~29%) and nitrous oxide (~72%), and other odors and emissions of pathogens (both unquantified). We place particular emphasis on ammonia and related emissions from animal feeding operations.



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Agricultural policies encouraged intensification, including the sustained use of chemical inputs, increasing field size and higher animal stocking densities. Traditional fallowing practices were discontinued, and crop rotations resulted in a displacement of leguminous fodder crops with increased use of silage and maize. Specialization and intensification resulted in fewer farm holdings and farm employment, as well as a homogenization of production leading to less diversity of local agricultural habitats.

Meanwhile, for the past half century, air quality research has primarily focused on the criteria pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone (O_3) and its precursors, and particulate matter (PM). Particulate matter of most concern includes fine particulate matter with aerodynamic diameter less or equal to $2.5 \mu\text{m}$ ($\text{PM}_{2.5}$); and coarse particulate matter with aerodynamic diameter between 2.5 and $10 \mu\text{m}$ ($\text{PM}_{10-2.5}$). Limited attention, however, has been paid to the non-criteria air pollutants such as reduced nitrogen-, sulfur, and carbon-containing compounds from agricultural sources (e.g., ammonia (NH_3), nitrous oxide (N_2O), hydrogen sulfide (H_2S), and volatile organic compounds (VOCs)). These compounds may play important roles in the formation of tropospheric O_3 , SO_2 , acids, and $\text{PM}_{2.5}$, (for N_2O) climate change, and (for NH_3) the eutrophication of aquatic ecosystems (Aneja et al., 2006 a, b; Aneja et al., 2008 a, b; and Aneja et al., 2009). Approximately ninety percent of the atmospheric ammonia (NH_3) emission results from animal and crop agriculture in the U.S. (Davison and Cape, 2003) and in many European countries (Van Der Hoek, 1998; Hutchings et al., 2001; Sotiropoulou et al., 2004). These compounds interact in atmospheric reactions (e.g. gas-to-particle conversion, Baek et al., 2006), are transported by winds, return to the surface by wet and dry deposition processes (Aneja et al., 2006b, 2008b, and 2009), and may have adverse effects on human health and the environment (Figure 1).

In the U.S., the size and geographical concentration of animal-feeding operations (CAFOs) and agricultural crop production are increasing. In North Carolina, for example the number of hogs (7.9 million) approaches that of the human

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Background

U.S. agriculture is extremely diverse, ranging from large, highly intensive and specialized commercial holdings to subsistence (e.g., family owned) farming mainly using traditional practices. Consequently impacts on the environment vary in scale and intensity and may be positive or negative. The U.S. and Europe largely focused on increased food production between the 1940s and the 1990s. Supported by public investment, this resulted in mechanization combined with the abandonment of traditional practices, reliance on non-renewable inputs such as inorganic fertilizers and pesticides, the cultivation of marginal land, and improvements in production efficiency through plant breeding.

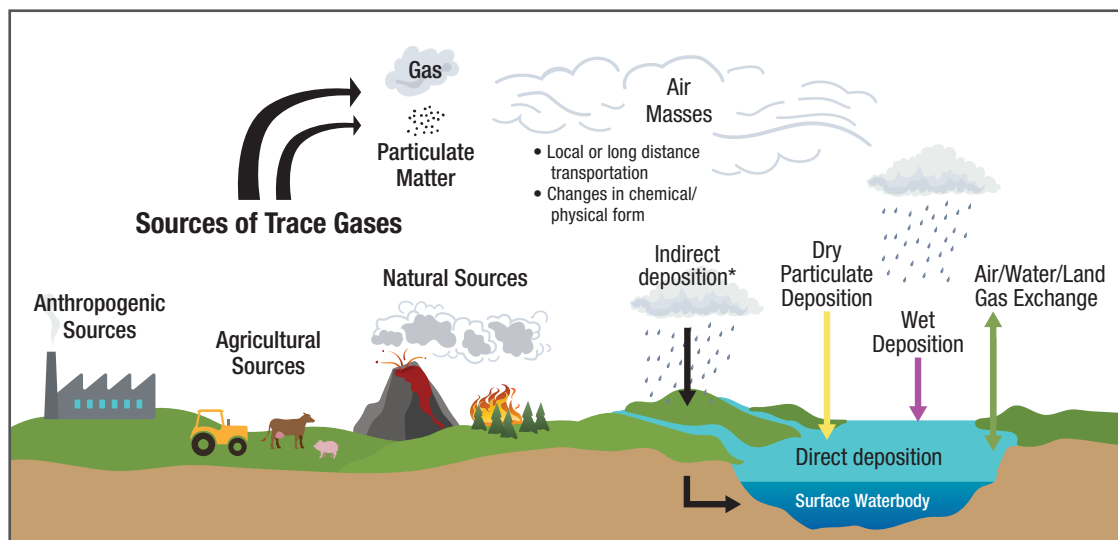
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Figure 1. Atmospheric emissions, transport, transformation, and deposition of trace gases.

*Note: *Indirect deposition is direct deposition to land followed by runoff or seepage through groundwater to a surface waterbody.*

Source: Aneja, Schlesinger and Erisman, 2008b, Nature Geoscience.



population (11.9). Increased CAFO emissions include coarse particles, odors (e.g., organic acids, H_2S , ammonia, etc.) and both GHG (e.g., methane (CH_4), N_2O , carbon dioxide (CO_2)) and air pollutant gases (NO_x , NH_3 , and H_2S) to the atmosphere (e.g., NRC, 2003; Aneja et al., 2008b, 2009; Rumsey and Aneja 2014; Rumsey et al., 2014) (Figure 2). Further raising both public and regulatory concerns are the increasing emissions of these compounds in the U.S. and abroad and their adverse impacts on the quality of the air, water, soil, and biodiversity. For example, atmospheric nitrogen deposition is thought to be a major cause for global biodiversity loss in this century, along with land use and climate change (Sala et al., 2000); and will continue to pose serious threats to biodiversity (Phoenix et al., 2006) and ecosystem function (Sanderson et al., 2006). The atmospheric deposition of nitrogen (AD-N) can play a key role in the “new” nitrogen budgets of coastal ecosystems. In nitrogen limited systems, such as the Neuse River Estuary, North Carolina, N inputs from the atmosphere, in the form of wet and dry deposition of ammonia, nitrate and organic nitrogen, can stimulate phytoplankton production and change phytoplankton community structure and composition, which in turn can affect water quality in general (hypoxia/anoxia, harmful or nuisance algal blooms, etc.) (Pearl et al., 1998; and Pearl and Whitall, 1999). In addition, NH_3 likely will play an increased role in $\text{PM}_{2.5}$ formation (Baek and Aneja, 2004b). Obviously in regions of intensive agriculture like North Carolina, the national

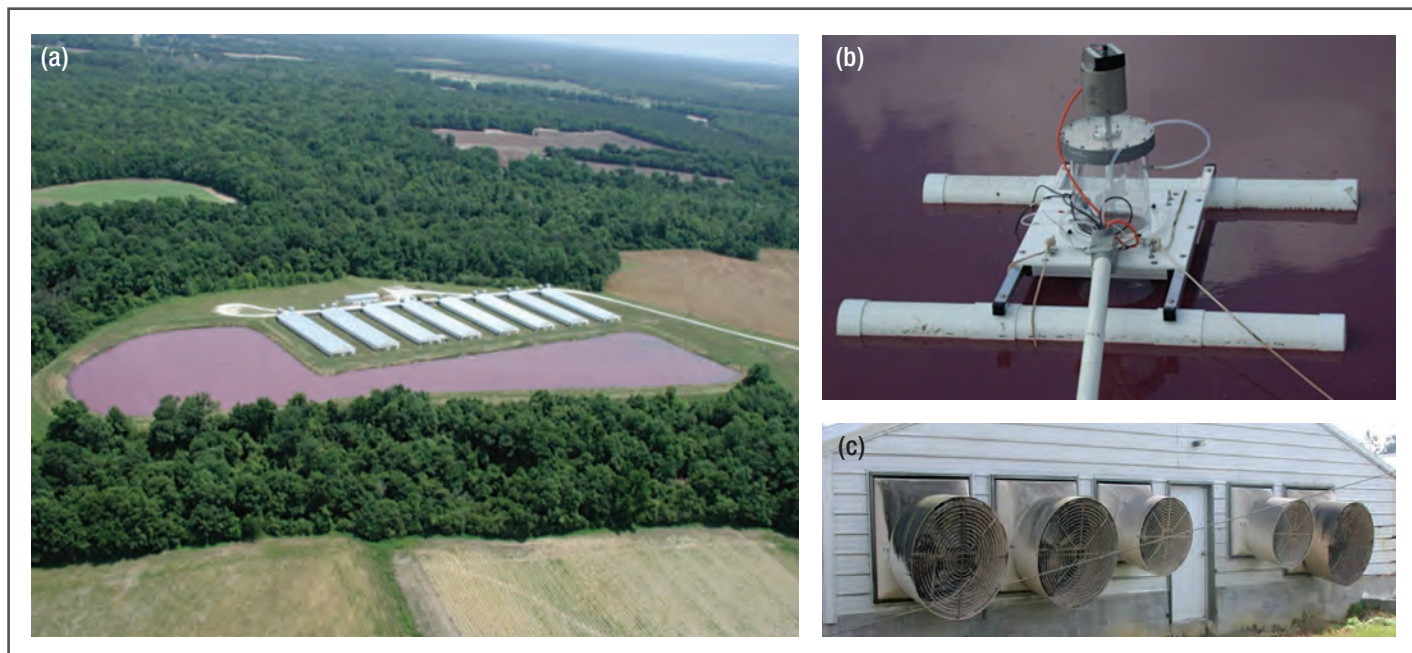
estimates of agricultural contributions to emissions noted above are too low.

Air Quality Models (AQMs) accounting for emissions, transport, transformation, and removal of air pollutants provide a powerful tool to predict the fate, distributions, and impact of agriculturally-emitted air pollutants. The National Research Council recommends better three-dimensional (3-D) transport/transformation models to assist in providing a scientific basis for the development of relevant mitigation strategies (NRC, 2003).

NH_3 Emission Control and Policy Implications

Public health and environmental concerns deriving from agricultural air pollutants have led regulators and policy makers from the U.S. and other countries to consider mitigation strategies for those pollutants. For example, regulations to reduce NH_3 emission from livestock farming have been initiated and enforced in the Netherlands to meet stringent targets for the emission and deposition of NH_3 (Lekkerkerk, 1998). In the U.S., although there are currently no national ambient air quality standards (NAAQs) for ammonia and hydrogen sulfide, reporting NH_3 and H_2S from CAFOs has been enforced under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA), as part of the Clean Water Act (CAA) and its amendments. In addition, mitigation measures are being taken in

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several states. Both Minnesota and Texas have state ambient air quality standards for H_2S , and the NC Environmental Management Commission was one of the first agencies in the U.S. to adopt rules for odor control from swine farms in 1999.

Although not much attention has been given to reducing NH_3 emissions in the U.S., it is an important policy in Europe. A number of studies have been performed to investigate the efficiency of various abatement options (e.g., McCubbin et al., 2002), which requires multidisciplinary assessments including environmental impacts, biophysical processes, and agricultural operations (e.g., soil, land use, crop, fertilizer, irrigation). Several models have been developed for regulatory applications. For example, Cowell and Apsimon (1998) developed the Model for the Assessment of Regional Ammonia Cost Curves for Abatement Strategies (MARACCAS) to assess the cost-effectiveness of potential abatement measures and to design the most efficient abatement strategies. McCubbin et al. (2002) applied the S-R matrix Air Quality Model (AQM) and their results suggest that a 10% reduction in livestock ammonia emissions can save over \$4 billion annually in particulate-related health benefits.

The Regional Air Pollution Information and Simulation (RAINS) model includes seven options for

NH_3 control including lower nitrogen contents in feed (LNF), air purification, animal housing adaptations, covered storage of manure, low NH_3 application of manure, urea substitution, and stripping and absorption techniques in the fertilizer industry (Klimont, 2001). This model has been applied to study impact of NH_3 abatement on the emissions of CH_4 and N_2O for 1990 and 2010 (Brink et al., 2001).

Best Management Practices (BMPs)

The most advanced reductions of NH_3 are found in the Netherlands, Denmark and the United Kingdom (UK). Erisman et al. (2005) reviewed the various policies and measures taken in the Netherlands to reduce nitrogen emissions to the environment. Ammonia emissions were abated by regulations to reduce the evaporation of NH_3 from manure and urea and as a side effect of quotas that regulated the milk production. Since the introduction of mineral bookkeeping in the Netherlands in 1998, there has been a significant reduction of the nitrogen surplus in the agricultural sector owing to the reduced use of inorganic fertilizers.

Injection of manure slurry into soil is an effective method for reducing ammonia emissions with decreases greater than 70% reported (Sommer et al., 2001; Leytem et al., 2009; Misselbrook et al., 2002; Rotz 2004). A major contribution to the

Figure 2. Emissions of gases and meteorological measurements associated with intensive hog agricultural operations in North Carolina (a) Commercial hog farm, (b) Dynamic chamber system in use during emission measurements, and (c) Barn exhaust.

Figure 3. Aerial view of Barham Farm. Ambient Temperature Anaerobic Digester is at far left; greenhouse is at far right. Hog houses and original lagoon are in the middle

Source: <http://www.bae.ncsu.edu/topic/waste-mgmt-center/inground-ambient.html>



decrease in ammonia emissions in Europe stems from manure injection systems (Van Jaarsveld, 2004), although there is still some debate over their efficacy. Currently, the numerical models are able to predict the changes in NH_3 concentrations reasonably well (Van Jaarsveld, 2004); however, the modeled concentrations are still 25-30% lower than measured. An extensive measurement and assessment study in the Netherlands, the so-called Veld project (Smits et al., 2005) revealed the same gap between measurements and models. The explanation for the ammonia gap is the limited description of dry deposition, especially in agricultural areas and the underestimation of emissions during land application of manure by injection.

Williams (2013) has suggested that “To ensure that pork production models are able to meet the demand for protein and remain generationally sustainable, the future of manure management will require technology applications that provide alternatives to current manure management practices”. Promising results have been reported in the U.S. for reducing ammonia from swine manure through the use of an “engineered system,” i.e. a treatment plant with solid-liquid separation (Animal and Poultry Waste Management Center, 2006). Szogi et al. (2006) reported a 73% reduction in ammonia emissions from the implementation of such a system and concluded: “These results overall demonstrate that alternative new wastewater technologies

can substantially reduce ammonia emissions from confined swine production.”

Vanotti (2006) found that when manure from such a system was applied there was a 98.8% reduction in greenhouse gases (GHG i.e. methane and nitrous oxide) emissions, as well as a potential additional income of \$9,100 to \$27,500/year (approximately \$0.91/finished pig) from implementing cleaner technology through the Supersoil program. Vanotti et al. (2008) found that replacement of the older lagoon technology with the cleaner aerobic technology reduced GHG emissions by 96.9%. The dollar value from implementation of the project at the swine farm was \$19,106/year using then-current Chicago Climate Exchange trading values. This translated into a direct economic benefit to the producer of \$1.75 per finished pig. The authors concluded that GHG emission reductions and credits could help compensate for the higher costs of environmentally superior technologies to replace current anaerobic lagoons in the U.S. In addition, when organic fertilizers with gypsum are applied, they can reduce ammonia volatilization by 11%. Gypsum also appears to reduce ammonia and trace gas emissions from animal waste (Model et al., 2006).

Another hog waste management technology to mitigate the emissions of ammonia and hydrogen sulfide being used in North Carolina is the

“Ambient Temperature Anaerobic Digester and Greenhouse for Swine Waste Treatment and Biore-source Recovery at Barham Farm” (Figure 3). The ambient digester consists of an impermeable cover over an in-ground digester. Waste is moved from the houses in which pigs are kept to the in-ground digester. Methane gas that is produced during the digestive process is extracted and delivered to a generator, where electricity is produced for use on the farm. Heat from the generator is captured and used to produce hot water that is used by the farm in its production activities. Effluent from the digester flows into a second-stage lagoon that was the primary lagoon before the digester was built. The nutrients in the effluent from the second-stage lagoon are used to fertilize plant and vegetable species in a greenhouse adjacent to the swine production facility (APWMC, 2006).

emission factors, poor spatial and temporal resolution, inconsistent source categories and methods;

2. inaccurate meteorological parameterization;
3. a lack of a detailed information on terrain characteristics and land use at a fine scale (e.g., surface roughness and vegetation);
4. missing or inadequate treatments of chemical and physical processes in the atmosphere;
5. an inability to simulate both the short-range dispersion and deposition of NH_3 near the ground and the long-range transport and fate of NH_4^+ at higher altitudes downwind of sources;
6. uncertainty in the parameterization of dry deposition of NH_3 ; and
7. a paucity of observations of emissions, concentrations, and deposition suitable for model verification and evaluation.

Research Challenges, Future Directions, and Outlook

Large uncertainties exist in current agricultural air quality modeling including:

1. inaccurate emission inventories as a result of erroneous activity levels, the use of uniform

Reducing these uncertainties presents significant research challenges and directions in the coming years. Resolving them will have profound impacts on how we manage air quality, human health, agro ecosystems, and biodiversity as well as important policy implications from local to global scales. It requires an integrated effort nationwide and

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worldwide from scientists, engineers, policy-makers, managers, and the public. Reconciling modeled results with measurements is further complicated by the weather, which has a profound effect on ambient NH_3 concentration. Small changes in temperature, wind speed or humidity may change the ambient NH_3 concentration regardless of emissions. The exponential increase in NH_3 concentration with temperature, due to gas/solution partitioning, is particularly important and an increase in NH_3 concentration as a consequence of a future, warmer climate should be expected.

Conclusions

As we rise to the challenge of feeding more than

nine billion fellow citizens of the world, the ancillary impacts of our food production systems will be severe and widespread unless we take action. We must not forget the importance of institutions that protect environmental quality (air, water, and soil), even as we may succeed in advancing the global position of our agricultural production.

Production agriculture has adopted modern technologies and chemistry to maximize productivity. However, it has not been subjected to the same environmental regulations that govern other modern industries. Farms do not have to be a source of air quality problems; they can and should be a source of solutions. **em**

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