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Emissions from

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The world's population has grown from approximately 1.5 billion at the beginning of the 20th century to approximately 6 billion today. This population increase has been accompanied by the rapid growth of "intensive" agriculture with significant impacts on the environment. Over the next 50 years, the population is predicted to increase to more than 9 billion, creating an increase in demand for both crop and animal agricultural commodities with the potential for a parallel increase in environmental impacts.[1-5]

The demand created by increased consumption of animal protein in developed and developing countries, for example, has resulted in a concentrated poultry and livestock production system, which, in turn, has produced concentrated emissions of pollutants. Emitted pollutants include odor emissions (e.g., organic acids), reactive nitrogen[6] (e.g., ammonia [NH_4] and nitrogen oxides [NO_X]), particulate matter (e.g., particles from tillage and burning), gaseous sulfur (e.g., hydrogen sulfide [H_2S]), greenhouse gases (methane [CH_4] and nitrous oxide [N_2O][7]), and fine particulates and bioaerosols. Many

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of these emissions have adverse human health and environmental affects.[8]

Emissions from animal and crop agriculture have become a significant problem, both politically and environmentally.[5,9] The potential environmental and health effects of air emissions from concentrated animal feeding operations (CAFOs) elevate the impacts of food production beyond those associated with traditional agricultural practices.[8,10] The increasing size and density of CAFOs, along with increasing concerns about the damage done to surrounding ecosystems, has moved some regulators and policy-makers to focus on mitigating the harmful effects of CAFO emissions.

Agricultural Nitrogen Emissions

Over the past 60 years, the increased availability of industrially-fixed nitrogen fertilizer has been instrumental in increasing crop yields globally. However, the subsequent rapid increase in the loading of reactive nitrogen has led to deleterious effects on the environment and increased public health risks.[5,8] The many forms of reactive nitrogen compounds released into the atmosphere from either anthropogenic or natural sources interact in the atmosphere (e.g., gas-to-particle conversion), are transported by winds, and return to the surface by wet and dry deposition processes (see Figure 1).

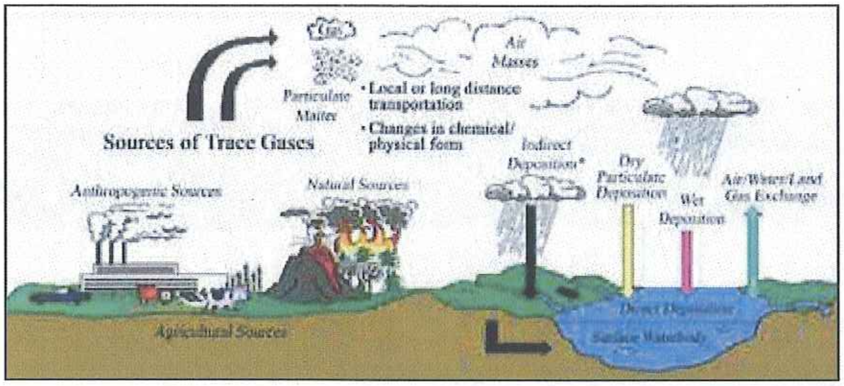

Figure 1. Atmospheric emissions, transport, transformation, and deposition of reactive nitrogen.[20]

Agricultural activity has more than doubled the flux of reactive nitrogen into the atmosphere, as well as significantly increasing deposition in ecosystems downwind of the agricultural areas. Such rates of reactive nitrogen introduction into the environment are unparalleled since the origin of the modern N cycle some 2.5 billion years ago.[11]

Globally, domestic animals are the largest source of atmospheric ammonia (NH_3), producing 32 x 10^{12} grams of NH_3-N per year (approximately 40% of natural and anthropogenic emissions combined).[12,13] Synthetic fertilizers and agricultural crops together contribute an additional 9 x 10^{12} grams of NH_3-N per year (12% of total emissions). However, management of the problem is complicated by the potentially negative economic impacts of regulations to curtail air pollution on agricultural economies 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 $149 billion for the United States in 2007.[14] By comparison, revenues for crop production were around $146 billion. Therefore, agriculture plays a vital role in the nation's economy.

Regulatory controls on traditional emissions sources (e.g., smokestacks and mobile sources) have been effective in reducing emissions of NO_X and sulfur oxides (SO_X) and are expected to continue to produce further reductions if current regulatory schedules are met. However, largely as a result of the increased intensity of livestock production, NH_3 emissions are increasing, exacerbating efforts to manage particulate matter pollution, eutrophication, terrestrial overfertilization, and acidification.

Potential Mitigation Opportunities

Agricultural air quality is an important emerging research area with significant multidisciplinary components. Agricultural, forest, and range operations are increasingly subject to federal and state regulations intended to protect air resources. Agricultural operations face regulatory challenges in the United States in areas of operating permits, compliance with environmental and agricultural policies, and enforcement of those policies by state and federal governments. There are ambiguities associated with U.S. federal operating permits (issued pursuant to Title V of the U.S. Clean Air Act) for pollutant sources and with emissions inventories for CAFOs. For example, the U.S. Environmental Protection Agency (EPA) is currently developing "emission estimating methodologies" for poultry and livestock production to determine air quality permit requirements.[15] There are also uncertainties in monitoring and measurement methodologies, unresolved standards for dispersions and transport/ transformation models, a lack of accurate emissions factors (i.e., average emission rate of a given pollutant for a given source relative to units of activity), and a need for a mechanistic model of agricultural emission processes.[16]

Much effort has been expended researching alternative poultry and livestock manure management, but it remains tremendously challenging to introduce environmentally superior technologies into intensive livestock production.[17,18] Anaerobic digestion is often touted as a solution to reducing atmospheric emission problems from livestock operations. While anaerobic digestion does offer numerous benefits, including offsetting methane emissions, renewable energy, odor management, and exclusion of rain water infiltration, it does not solve the nitrogen management issues. All the nitrogen in the manure or litter that went into the digester remains in the effluent or solids. Ammonia levels can get very high within anaerobic digester.[19] When the effluent is discharged from the digester typically into an open storage/treatment structure, large quantities of ammonia may be volatilized.

However, anaerobic digesters do improve the potential for ammonia emissions management as a previously large area source (e.g., open air lagoon) has now been reduced to effluent from a pipe. Basically, two types of treatments are available to control ammonia emissions: nitrification (i.e., the microbial process of oxidizing ammonium to nitrate), which is often coupled with denitrification (i.e., the microbial process of reducing nitrate to di-nitrogen gas; N_2); and ammonia capture in an acid trap or in biomass.

Nitrification can be effective in greatly diminishing ammonia volatilization, although as a microbial process, reaction rates are temperature-dependent and thus can be very low during the cooler winter months. If not coupled with denitrification, the livestock producer will have much higher quantities of nitrogen to manage. If additional nitrogen can be effectively used, especially if it offsets the use of inorganic fertilizer, that is a positive for the producer and society. However, due to the distribution of livestock in concentrated areas around the country, land available to productively use the additional nitrogen is often too far away to make transport economically feasible. When nitrification is coupled with denitrification, most of the manure or litter nitrogen can be converted to N_2, a benign end product. However, losses of nitrous oxide, a byproduct of both nitrification and denitrification, can be high and attention to operational detail is needed to minimize emission of this potent greenhouse and stratospheric ozone destroying gas. Unfortunately, the potential nitrous oxide losses from nitrification and denitrification are typically overlooked both on the farm and at industrial and municipal waste treatment operations. In addition, like nitrification, denitrification is a microbial process and its reaction rate is much slower in low temperatures.

Alternatively, the capture of NH_3 emissions in an acid solution is relatively straightforward. The product can be a fairly concentrated ammonia solution, which can be used as a fertilizer. Nitrogen capture into biomass through aerobic treatment or into plants such as duckweed is also possible. However, the cost of the process currently may not be competitive with inorganic N fertilizer. Given the positive societal attributes of recycled ammonia from manures and litters, perhaps a system can be developed to provide incentives to producers (e.g., through the Farm Bill) to cover the cost differential between inorganic N fertilizer and ammonia captured from livestock and poultry.

Nitrogen trading programs are operating or being considered in numerous places across the country. The amount of ammonia emissions and subsequent downwind deposition being offset by ammonia capture on poultry or livestock operations could be estimated with fate and transport modeling and sold as nitrogen pollution reduction credits. In addition, the recycling of manure and litter nitrogen as fertilizer could result in lower N_2O emissions as less nitrogen overall would be released into the environment. If inorganic fertilizer use is offset by use of recycled manure and litter nitrogen, further reductions in greenhouse gas emissions would occur as fertilizer production is an energy-intensive process. Potentially, the overall reduction in greenhouse gas emissions could be sold as offset credits.

Educational and Outreach Needs

Along with an increasing demand for interdisciplinary research related to agricultural air quality, there is a corresponding need for programs designed to reach out to citizens, regulators, the agricultural industry, and farm operators, to increase their understanding of issues related to air quality and public health. The success of these programs can be evaluated based upon the implementation of 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. Environmental curriculum in primary and secondary education should show the relationships between human food production, air, water, and soil pollution, and biodiversity.

Conclusions

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 policy-makers. The development of markets to provide incentives for the control of ammonia and other emissions from livestock production, in particular, is needed to deal with the economic constraints of the industry. Elected officials and regulatory agencies have a critical role to play in the creation and regulation of market-based systems to provide incentives for agricultural emissions controls and to assure that such systems produce net environmental benefits.

Gases, hazardous air pollutants, odor, and particulate matter emissions from livestock agriculture are showing an upward trend. In addition to the direct impact on human health, greenhouse gas emissions and volatilization of S, N, and C compounds continue to be air quality concerns. Current regulatory or voluntary programs are ineffective. Creative solutions are available, but currently there are no effective incentives or regulatory pressures to drive livestock producers to adopt alternative treatment options. From an economic standpoint, compensation for the ecosystem services provided by more fully recycling manure and litter nitrogen may be able to cover the costs of the additional treatment. em

Globally, domestic animals are the largest source of atmospheric ammonia.

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