

# Ammonia Emissions from Agricultural Operations: Livestock

By Shabtai Bittman and Robert Mikkelsen

The global abundance of N fertilizer has dramatically increased agricultural productivity. However, when N escapes to the atmosphere as ammonia ( $\text{NH}_3$ ) gas,  $\text{NH}_3$  loss can cause undesirable effects. In addition to a loss of a valuable resource, it can have negative impacts on air quality, ecosystem productivity, and human health. Animal production is the largest source of  $\text{NH}_3$  emission in North America. Improved manure and fertilizer management practices will help reduce volatile losses of this valuable resource.

The century-old Haber Bosch process for transforming atmospheric  $\text{N}_2$  into valuable  $\text{NH}_3$  has been one of the most important discoveries for the benefit of humanity. The synthesis of  $\text{NH}_3$  and other N fertilizers has fed and improved the diet and living conditions for billions of people. However, when reactive N escapes into the environment, it can have unintended and sometimes undesirable consequences (Figure 1).

Farmers are continually reexamining the impacts of their operations on the surrounding environment. Many practices have been implemented in recent years to reduce soil erosion and to avoid water quality degradation. More recently, air quality issues related to agricultural production have captured the attention of environmental agencies. Nitrous oxide ( $\text{N}_2\text{O}$ ) is a concern due to its contribution as a global greenhouse gas. Ammonia has also emerged as an atmospheric gas of concern.

Farmers using anhydrous  $\text{NH}_3$  or ammonium ( $\text{NH}_4^+$ )-based fertilizers (such as urea) for their crops are fully aware of the potential for volatile losses and take extra efforts to minimize the loss of this economically valuable resource. This article primarily reviews  $\text{NH}_3$  losses from livestock operations. An article in the next issue of this magazine will cover  $\text{NH}_3$  losses from fertilizer in more detail.

## Ammonia from Animals

Agriculture is responsible for over three-fourths of the  $\text{NH}_3$  emissions in the USA and Canada, with animal production accounting for the major share (Figure 2). Ammonia becomes a constituent of animal waste when N-rich protein in feed is not completely converted into animal products (such as meat, milk, wool, and eggs). For example, only 25 to 35% of the N fed to dairy cows is converted into milk, with the remainder excreted in urine and manure in a variety of simple and complex forms of N. Chemical and microbial processes release  $\text{NH}_3$  into the air. Nitrogen in poultry manure is mainly in the form of uric acid, which also rapidly converts to urea and to  $\text{NH}_3$ .

The loss of volatile  $\text{NH}_3$  occurs when  $\text{NH}_4^+$  is converted to a gas in the reaction:



Ammonia-containing materials are more prone to volatilization in alkaline conditions than under acidic conditions ( $\text{pK}_a=9.2$ ). This  $\text{NH}_3$ -emitting reaction accelerates when the temperature increases or when the concentration of  $\text{NH}_4^+$  increases.

**Abbreviations and notes for this article:** N = nitrogen.

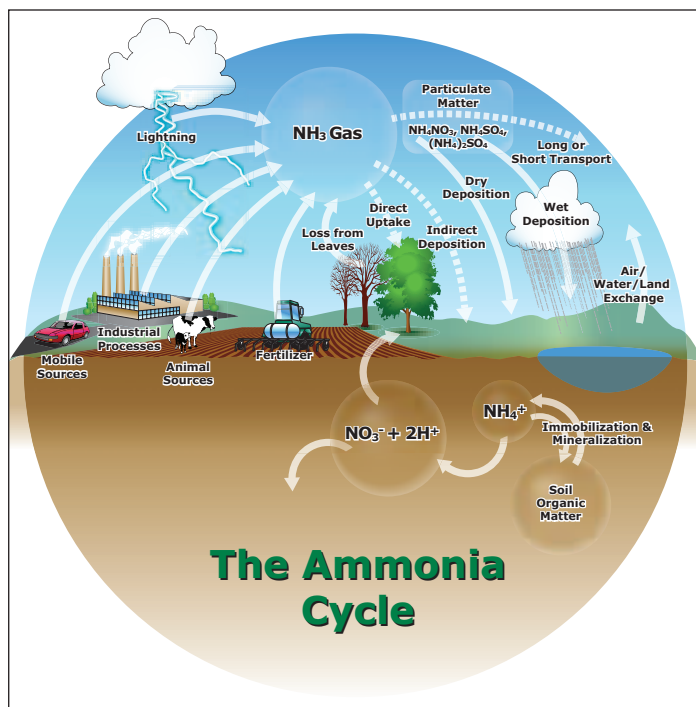


Figure 1. Ammonia emission, transport, and deposition from major sources.

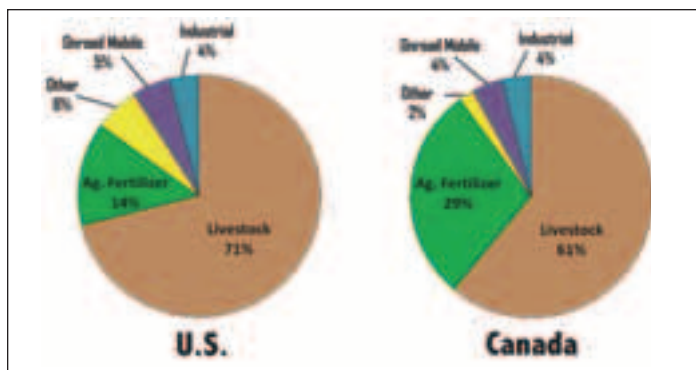


Figure 2. Primary sources of  $\text{NH}_3$  emission from the USA and Canada. (USEPA, 2005; Environ. Canada 2006.)

The greatest  $\text{NH}_3$  losses from animal production typically come from animal buildings and barns, and during land application of manure. Animal grazing and manure storage can also be important sources of  $\text{NH}_3$ . For example, a recent study from a cattle feedlot in Alberta found that daily emissions averaged 140 g  $\text{NH}_3$ /head (0.3 lb  $\text{NH}_3$ ) throughout the summer. With a feedlot population of 22,500 cattle, a single facility can make an important regional impact on air quality (McGinn et al., 1977).

Across all livestock sectors in Canada, 50 to 63% of the excreted  $\text{NH}_4\text{-N}$  is lost from animal housing, during manure storage, or when applied to the land. Emission losses of the excreted  $\text{NH}_4^+$  are approximately 50% for dairy, 50% for beef, 60% for poultry, and 60% for swine. Of these losses, typically 40 to 50% occurs in housing (and pasture), 5 to 15% from storage, and 40 to 55% during land application.

It is important to consider  $\text{NH}_3$  loss from a whole-farm perspective, because some of the  $\text{NH}_3$  conserved in barns may later be lost during manure application. Improved management to conserve  $\text{NH}_3$  during manure application will only conserve  $\text{NH}_3$  that has not already been lost from barns and storage. Thus to conserve  $\text{NH}_3$ , a whole-farm strategy is needed.

Various techniques can be used to minimize  $\text{NH}_3$  loss during animal production. For example, acidic amendments (such as sodium bisulfate and aluminum sulfate) maintain much of the N in the non-volatile  $\text{NH}_4^+$  form in poultry litter. Microbial and enzyme inhibitors that delay conversion of urea to  $\text{NH}_4^+$  have been successfully used to reduce the release of  $\text{NH}_3$  from animal facilities. Absorbing agents (such as bedding and zeolite minerals) can reduce volatile losses of  $\text{NH}_3$ , as do natural or artificial covers or other methods (such as deep storage) that reduce exposed manure surfaces. Increasing animal productivity, most notably milk production per cow, and reduction of excess protein in animal diets have major benefits for reducing emissions. Management practices during field application which reduce the exposure of applied manure to the atmosphere can help minimize  $\text{NH}_3$  loss (**Table 1**).

High concentrations of atmospheric  $\text{NH}_3$  have a negative effect on animal production in confined buildings. Therefore, good ventilation of barns and buildings with fresh air is important for healthy animals. Farm workers should also avoid prolonged exposure to high concentrations of  $\text{NH}_3$  in barns. Ammonia is lighter than air and is easily removed from livestock buildings with adequate ventilation.

There are many good methods used for measuring  $\text{NH}_3$  emissions from agricultural sources, but no method is perfect for all studies. Wind tunnels on small plots are well suited for comparing treatments and for validating  $\text{NH}_3$  loss models. Field measurements that utilize sophisticated micrometeorological methods are commonly used for measurements over larger areas (such as fields, manure stockpiles, and lagoons) and are thought to give more reliable values.

### Ammonia Particle Formation and Deposition

Ammonia in the atmosphere has become a concern for environmental (EPA and Environment Canada) and health agencies for two primary reasons – the formation of fine particle matter and uncontrolled N deposition – both of which can have negative consequences.

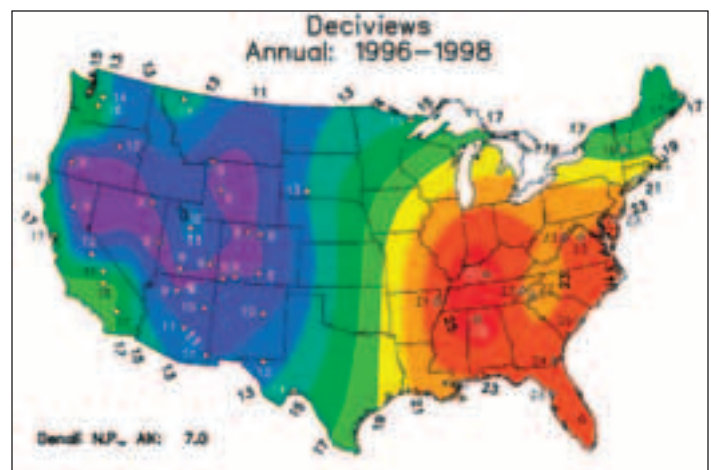
When  $\text{NH}_3$  (an alkaline compound) is released into the air, it rapidly adsorbs to surfaces and significant deposition (up to 20%) may occur within a few hundred meters of the source. The remaining atmospheric  $\text{NH}_3$  can rapidly react with a number of acidic compounds (such as nitric acid or sulfuric acid) to form very small secondary aerosol particles. This fine particulate matter has a diameter of <2.5 microns (referred to as PM 2.5), which is about 30 times smaller than a human hair. Some of these very small particles can persist in the air for up to 2 weeks.

PM 2.5 particles are a health concern for their impacts on respiratory function. These extremely small particles are inhaled deeply into the lungs. Short-term exposure to PM 2.5 aerosols can cause eye, nose, throat, and lung irritation, plus coughing and sneezing, among other symptoms. Long-term exposure to PM 2.5 materials has been linked to a variety of respiratory and cardiovascular ailments. Children, elderly, and individuals with impaired respiratory capacity due to asthma or emphysema may be particularly sensitive to problems caused by PM 2.5.

The fine airborne PM 2.5 particles also contribute to atmospheric haze and low visibility (**Figure 3**). Haze occurs when sunlight encounters particles in the air – thereby obscuring visual clarity and colors in the landscape. There are many sources of primary PM 2.5 into the air (including dust and smoke from fires), but the contribution of  $\text{NH}_3$  in forming secondary PM 2.5 can be significant. For example, the adverse effects of PM in the Lower Fraser Valley of British Columbia and Southern Ontario have been well documented. In the USA, the overall trend is a steady decline in PM 2.5 since the year 2000. However, there are several notable exceptions to this national trend.

Ammonia in the atmosphere will be transported with the wind and may become redeposited in previously pristine regions, often hundreds of miles from the original source of  $\text{NH}_3$ . Ammonium deposited on the soil is generally converted rapidly to nitrate ( $\text{NO}_3^-$ ), with an accompanying release of acidity ( $\text{H}^+$ ) during nitrification. The  $\text{NH}_3$  may enter the leaves of plants through the stomata or may enter the leaf as  $\text{NH}_4^+$  after it is dissolved in water. The  $\text{NH}_4^+$  may also be taken up from the soil by plant roots. Plants that primarily utilize  $\text{NH}_3$  and  $\text{NH}_4^+$  as the major N source will excrete  $\text{H}^+$  from the roots, increasing the acidity of the rooting zone. Note that plant leaves can also serve as a source of  $\text{NH}_3$  emissions, especially during plant maturation and senescence.

Widespread  $\text{NH}_3$  fertilization through atmospheric deposition can cause enhanced plant growth in areas where N was previously limiting. Changes in plant species have been noted in undisturbed ecosystems where high  $\text{NH}_3$  deposition occurs. In some ecosystems, the plant species that are



**Figure 3.** Map of haze distribution of the USA. Units are expressed as deciviews which measures haze and visibility. Higher deciview levels are hazier, while lower deciview levels are clearer. (IMPROVE, 2009).

**Table 1.** Factors affecting NH<sub>3</sub> loss from field-applied animal manure.

Climate	Soil Properties	Manure Properties	NH <sub>3</sub> Reduction Strategies
Volatilization losses increase as temperature and solar radiation rise. This results from a combination of factors such as atmospheric turbulence, faster drying, increased NH <sub>3</sub> concentration, and faster diffusion.	When manure slurries infiltrate into the soil, the potential for volatilization decreases. Sandy soils with a high infiltration rate commonly have less NH <sub>3</sub> loss than from slurries applied to finer-textured soils.	The dry matter content of the animal waste influences NH <sub>3</sub> loss. Effluents and slurries with a low solid fraction tend to infiltrate more quickly and have less NH <sub>3</sub> loss than high dry-matter materials that remain on the surface for a longer time.	Manure separators produce a liquid and solid material that allow more precise nutrient management and may also reduce the hauling costs. The liquid generally infiltrates more quickly than the whole manures.
Increased wind speed generally results in higher NH <sub>3</sub> losses by maintaining a large gradient between the manure and the air.	Since NH <sub>4</sub> <sup>+</sup> is retained on soil cation exchange sites, increased exchange capacity is typically associated with less NH <sub>3</sub> loss.	Liquid manures have a very high initial NH <sub>3</sub> loss rate after application. Therefore, abatement measures such as incorporation or irrigation, must be done immediately after application. Ammonia loss rates from solid manures are slower, so there is more time to perform field practices. Waste water and effluents are not generally incorporated.	Cultivating the soil before application can improve the infiltration rate and reduce NH <sub>3</sub> loss. Cultivation after application reduces NH <sub>3</sub> loss by burying the majority of the manure.
Rainfall can dilute the NH <sub>3</sub> and help move it into the soil, thereby reducing volatilization losses. However, a light rainfall may have an opposite effect by stimulating biological processes that increase NH <sub>3</sub> losses after the manure dries again.	Saturated soils, compacted soils, and high-pH soils are more susceptible to NH <sub>3</sub> losses.	Manure that sticks to vegetation when applied will tend to have greater volatile loss than manure that makes direct contact with the soil. Surface banding the manure is a low-cost method of minimizing contact with vegetation and taking advantage of the protective effect of vegetation or crop stubble.	Soil incorporation should be done immediately after application for liquid manure, but may be delayed slightly for solid manures. A one-pass system for application and incorporation is preferred when applying liquid manures.
If possible, apply manure when conditions favor conservation of the NH <sub>3</sub> . While application during cool weather or when rain is expected is desirable, it is not always feasible to wait until weather conditions are ideal. Remember that a heavy rainstorm after manure application may cause leaching and runoff of NH <sub>4</sub> <sup>+</sup> , NO <sub>3</sub> <sup>-</sup> , and pathogenic microbes.		Larger manure application rates are typically associated with a greater percentage NH <sub>3</sub> loss. However, there are circumstances where light application rates result in a greater percentage loss of the total applied N.	Injecting animal waste beneath the soil surface is very effective for minimizing NH <sub>3</sub> emissions. However, factors such as energy costs, crop and soil disturbance, potential soil compaction, and the NO <sub>3</sub> <sup>-</sup> leaching potential must also be considered. Where deep injection is not possible, consider shallow injection, surface banding, s-tine cultivators, sweep injectors, or other application methods that minimize NH <sub>3</sub> loss.
		High pH of manure increases NH <sub>3</sub> emissions. As the pH increases, a greater proportion of the N is in the volatile NH <sub>3</sub> form, compared with NH <sub>4</sub> <sup>+</sup> favored at lower pH. Amendments that are added to reduce manure pH will generally reduce NH <sub>3</sub> losses.	Higher application rates generally result in greater NH <sub>3</sub> losses, especially on wet soils. If the manure is applied in excess of the soil's capacity to assimilate the material, more of the N may be subject to loss. The rate of application is typically determined by the field equipment and the desired rate of nutrient application to meet the crop requirement.
		Manure residue after anaerobic digestion for methane generation tends to have elevated pH and greater potential for NH <sub>3</sub> loss.	Have the manure regularly tested to determine the chemical content so application rates match the nutrient requirement of the crop.



naturally adapted to low-N conditions have been replaced by plant species with a higher N demand because of NH<sub>3</sub> deposition. Enrichment of surface water with additional N can lead to eutrophication, especially in coastal waters. Accelerated soil acidification following nitrification is also a potential impact from NH<sub>3</sub> deposition. Direct damage to sensitive vegetation (lichens and bryophytes) can occur even at very low NH<sub>3</sub> concentrations.

There are no current policies or regulations in the USA or Canada that require a reduction in NH<sub>3</sub> emissions from agriculture. However, there are restrictions on NH<sub>3</sub> loss in European countries under the U.N. Convention on Long-Range Transboundary Air Pollutants (Gothenburg Protocol). The Netherlands was the first country to set limits on NH<sub>3</sub> emissions. Ammonia emissions in that country have decreased by more than 40% since 1995. Both the USA and Canada are signatories of the Protocol and regularly submit NH<sub>3</sub> emission inventories.

With attention focused on environmental impacts of agriculture, awareness of the issues related to NH<sub>3</sub> emissions in North America is increasing. The loss of NH<sub>3</sub> not only presents a potential environmental problem, but the loss of a nutrient that could be conserved for beneficial plant nutrition.

Agricultural emissions of NH<sub>3</sub> are primarily associated with animal production. Additional research is needed to measure the extent and the location of these NH<sub>3</sub> losses on the farm. Implementing advanced management practices will assist the animal industry to effectively manage animal manures for their maximum benefit. **BC**

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## Conversion Factors for U.S. System and Metric Units

Because of the diverse readership of *Better Crops with Plant Food*, units of measure are given in U.S. system standards in some articles and in metric units in others...depending on the method commonly used in the region where the information originates. For example, an article reporting on corn yields in Illinois would use units of pounds per acre (lb/A) for fertilizer rates and bushels (bu) for yields; an article on rice production in Southeast Asia would use kilograms (kg), hectares (ha), and other metric units.

Several factors are available to quickly convert units from either system to units more familiar to individual readers. Following are some examples which will be useful in relation to various articles in this issue of *Better Crops with Plant Food*.

To convert Col. 1

into Col. 2, multiply by:

Column 1

Column 2

To convert Col. 2 into  
Col. 1, multiply by:

	Column 1	Column 2	
	Length		
0.621	kilometer, km	mile, mi	1.609
1.094	meter, m	yard, yd	0.914
0.394	centimeter, cm	inch, in.	2.54
	Area		
2.471	hectare, ha	acre, A	0.405
	Volume		
1.057	liter, L	quart (liquid), qt	0.946
	Mass		
1.102	tonne <sup>1</sup> (metric, 1,000 kg)	short ton (U.S. 2,000 lb)	0.9072
0.035	gram, g	ounce	28.35
	Yield or Rate		
0.446	tonne/ha	ton/A	2.242
0.891	kg/ha	lb/A	1.12
0.159	kg/ha	bu/A, corn (grain)	62.7
0.149	kg/ha	bu/A, wheat or soybeans	67.2

<sup>1</sup>The spelling as "tonne" indicates metric ton (1,000 kg). Spelling as "ton" indicates the U.S. short ton (2,000 lb). When used as a unit of measure, tonne or ton may be abbreviated, as in 9 t/ha. A metric expression assumes t=tonne; a U.S. expression assumes t=ton.