Ammonia Emissions and Animal Agriculture

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Agricultural producers are under constant pressure to minimize the impact their management practices have on the environment. Although most environmental concerns related to animal agriculture have focused on water quality during the past two decades, air quality issues have become an increasing concern. Odors have been the main air quality concern related to agricultural animal production. However, ammonia emissions from livestock and poultry operations have recently received significant attention. New air quality standards that cover ammonia emissions in the United States were adopted in 1997. These regulations will have a significant impact on the future of animal production operations. The purpose of this publication is to provide an overview of ammonia production associated with animal agriculture and to explain why it is receiving greater attention from those concerned with environmental quality.

Ammonia

Ammonia is a common by-product of animal waste due to the often inefficient conversion of feed nitrogen into animal product. Livestock and poultry are often fed high-protein feed, which contains surplus nitrogen, to ensure that the animals' nutritional requirements are met. Nitrogen that is not metabolized into animal protein (i.e., milk, meat, or eggs) is excreted in the urine and feces of livestock and poultry where further microbial action releases ammonia into the air during manure decomposition (Figure 1).

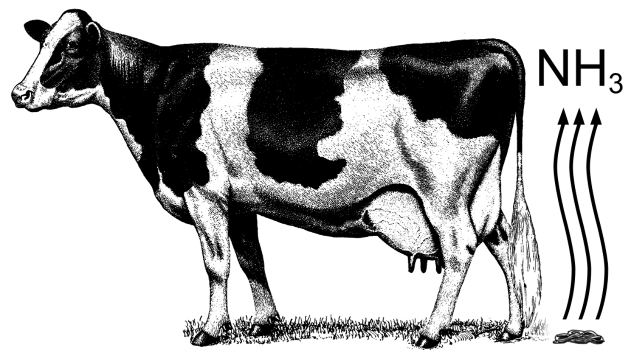

Figure 1. The microbial decomposition of animal wastes is the main source of ammonia volatilization from animal feeding operations.

Indoor Ammonia Concerns

Ammonia is typically considered an indoor air quality concern by livestock and poultry producers because the gas often accumulates inside poorly ventilated or poorly managed animal facilities. Elevated levels of ammonia can have a negative impact on animal health and production. For example, reduced final body weights have been observed in poultry produced in houses with indoor ammonia levels of approximately 25 parts per million (ppm) or higher during brooding (Reece et al, 1980).

Ammonia can also have a negative impact on human health. Exposure to even low levels of ammonia can irritate the lungs and eyes. The Occupational Safety and Health Administration (OSHA) has established a permissible worker exposure limit for ammonia of 50 ppm over an eight-hour period. The American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a short-term (15-minute) exposure limit of 35 ppm.

One strategy to decrease ammonia levels inside animal facilities is to increase the ventilation rate. This dilutes the ammonia concentration by increasing its removal from the facility. Increased ventilation also increases the drying rate of litter or bedding on which animals excrete; thus, further decreasing indoor ammonia levels.

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Produced by Communications and Marketing, College of Agriculture and Life Sciences,
Virginia Polytechnic Institute and State University, 2009

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Outdoor Ammonia Concerns

Dramatic increases in atmospheric ammonia emissions have been reported in recent years in areas of intensive animal agriculture. The U.S. Environmental Protection Agency (EPA) estimates that animal agriculture accounts for 50 percent to 85 percent of total man-made ammonia volatilization in the United States (Figure 2; Battye et al, 1994).

A recent study by the National Research Council (NRC, 2002) identified ammonia emissions as a major air quality concern at regional, national, and global levels. The potential negative impacts of ammonia are many. Deposition of atmospheric ammonia can cause eutrophication of surface waters, where phosphorus concentrations are sufficient to support harmful algal growth. Nutrient enrichment and eutrophication lead to the decline of aquatic species, including those with commercial value. Sensitive crops such as tomatoes, cucumbers, conifers, and fruit cultures can be damaged by over-fertilization caused by ammonia deposition if they are cultivated near major ammonia sources (van der Eerden et al, 1998). The deposition of ammonia on soils with a low buffering capacity can result in soil acidification or basic cation depletion.

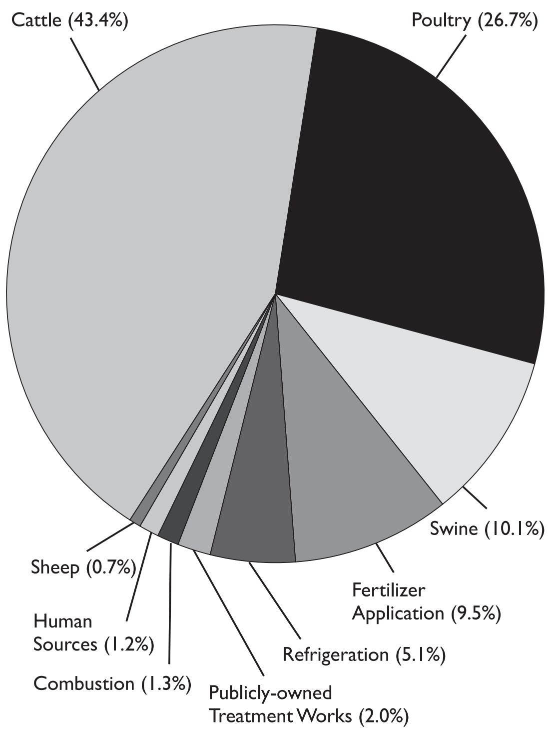

Figure 2. Estimates of ammonia emissions from man-made sources in the U.S. in 1994 (Battye et al., 1994).

Volatilized ammonia can travel hundreds of miles from the site of origin. In Europe, scientists have concluded that nitrogen pollution in the Mediterranean Sea is caused in large part by ammonia emissions in northern Europe. Ammonia emissions from the midwestern United States may contribute to eutrophication of the Gulf of Mexico. The Chesapeake Bay is likely receiving ammonia deposition from upwind areas with intensive agricultural operations such as Ohio and North Carolina.

In addition to its effects on water, plant, and soil systems, ammonia reacts with other compounds to form particulate matter (PM) with a diameter of 2.5 microns or less, which is referred to as $PM_{2.5}$ (Figure 3). This classification of PM is of particular concern because the small size of the particles allows them to penetrate deep into the lungs. Several recent community health studies indicate that significant respiratory and cardiovascular problems are associated with exposure to $PM_{2.5}$. Other problems associated with long-term exposure to fine particles include premature death and increased hospital admissions from respiratory causes. Children, the elderly, and individuals with compromised cardiovascular health or lung diseases, such as emphysema and asthma, are especially vulnerable to such health problems caused by $PM_{2.5}$.

These fine particles also contribute to the formation of haze. In the United States, haze has reduced natural visibility from 90 miles to between 15 and 25 miles in the

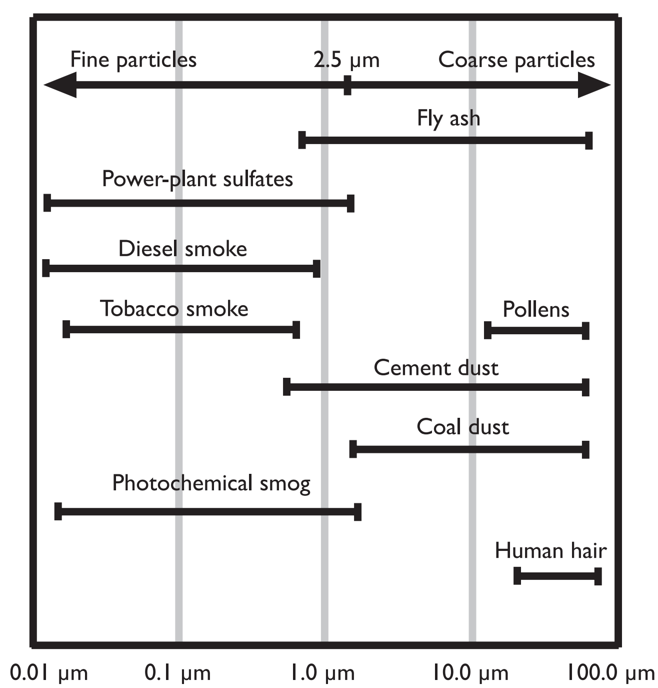

Figure 3. Size ranges of selected airborne particles in micrometers (Adapted from Heinsohn and Kabel, 1999).

East and from 140 miles to between 35 and 90 miles in the West (EPA, 2004). Visibility in the eastern United States is generally worse due to higher average humidity levels and higher levels of particulate matter.

Ammonia Emissions Regulation

Currently, ammonia emissions from animal agriculture are not directly regulated. However, in 1997, the EPA issued national Ambient Air Quality Standards (NAAQS) for $PM_{2.5}$ (EPA, 1997). Because a large fraction of $PM_{2.5}$ is derived from ammonia, regulations aimed at reducing $PM_{2.5}$ concentrations and emissions will likely require reductions in ammonia emissions from animal production operations.

The EPA recognized the long lead time required to plan for and meet the NAAQS and has established a timeline for implementation accordingly (Table 1). A monitoring system is in place to identify areas where $PM_{2.5}$ persistently exceeds the NAAQS, which are referred to as non-attainment areas. States were required to identify non-attainment areas in February 2004 and the EPA published final designations of non-attainment areas in December 2004. States must develop implementation plans that identify control measures for reducing $PMS_{2.5}$ levels to the NAAQS by April 2008. The $PM_{2.5}$ standards must then be attained by April 2010, although an extension to April 2015 is possible.

Ammonia Production from Animal Manure

Understanding how ammonia is formed is the key to understanding how manure can be managed to minimize ammonia emissions. Nitrogen is excreted in the form of urea (in mammals) or uric acid (in birds) in the urine of livestock and poultry and in the form of urea, ammonia, and organic nitrogen in animal feces. Conversion of urea or uric acid to ammonia requires the enzyme, urease, which is excreted in animal feces. This conversion occurs rapidly, often within a few days. The breakdown of complex organic nitrogen forms in feces occurs more slowly (within months or years). In both cases, the nitrogen is converted to either ammonium (NH_4^+) under acidic or neutral pH conditions or ammonia (NH_3) at higher pH levels.

The effect of pH on the amount of $NH_4^+$and NH_3 formed (Figure 4) is crucial in determining the fate of manure nitrogen. Ammonia is less soluble in water than NH_4^+; therefore, NH_3 is rapidly converted to a gaseous form and emitted from manure. The rate of NH_3 volatilization is influenced by a number of factors including the concentrations of manure NH_3 and urea, temperature, air velocity, surface area, and moisture.

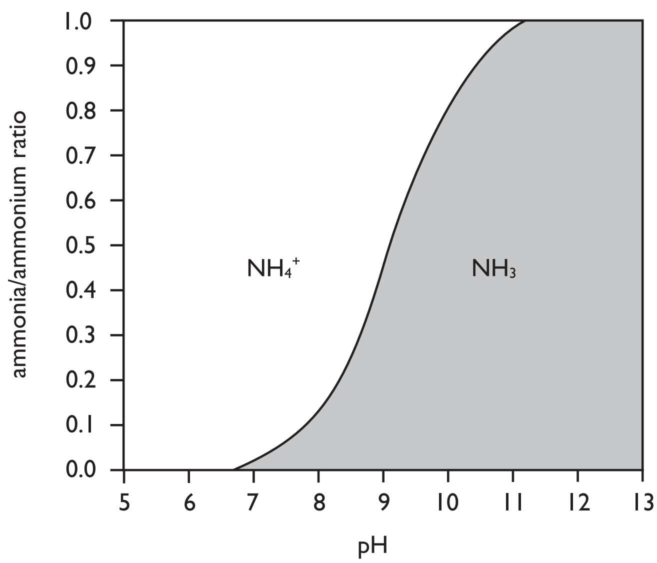

Figure 4. The dependence of the ammonia/ammonium (NH_3 /NH_4^+) ratio as a function of pH.

Table 1. Timeline for implementing $PM_{2.5}$ Standards (adapted from EPA, 2005).

Date	Action
February 2004	State designation of non-attainment areas recommended to EPA
December 2004	EPA finalizes designations of state non-attainment areas
April 2008	State implementation plans to achieve attainment submitted to EPA
April 2010	Non-attainment areas to attain NAAQS
April 2015	Possible extension for non-attainment areas to attain NAAQS

Ammonia Emissions Reduction

Ammonia emissions occur at several different stages of livestock production. These losses vary significantly among farms due to differences in methods of collecting, storing, and treating manure. In general, the greatest ammonia losses are associated with land application of manure (35%-45%) and housing (30%-35%). Significant losses can also occur from grazing land (10%-25%), if applicable, and manure storage (5%-15%) (Meisinger and Jokela, 2000). As a result, there are multiple opportunities to reduce ammonia emissions from animal production operations.

Two different strategies can be used to limit ammonia emissions from animal production operations. The first strategy is a pre-excretion approach to reduce the amount of ammonia that is generated on the farm. The second strategy is to limit ammonia emissions from animal agriculture by treating or managing manure post-excretion.

Pre-excretion Strategies

Pre-excretion strategies manipulate animals' diets (Powers, 2002). This can be accomplished through the addition of acid-producing phosphorus sources and/or calcium chloride and calcium sulfate to feed, although the use of phosphorus-based manure additives will reduce allowable land-application rates where phosphorus-based controls are in effect. The use of feed additives such as yucca plant extracts and the reduction of dietary protein may also reduce ammonia emissions. Monitoring and reducing the dietary crude protein for swine, poultry, and cattle have also been shown to reduce ammonia losses. Although the excretion of nitrogen supplied in feed cannot be avoided, careful control of dietary protein and amino acids can be used to minimize the amount of nitrogen that ends up in manure and serves as a source for ammonia emissions.

Post-excretion Strategies

Post-excretion strategies include the treatment or management of manure. One popular method is to apply chemical amendments to manure where animals are housed to reduce ammonia generation. Application of urease inhibitors to cattle and/or swine manure has effectively limited urea hydrolysis in laboratory and field studies (Powers, 2002). Such inhibitors are easily degradable and must be continuously applied to manure in order to reduce the production of ammonia from urea.

Similarly, a variety of amendments, including aluminum sulfate (alum), ferrous sulfate, phosphoric acid, and proprietary products, have been used to acidify poultry litter and convert ammonia to the non-volatile ammonium form and reduce ammonia emissions. Such a reduction can be maintained as long as the pH remains relatively neutral or slightly acidic; however, an eventual increase in pH will cause the resumption of ammonia volatilization. Surface application of calcium salts to maintain low pH has also been demonstrated to reduce ammonia emissions.

Separation of feces and urine to prevent urea hydrolysis is not a feasible approach for reducing ammonia emissions from poultry litter. However, handling systems that separate feces from urine, using a separator or belt conveyor, are being investigated on swine operations as a way to reduce ammonia generation. Maintaining low manure-moisture content through separation or dewatering may slow the rate of reactions that lead to ammonia generation and may help to minimize ammonia volatilization.

In addition to reducing ammonia generation, several post-excretion strategies use methods to prevent the transport of ammonia off the farm. Covering manure storage facilities can result in substantial reductions of ammonia volatilization. Housing ventilation systems may be equipped with a variety of different filters or other treatment systems that remove ammonia using physical, chemical, or biological mechanisms. One of the most effective methods is the sub-surface application of manure through the use of injectors (Figure 5) or tillage equipment, which significantly reduces ammonia losses compared to the surface broadcasting of manure.

Figure 5. Sub-surface application of liquid manure on land using a slurry tank with injection toolbar to reduce ammonia volatilization.

Ammonia Emissions and the Future

Researchers are studying ammonia emissions from animal feeding operations (AFOs) and there is much to be learned about the regulation and control of these emissions. Agricultural producers concerned about future requirements related to ammonia emissions from these facilities should consider doing the following:

- Become familiar with the mechanisms and methods for ammonia production and control from AFOs.
- Consider the ammonia emission potential of different practices when making decisions about feeding, management, and manure handling for AFOs.
- Become involved with research studies and regulation development related to ammonia emissions from AFOs.

Acknowledgements

The authors would like to express their appreciation for the review and comments made by Robert "Bobby" Grisso, professor and Extension engineer, Department of Biological Systems Engineering; Carl E. Zipper, associate professor, Department of Crop and Soil Environmental Sciences; Rebecca W. Zeckoski, research associate, Department of Biological Systems Engineering; and, Eric Bendfeldt, Extension agent, Environmental Sciences, Rockingham County.

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Publication Modified from:

Becker, J.G., and R.E. Graves. 2004. Ammonia emissions and animal agriculture. In *Proceedings Mid-Atlantic Agricultural Ammonia Forum*. Woodstock, Va. March 16.

Knowlton, K.F. Ammonia emissions: the next regulatory hurdle. *The Jersey Journal*, October 2000, 47: 56-57.

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