AIR QUALITY

Ammonia Emissions from Cattle-Feeding Operations Part 1 of 2: Issues and Emissions

AIR QUALITY EDUCATION IN ANIMAL AGRICULTURE

Issues: Ammonia
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This publication discusses how ammonia emissions from cattle-feeding operations impact animal and human health, and the environment.

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Ammonia (NH_3) is a lighter-than-air, colorless gas with a recognizable pungent smell. It is a source of the essential nutrient nitrogen for plants and animals, but also is classified as a hazardous substance by the U.S. Environmental Protection Agency (EPA). Ammonia occurs naturally and is normally found in trace amounts in the atmosphere where it is the dominant base, combining readily with acidic compounds. It is produced by the decomposition or fermentation of animal and plant matter containing nitrogen, including livestock manure. There is concern about ammonia because of its potential to negatively affect air and water quality, and human and animal health.

Sources and Emissions

Concentrated animal feeding operations (CAFOs) import feed ingredients that contain large quantities of nutrients such as nitrogen. Cattle retain a proportion of the nitrogen they consume, but approximately 70-90 percent is excreted in feces and urine (Cole et al., 2008a). Ammonia is produced by breaking down nitrogenous molecules in manure, such as urea and protein. Urea in urine is rapidly converted to ammonia and is a major ammonia source in manure, while more complex nitrogen-containing compounds, such as proteins, are decomposed more slowly by microbes.

Historically, ammonia was considered a problem only within livestock buildings with inadequate ventilation or poor management. High ammonia levels negatively affect animal health and production, and threaten the health of humans working inside. Correcting ventilation problems and periodically removing animal waste reduces ammonia levels within the building, but these measures do not address the problem of ammonia emissions into the atmosphere. Ammonia emissions to the atmosphere from open-lot CAFOs now also must also be addressed.

Ammonia begins to volatilize (convert to a gas and be lost to the atmosphere) almost immediately after urea is excreted. The loss can continue as manure is handled, stored, or land-applied as fertilizer. As an essential plant nutrient, nitrogen is a primary component of fertilizer; nitrogen lost to the atmosphere from manure by ammonia volatilization is a loss of fertilizer value.

Ammonia in the atmosphere eventually returns to the Earth. Ammonia deposition occurs when ammonia in the atmosphere is deposited as gas, particulates, or in precipitation onto surfaces such as soil or water. Ammonia deposition on nutrient-starved farmlands may be beneficial to crops; however, deposition in sensitive areas may be undesirable.

The complexity of biological and chemical processes, coupled with management decisions, complicates the understanding of ammonia emissions from livestock operations. Differences in livestock digestive systems, diets fed, feed and manure management systems, facility design, location, and weather are just a few of the factors that affect ammonia sources and emissions.

Ammonia in the atmosphere eventually returns to earth. Ammonia deposition in sensitive areas may be undesirable.

Environmental Concerns

Undesirable ammonia deposition may occur locally as dry deposition when ammonia is transferred to sensitive land and water surfaces by air currents or at longer distances as wet deposition. Ammonia deposition can harm sensitive ecosystems when excessive nitrogen stimulates excessive growth of algae in surface waters or weeds in fields or pastures. When algae growth dies, its decomposition consumes oxygen, resulting in hypoxia (low oxygen) in aquatic environments.

For example, the hypoxic "dead zone" near the mouth of the Mississippi River is caused by excess nitrogen and phosphorus carried by the river into shallow coastal waters. This process of eutrophication is characterized by significant reductions in water quality, a disruption of natural processes, imbalances in plant, fish, and animal populations, and a decline of biodiversity.

Sensitive terrestrial ecosystems may experience excessive weedy plant growth, which outcompetes more desirable native species (Todd et al., 2004). Ammonia deposited in soil can undergo nitrification, which converts ammonia to nitrate, which is mobile in water. This chemical reaction lowers (acidifies) the pH of soil (Myrold, 2005). Forests in the humid eastern United States are especially susceptible to soil acidification, which can cause winter injury, loss of tree vigor, and decline of desirable species.

The National Atmospheric Deposition Program (NADP, 2007) and the Clean Air Status and Trends Network (CASTNET) are excellent sources of long-term deposition data. Multiple monitoring stations are located in strategic areas across the United States to monitor and document wet and dry deposition of ammonium, nitrates, and other pollutants. Data from NADP and CASTNET are available online at *http://nadp.sws.uiuc.edu/* and *http://www.epa.gov/castnet/*, respectively.

Human Health Concerns

Ammonia can significantly contribute to reduced air quality when it reacts with sulfur dioxide or nitrogen dioxide in the atmosphere to form aerosols. Aerosols, also known as particulate matter (PM), are atmospheric particles that are classified by the EPA according to their aerodynamic diameter.

Figure 1. Ammonia emissions to the atmosphere from open-lot CAFOs have the potential to negatively affect environmental quality and animal health.

Respirable aerosols are particles that can be deeply inhaled into the lungs and have a mean aerodynamic diameter of less than 2.5 micrometers ($PM_{2.5}$). $PM_{2.5}$ poses a threat to human health because it is associated with respiratory symptoms and diseases that lead to decreased lung function and, in severe cases, to premature death (EPA, 2009). Aerosols also reduce visibility in air, diminish irradiance, affect cloud formation, and alter the ozone layer (Romanou et al., 2007; Chin et al., 2009).

Ammonia deposition can contaminate drinking water by increasing the nitrate concentration. This may occur by direct deposition onto water bodies, or indirectly by leaching of nitrogen from soils or erosion of nitrogen-laden soil particles into surface water.

Odor implications of ammonia are localized to regions in the vicinity of the CAFO. Ammonia is easily recognized by its smell, but is seldom associated with nuisance odor complaints near CAFOs any more than other manure constituents such as sulfides, cresols, or volatile fatty acids. Ammonia readily disperses from open lot feedyards and dairies, which helps to reduce its odor intensity to below human detection thresholds. Ammonia odors tend to be more noticeable inside animal barns than in open lots and are greater on or near CAFOs than at more distant off-site locations.

Measuring Ammonia

Two categories of air quality measurements are commonly applied to ammonia at or near CAFOs: ambient concentrations and emission rates. Ambient concentrations are measurements of the ratio of ammonia to air in the atmosphere, usually measured in parts per million by volume (ppmv), parts per billion by volume (ppbv), or micrograms per cubic meter ($\mu g/m^3$). Accurate measurement of the atmospheric concentration in a large mass of dynamic, open air is difficult and requires special instrumentation and/or significant labor inputs.

Emission rates quantify ammonia flux from surfaces to the atmosphere and are reported in units of mass per unit area per unit time as in kilograms per square meter per day ($kg/m^2/day$), and also in units of mass per unit animal per unit time such as kilograms per thousand head per year (kg/1000 hd/yr).

Measurement of ammonia emissions from nonpoint sources such as CAFOs is also difficult because once produced, ammonia quickly volatilizes and is dissipated by air currents. Quantifying ammonia flux from the feedyard surface to the atmosphere relies on direct measurement using fast-response instrumentation, or on a flux model, which attempts to accurately predict the dispersion of gases and particulates through turbulent air. Further, emissions will vary depending on the type of surface (pens, lagoons, buildings) and the nature of processes at individual facilities.

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Regulatory Issues

Federal reporting requirements (EPCRA)

Ammonia emission is regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-To-Know Act (EPCRA). In December 2008, the EPA published a final rule that exempted CAFOs from reporting ammonia emissions under CERCLA. However, under EPCRA [40 CFR §355 App A], CAFOs are required to report ammonia emissions in excess of 45 kilograms (100 pounds) per day. Despite the challenges in accurately measuring ammonia emissions from CAFOs, an estimate of the lower and upper bounds can be calculated based upon animal headcounts and research-based figures for average emission rates per head. Noncompliance with the EPCRA ammonia emission reporting requirements could result in fines of $37,500 per day, criminal charges, and up to five years imprisonment.

Ammonia emissions may be indirectly addressed by federal and state regulations aimed at $PM_{2.5}$ concentrations such as those in the National Ambient Air Quality Standards (NAAQS). Because ammonia is a precursor to $PM_{2.5}$, it may be necessary to

Few state regulations currently are directed at ammonia emissions from animal agriculture.

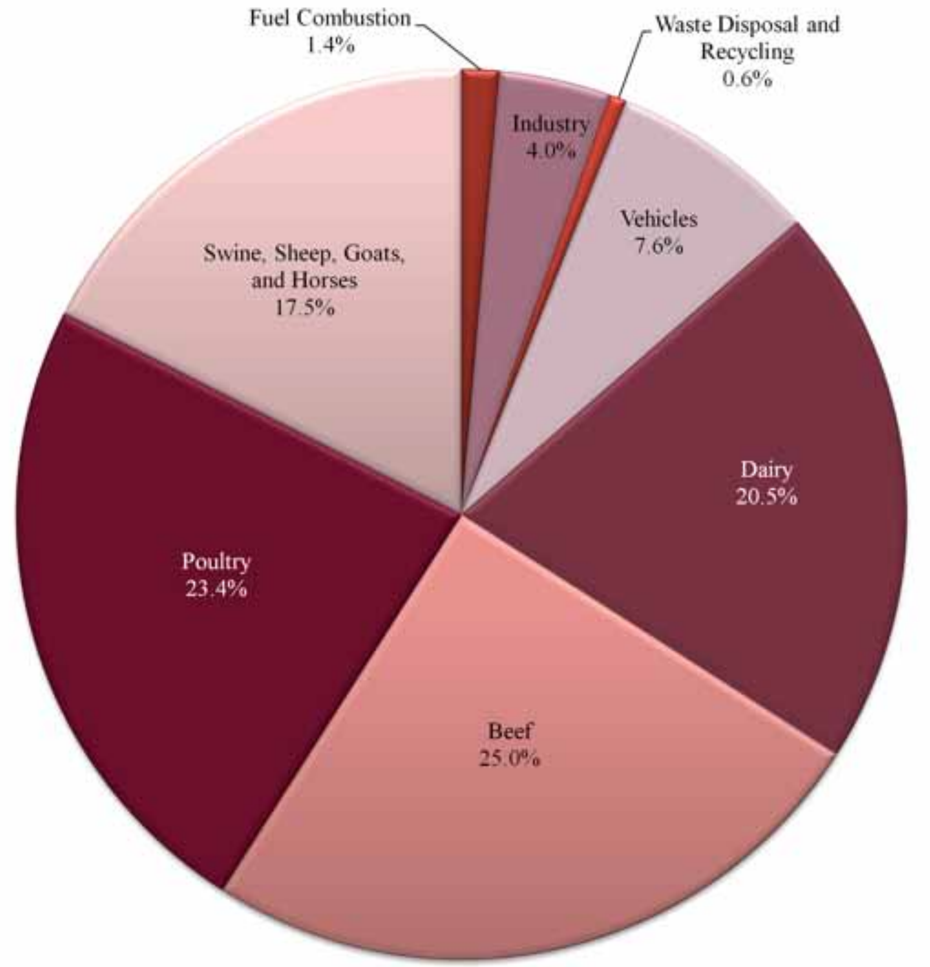

Figure 2. Estimated contributions of various U.S. ammonia sources based on the National Emissions Inventory (EPA, 2008).

reduce ammonia emissions to obtain a reduction in $PM_{2.5}$ concentrations.

Few state regulations currently are directed at ammonia emissions from animal agriculture. In 2003, California's Senate Bill 700 removed the reporting exemption from agricultural sources, and in 2006, Idaho put into force its "Permit By Rule" program requiring dairy farms with the capacity to produce more than 100 tons of ammonia annually to comply.

Except for Idaho and California, existing agricultural state regulations of ammonia are aimed primarily at the distribution, storage, and land application of anhydrous ammonia fertilizer. However, states can directly address ammonia emissions in $PM_{2.5}$ non-attainment areas in any case in which ammonia has been shown to be a significant contributor to $PM_{2.5}$ concentrations. In some states, general air quality regulations are based on atmospheric concentrations, and in other states they are based on actual emissions similar to those stipulated by EPCRA. However, atmospheric concentrations and ambient emissions of pollutants like ammonia are not well correlated. How these existing air quality regulations will be applied to livestock ammonia sources in the future is unknown.

Ambient Concentrations at Cattle Feedyards

The determination of atmospheric concentrations of ammonia requires highly sophisticated and expensive equipment, considerable labor, and much time. Measurements must be taken over large areas and extended periods, including all annual seasons, to represent the large spatial and temporal variability.

Other factors that must be reported include a detailed description of the facility, the animals, management practices, on-site weather, and sampling height. Data collected on atmospheric ammonia concentrations at CAFOs vary considerably, but tend to exhibit a 24-hour pattern, with daytime concentrations greater than those observed at night. Ammonia concentrations at cattle feedyards have rarely been observed over 3 ppm.

A variety of methods are available to measure atmospheric concentrations of ammonia, each with a unique set of advantages and disadvantages.

Gas washing, denuders, and passive samplers provide average ammonia concentrations over relatively long periods of 1 to 4 hours. Gas washing is useful for calibration and standardization, but is labor intensive. Fourier-transformed infrared (FTIR) spectroscopy, laser spectrometry, ultraviolet differential optical absorbance spectroscopy (UVDOAS), and chemiluminescence allow collection of nearly real-time measurements and relatively short periods of 5 seconds. Open-path lasers, UVDOAS, and FTIR have the added advantage of integrating measurements over distances from 50 to 500 meters. Dust concentration in the vicinity of feedyards tends to be high, so special measures must be taken when sampling for atmospheric ammonia to avoid errors. Examples of these special measures include installing Teflon® filters preceding detectors, or shortening measurement path lengths.

Emission Rates from Cattle Feedyards

An estimated 64-86 percent of total global anthropogenic ammonia emissions come from CAFOs (Baum and Ham, 2009; EPA, 2008; Becker and Graves, 2004; Battye et al., 1994). Of the CAFO emissions, roughly 43-48 percent come from cattle operations (EPA, 2008; NRC, 2003; Battye et al., 1994). *Figure 2* presents a graphic illustration of the relative contributions to ammonia emissions by various U.S. sources, based on the National Emissions Inventory (EPA, 2008). This inventory considered ammonia emissions based on ammonia emission factors and county-level populations of livestock intentionally reared for the production of food, fiber, or other goods, or for the use of their labor. The livestock included beef cattle, dairy cattle, ducks, geese, horses, poultry, sheep, and swine.

There is extensive literature regarding ammonia emissions from swine and poultry facilities, but relatively little comprehensive research on large, open-lot beef cattle feedyards (Todd et al., 2008). Methods for estimating ammonia emissions from area sources such as feedyards include mass balance, micrometeorology, flux chambers, wind tunnels, and dispersion models (Hristov et al., 2011). The accuracy and applicability of these estimation methods vary greatly. For example, flux chambers and wind tunnels are appropriate for comparing treatments or assessing relative emission rates, but not for quantifying actual emissions (Cole et al., 2007a; Paris et al., 2009; Parker et al., 2010). Dispersion models all rely on specific assumptions that are often challenged by the feedyard environment and can induce error in emission estimates (Flesch et al., 2005, 2007). Mass balance restraints are necessary to set an upper bound on emission estimates.

Calculating a total nitrogen balance for a facility, which involves determining the amount of nitrogen imported and exported from a feedyard and assuming that unaccounted nitrogen is mostly ammonia, can provide reasonable estimates of ammonia emissions (Bierman et al., 1999; Farran et al., 2006; Cole and Todd, 2009). This is because the majority of gaseous nitrogen loss to the atmosphere is in the form of ammonia, as opposed to nitrous oxide, nitrogen gas, or nitrogen oxides (Todd et al., 2005).

Comparing estimates obtained by multiple methods with calculations from a complete nutrient balance, and local atmospheric concentration data can minimize errors. However, this approach is site-specific and impractical for the purpose of regulatory monitoring at every livestock operation.

Micrometeorological methods such as eddy covariance (EC) and relaxed eddy accumulation (REA) are ideal for feedlots because they provide measurements of

Because so many variable and interactive system components must be considered, using a single emission factor is inadequate to predict ammonia rates.

ammonia flux for large areas without disturbing the emitting surface. EC involves high frequency measurements using a fast-response analyzer, accounting for vertical air movements and the mixing ratio of ammonia in the air. REA is an adaptation of EC in which samples from air moving vertically are accumulated over time and analyzed with slower-response analyzers.

The most common method currently used by regulatory agencies to estimate ammonia emissions from CAFOs is to multiply a research-based emission factor by the number of animals on location. However, a single emission factor is not appropriate because ammonia emissions are affected by multiple, complex, and dynamic environmental variables. Therefore, the National Research Council (NRC, 2003) has recommended a process-based modeling approach over the use of emission factors. Process-based models are based on the physical, chemical, and biological processes that contribute to emissions, and take into account dynamic variables such as weather conditions, management practices, and technologies. Thus, they are applicable to a wide range of feedyard situations.

Research Needs

Statistical, empirical, and process-based models are available to estimate ammonia emissions from CAFOs. Statistical models are usually based on data collected from a particular location and provide estimates that may not be appropriate for a different site. Empirical models are commonly built from data collected under controlled conditions and predict well only when those particular conditions exist. Process-based (also known as mechanistic) models apply chemical and physical principles to a theoretical model of a real system, such as a CAFO. Their ability to predict ammonia emissions depends on how well the model represents real processes and the accuracy of important process factors used as inputs in the process-based model.

Many cross-disciplinary factors are considered in the construction of a process-based model, such as animal nutrition, feedyard management strategies, environmental aspects, and meteorological factors (*Figure 3*). Process-based models of emissions from CAFOs often begin by describing the effects of diet and facility management on nutrient excretion by the animals. In the case of nitrogen, the various chemical forms, routes, and processes the nitrogenous molecules undergo as a feed constituent consumed and excreted by animals is described. Next, the nitrogenous manure

Figure 3. Developing a process-based model requires research inputs from multiple disciplines to estimate ammonia emissions.

constituents are accounted for and partitioned into several pools. Depending on the facility, these pools may include feces, urine, pen surfaces, manure stockpiles, effluent lagoons, and so forth. Finally, the chemical and physical transformations, transfer, and equilibria that occur during manure storage, handling, treatment, and export in each of the several cases are modeled. The model may then be used to predict ammonia emissions.

Models must consider atmospheric ammonia phases, which include gaseous ammonia (NH_3), fine particulate ammonia ($(NH_4)_2SO_4$ and NH_4NO_3), and liquid ammonia (NH_4OH) as clouds or fog. The transition between these three phases depends on other inconstant atmospheric constituents. Therefore, the proportion of the phases relative to one another is also continually changing. Ammonia readily forms strong hydrogen bonds with water and will attach to many surfaces. Therefore, most materials exposed to air containing ammonia will absorb or adsorb ammonia compounds. In a CAFO environment, gaseous ammonia is prevalent and attaches to the airborne particulate matter emitted from the facility.

The dynamic nature of the atmosphere and its constituents results in significant variations in ammonia concentrations with respect to time, location, and height above the ground. Increasing the distance from the emission source can result in decreasing ammonia concentrations, with the rate of decrease depending on other factors such as air temperature, relative humidity, or wind speed. Dry deposition rates proximate to the CAFO also can decrease with respect to distance, and range widely, depending on atmospheric conditions and emission rates.

Measuring Emissions

It is difficult to measure ammonia emission rates from open-lot CAFOs. Ammonia tends to collect inside sampling instruments, adversely affecting measurement. Open-lot CAFOs have lower ammonia concentrations than those typical of facilities with livestock housing, so more sensitive instrumentation is required. There is relatively little data on ammonia emission rates, flux rates, or emission factors from open-lot beef cattle facilities.

Despite sampling challenges, changeability of ammonia concentrations, and scarcity of data, the average daily ammonia concentrations observed at several facilities by different researchers are consistent. *Table 1* presents ammonia concentrations observed at several commercial feedyards in different studies conducted at different times of the year.

Table 1. Ammonia concentrations (ug/m^3) measured at commercial open-lot beef cattle feedyards. Adapted from Hristov et al., 2011.

Study	***Time***	***Location***	***Mean or Range***
Hutchinson et al., 1982	April-July	Colorado	290 - 1,200
McGinn et al., 2003	May	Canada	66 - 503
	July		155 - 1,488
Todd et al., 2005	Summer	Texas	90 - 890
	Winter		10 - 250
Baek et al., 2006	Summer	Texas	908
	Winter		107
McGinn et al., 2007	June-October	Canada	46 - 1,730

When estimating ammonia emissions from open-lot beef cattle facilities, several components of the CAFO system must be considered. Emission factors fail to account for effects of particular components included in process-based models, such as animal diet and age, air and surface temperatures, time of year, geographic location, and many others. So many variable and interactive system components must be considered that using a single emission factor is inadequate to predict ammonia emission rates (Hristov et al., 2011).

Processed-based models, which describe physical processes mathematically as opposed to statistically, are better suited to this task than emission factors. A single ammonia emission factor based primarily on European data proposed by the EPA (2005) is 13 kg/hd annually for feedlot cattle or 23 percent of the total amount of imported nitrogen. This EPA report also estimates the following nitrogen losses as ammonia: 1) stockpiles — 20 percent of nitrogen entering, 2) storage ponds — 43 percent, and 3) land application — 17-20 percent. Because European beef systems vary greatly from U.S. systems, these values may not apply to U.S. feedlot systems.

Studies conducted at North American feedyards using a variety of measurement methods observed a wide range of emission and flux (quantity per unit area per unit time) rates. Reported emission factors ranged between 18 and 104 kg/hd annually, and flux rates ranged from 3.6 to 88 $\mu g/m^2/s$. Most studies also noted seasonal or 24-hour patterns in ammonia flux rates (Hristov et al., 2011). Reported losses from runoff holding ponds ranged from 3-70 percent of the N entering the pond. Other sources of ammonia loss on beef cattle feedyards include compost piles, which have been estimated to lose 10-45 percent of the N entering the compost (Hristov et al., 2011).

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