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Ammonia Emissions and Animal Agriculture

Jennifer G. Becker[1] and Robert E. Graves[2]

Nitrogen is found in relatively high levels in all excreted animal manures. It can exist in many chemical forms and can move easily in the environment as a gas in air, a dissolved constituent of ground or surface water, or in combination with other materials. Nitrogen in the form of ammonia (NH_3) is of particular concern because of its potential to create odors and negatively impact air and water quality and animal and human health. The purpose of this fact sheet is to provide an overview of ammonia production associated with animal agricultural operations and why it is receiving greater attention from regulators and other individuals who are concerned with environmental quality. In particular, it is important to recognize that efforts to satisfy local demands for control of odors from animal feeding operations (AFOs) do not guarantee control of ammonia emissions.

How does ammonia impact animal and worker health?

Traditionally, the agricultural community has considered ammonia as a problem inside poorly ventilated or managed livestock facilities. In particular, ammonia that accumulates within animal housing systems can have a negative impact on animal health and, consequently, 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. Ammonia can also have a negative impact on human health; exposure to ammonia can irritate the respiratory tract and eyes, even at low levels. Therefore, the Federal Occupational Safety and Health Administration (OSHA) permissible worker exposure limit for ammonia is 50 ppm over an 8-hour period and the American Conference of Governmental Industrial Hygienists (ACGIH) has established a short-term (15-min) exposure limit of 35 ppm.

One strategy to decrease ammonia levels inside animal housing has been to increase ventilation rates. This dilutes indoor ammonia levels and increases the removal of ammonia from the house. Increased ventilation rates also increase the drying rate of the litter or bedding, which further decreases indoor ammonia levels. However, it is important to note that these measures do not reduce the level of ammonia emissions to the atmosphere.

[1] Dept. of Biological Resources Engineering, University of Maryland College Park, College Park, MD 20742-2315 jgbecker@wam.umd.edu
[2] Dept. of Agricultural and Biological Engineering, The Pennsylvania State University, University Park, PA 16802 reg2@psu.edu

Why are ammonia emissions from AFOs a national concern?
Recently, the National Research Council (NRC) completed a study of air emissions from AFOs. Table 1 lists the key air pollutants that are emitted from AFOs, as identified by the NRC report, and their importance with respect to air quality at different geospatial scales. Odor was identified as the major concern associated with air emissions from AFOs at the local level. Ammonia, which has an offensive odor that is easily detected by humans at low concentrations, is just one of the numerous compounds that contribute to the odors emitted from AFOs. Typical approaches for controlling odors include diluting these compounds and/or directing them away from sensitive areas. However, according to the NRC, concerns about AFO odors are insignificant at global, national, and regional levels, whereas ammonia emissions are a major air quality concern at these larger scales (NRC 2002). Thus, efforts to address the negative effects of AFO odors on quality of life at the local level do not help mitigate the environmental impact of ammonia at or beyond the regional scale.

Table 1. Scientific Evaluation of the Potential Importance of AFO Emissions at Different Spatial Scales (adapted from NRC 2002).

Emissions	Scale of Concern		Primary Effects of Concern
	Global, National, and Regional	*Local—Property Line or Nearest Dwelling*	
NH_3	Major	Minor	Atmospheric deposition, haze
N_2O	Significant	Insignificant	Global climate change
NO_x	Significant	Minor	Haze, atmospheric deposition, smog
CH_4	Significant	Insignificant	Global climate change
Volatile organic compounds	Insignificant	Minor	Quality of human life
H_2S	Insignificant	Significant	Quality of human life
PM_{10}	Insignificant	Significant	Haze
$PM_{2.5}$	Insignificant	Significant	Health, haze
Odor	Insignificant	Major	Quality of human life

The potentially negative environmental impacts of ammonia can occur through several different routes (Kurvits and Marta 1998). For example, deposition of atmospheric ammonia can cause a number of harmful effects in a variety of ecosystems. These effects include over-enrichment of nitrogen in sensitive aquatic ecosystems. Approximately 35 to 60% of the total nitrogen loading to North Carolina coastal waters is estimated to be associated with ammonia deposition (Paerl 1995). Eutrophication of surface waters can lead to the decline of aquatic species, including those with commercial value, and an overall decrease in biological diversity.

Similarly, sensitive crops (e.g., conifers, tomatoes, cucumbers, and fruit cultures) that are cultivated near significant sources of ammonia can be damaged by over-fertilization caused by ammonia deposition (van der Eerden et al. 1998). Acidification of soils also results from the deposition of ammonia followed by oxidation to nitrate (NO_3^-) and may be of particular concern where soils have a low capacity to buffer acid.

In addition to being a non-point source (NPS) pollutant of water and soil systems, ammonia can have a negative impact on the environment by contributing to the formation of an air pollutant known as particulate matter (PM) (U.S. EPA 1997). Particulate matter refers to very small (0.005-100 µm in diameter) airborne solid particles or liquid droplets that are also known as soot. One specific form of particulate matter, $PM_{2.5}$, refers to particles with a diameter of 2.5 µm or less. Indirect formation of $PM_{2.5}$ can occur when ammonia reacts with nitrogen and sulfur oxides (NO_x and SO_x) in the atmosphere to form fine particles. This form of PM is of particular concern because the small size of the particles allows them to penetrate deep into the lungs, where they can contribute to respiratory disease and stress the cardiac and immune systems. In addition, $PM_{2.5}$ and larger particulates contribute to the formation of haze and associated reductions in visibility.

What are the contributions of animal agricultural operations to ammonia emissions?
Only a few studies in which ammonia emissions from U.S. livestock production operations were directly measured have been conducted to date. As a result, quantification of nitrogen emissions from livestock operations has been identified as a critical research need by the NRC (NRC 2002). This is an urgent concern because recent estimates based on per animal emission factors and numbers of animal units suggest that ammonia derived from animal production operations constitutes as much as 81% of the total emissions associated with human activities sources (Figure 1; Battye et al. 1994).

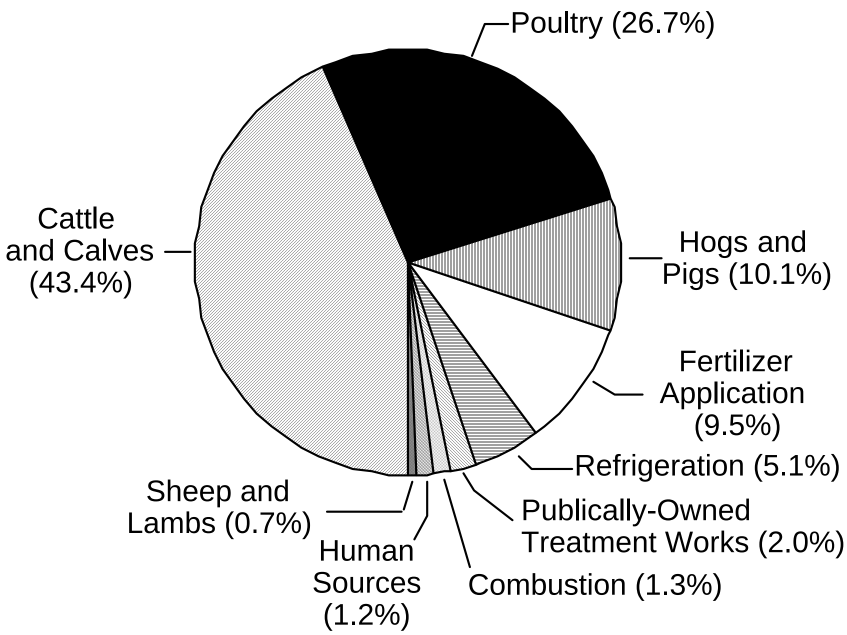

Figure 1. Estimated ammonia emissions from livestock production facilities and other human activities (adapted from Battye et al. 1994).

The majority of the ammonia emitted as a result of livestock production is derived from cattle and calf operations; however, poultry and swine operations also produce large quantities of ammonia. Smaller sources of ammonia include fertilizer application (9.5%), refrigeration (5.1%), municipal wastewater treatment systems (2.0%), and combustion processes (1.2%). Ultimately it is the cumulative affect of ammonia sources and their location that determine the impact on water quality. The trend toward increasingly intensive feeding operations will likely influence the environmental impact of ammonia emissions associated with livestock. For example, between 1982 and 1997, total livestock production increased approximately 10%, but the number of AFOs decreased 51% during this period. At the same time, production became more geographically concentrated. As the size and density of these ammonia sources increase, it is likely that their effects on regional air and water quality will also become more significant.

How is ammonia produced from manure?

Once manure is excreted, microbial processes begin to release manure nutrients in forms that can be taken up by plants or readily transported in the environment. Nitrogen is excreted in the form of urea and uric acid in the urine of mammals and birds, respectively. Conversion of nitrogen in the form of urea or uric acid requires the enzyme, urease, which is excreted in the feces. This conversion occurs rapidly, often within a few days). The breakdown of complex organic nitrogen forms in the feces occurs more slowly (within months or years). In both cases, the nitrogen that is released exists predominantly in the form of ammonium (NH_4^+) under acidic or neutral conditions, or in the form of NH_3 at higher pH levels. The relationship between NH_4^+, NH_3, and pH (Figure 2) plays an important role in determining the fate of manure nitrogen because NH_3 is much less soluble in water than NH_4^+. Therefore, NH_4^+ is not readily volatilized from manure, whereas NH_3 is rapidly converted to a gaseous form and emitted from manure. The rate of NH_3 volatilization is influenced by the concentrations of manure NH_3 and urea, temperature, air velocity, surface area, and moisture. Understanding how NH_4^+ and NH_3 are formed, the characteristics of these compounds, and the effects of various conditions on their environmental fate is the key to understanding how manure can be managed to minimize NH_3 emissions.

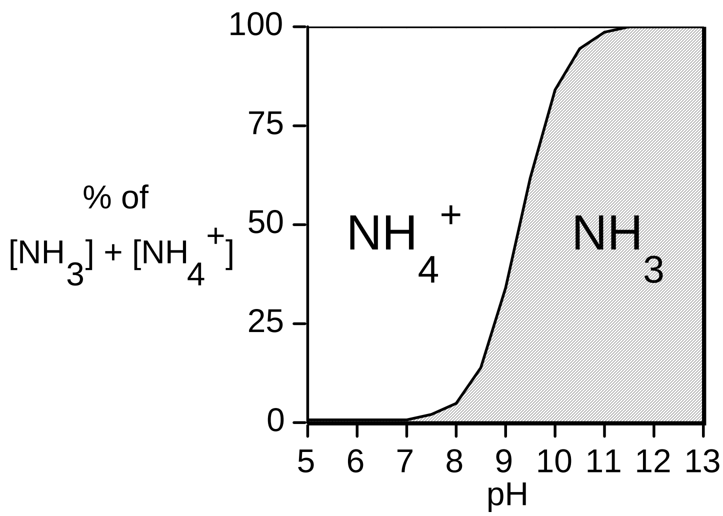

Figure 2. Relationship of ammonia (NH_3) and ammonium (NH_4^+) as a function of pH.

What management strategies can reduce ammonia emissions from animal agricultural operations?

Ammonia can be emitted at several different stages of livestock production. Although ammonia losses will vary significantly among farms due to differences in management practices, especially those used to collect, store, and/or treat manure, a recent estimate suggested that the greatest ammonia losses are expected to be associated with land application of manure (35-45%) and housing (30-35%). Significant losses can also occur during grazing (10-25%), if applicable, and manure storage (5-15%) (Meisinger and Jokela, 2000). This suggests that there are multiple opportunities to reduce the loss of ammonia from livestock production operations.

Two different strategies can be used to limit the amount of ammonia that is released to the environment. One approach is to reduce the amount of ammonia that is generated in the first place. The second strategy is to reduce the transfer of ammonia that is produced by agricultural operations to the environment. Management practices that target ammonia generation can be divided into pre-excretion (nutritional) and post-excretion approaches. While some of these management practices may be universally applicable, other approaches may be applicable only in certain cases, depending on manure characteristics, type of housing, and/or other factors.

Pre-excretion strategies (Powers 2002).

Dietary manipulation of manure pH has been shown to reduce manure ammonia emissions. This is accomplished through the addition of acidogenic phosphorus sources and/or calcium salts to feed in order to counteract the pH increases that occur as a result of urea hydrolysis. The use of feed additives such as yucca plant extracts that purportedly inhibit urease activity may also be a useful pre-excretion strategy for reducing ammonia emissions. Other potential pre-excretion strategies include reduction of dietary protein and manipulation of fecal and urinary nitrogen ratios. Excretion of nitrogen supplied in feed cannot be avoided; however, 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 of ammonia emissions. Reduction of crude protein in the diets of swine (grower and finisher), poultry (broiler), and cattle (heifer) has also been shown to reduce ammonia losses. Organic nitrogen associated with feces is degraded more slowly than urea in the urine. Therefore, dietary changes that shift nitrogen from the urine to the feces may reduce ammonia emissions. For example, inclusion of fermentable carbohydrates such as sugar beet pulp into swine diets increased fecal nitrogen at the expense of urinary nitrogen and decreased ammonia emissions.

Post-excretion strategies (Powers 2002).

Application of urease inhibitors such as N-(n-butyl) thiophosphoric triamide, cyclohexylphosphoric triamide, and phenyl phosphorodiamidate to cattle and/or swine manure has been shown to effectively limit urea hydrolysis in laboratory and field studies. Presumably, urease inhibitors would also be effective with poultry manures.

However, these inhibitors are easily degraded and must be continuously applied to manure in order to reduce the production of ammonia from urea.

Separation of feces and urine in order to prevent hydrolysis of urea 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 to reduce ammonia generation at swine operations are being investigated. Similarly, maintaining low manure moisture content may slow the rate of reactions that lead to ammonia generation and may help to minimize ammonia volatilization.

The use of a variety of amendments, including aluminum sulfate (alum), ferrous sulfate, phosphoric acid, and proprietary products to acidify poultry litter and maintain ammonia in the non-volatile ionized form has been evaluated. Significant reduction in ammonia emissions following the addition of the acidifying agents has been observed. Furthermore, the addition of alum or ferrous sulfate may be beneficial because the metal ions form insoluble compounds with phosphorus, which help immobilize manure phosphorus. However, reductions in ammonia production are observed so long as pH levels remain low. If manure has sufficient buffering capacity, the pH may eventually increase, which results in a resumption of ammonia volatilization. As noted above, inclusion of calcium salts in feed rations has been used to manipulate manure pH and ammonia emissions and surface-application of calcium salts to manures has also been shown to reduce ammonia emissions.

In addition to strategies for reducing ammonia generation, several post-excretion strategies may be used to effectively reduce ammonia emissions. Perhaps most importantly, sub-surface application of manure through the use of injectors or tillage equipment has been shown to significantly reduce ammonia losses compared to surface broadcasting of manure. Similarly, covering of manure storage facilities can result in substantial reductions in ammonia volatilization. Finally, 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.

What relevant regulations may drive management of agricultural ammonia emissions?
According to recent inventories, ammonia emissions from animal operations constitute a large portion of total ammonia emissions, and a significant fraction of $PM_{2.5}$ appears to be derived from ammonia. Therefore, regulations aimed at reducing $PM_{2.5}$ concentrations may require reductions in ammonia emissions from animal agricultural operations. Specifically, the regulation of $PM_{2.5}$ as a criteria pollutant through the National Ambient Air Quality Standards (NAAQS) was proposed and annual (15 $\mu g/m^3$) and 24-h (65 $\mu g/m^3$) standards were established in 1997 (U.S. EPA 1997).

A monitoring system is currently in place to identify areas where $PM_{2.5}$ persistently exceeds the NAAQS, also referred to as $PM_{2.5}$ non-attainment areas. States are required to identify $PM_{2.5}$ non-attainment areas by July 2004 and the EPA will publish final designations of $PM_{2.5}$ non-attainment areas by December 2004. State implementation plans that identify control measures for reducing $PM_{2.5}$ levels to the NAAQS are required by December 2007, and the $PM_{2.5}$ standards must be attained within five years of the designation date (December 2009-2014). Therefore, if state implementation plans require changes in management practices associated with animal production operations, these changes will likely be realized in less than ten years.

What should I do now?

There is still much to be learned about ammonia emissions from AFOs and the regulation and control of these emissions. Individuals 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.

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