



BUL 926

Understanding Factors Controlling Ammonia Volatilization from Fertilizer Nitrogen Applications

Biswanath Dari

Postdoctoral Fellow, Barley Agronomy
University of Idaho, Plant Sciences

Christopher W. Rogers

Barley Agronomy
University of Idaho, Plant Sciences

Olga S. Walsh

Cropping Systems Agronomy
University of Idaho, Plant Sciences

Contents

- 1 Introduction
- 2 Sources of Ammonia Volatilization
- 2 Factors Affecting Ammonia Volatilization
- 4 Summary

Introduction

NITROGEN (N) IS THE ESSENTIAL SOIL MINERAL NUTRIENT needed in the greatest quantity by plants and is a primary component of biological cycles. While N makes up 78% of the atmosphere, few plants (for instance, legumes) are adapted to convert or “fix” N directly from the atmosphere to satisfy their need for N. Thus, plants rely on available forms of N (ammonium; NH_4 and nitrate; NO_3) from mineralization of organic soil N or the application of fertilizer N to optimize their growth and development. Crop production removes soil nutrients when crop outputs such as grain, straw, tubers, etc., are removed at harvest.

The primary forms of N found in N fertilizers are ammonium (NH_4), nitrate (NO_3), and urea ($\text{CO}(\text{NH}_2)_2$) or combinations thereof. Plant availability and recovery of N from NH_4 or NH_4 -forming fertilizers are reduced by N losses via leaching and runoff, denitrification, and ammonia (NH_3) volatilization. Gaseous N loss via NH_3 volatilization is a major potential pathway of loss (Fig. 1). Therefore, NH_3 volatilization can potentially reduce a grower’s economic return and have negative impacts on the environment.

Ammonium-forming fertilizers are susceptible to NH_3 loss, especially when left on the soil surface. Under specific conditions, NH_3 volatilization from urea and NH_4 -forming fertilizers has been reported to account for up to 50% of total N loss in agricultural systems (Lightner et al. 1990; Hamid and Mahler 1994; Eckard et al. 2003; IPNI 2011). The extent of N loss is dependent on a variety of factors including weather conditions, soil characteristics, and management. Thus, to maximize a cropping system’s sustainability, the mechanisms and factors that affect NH_3 volatilization need to be understood and addressed through appropriate management practices.



University of Idaho
Extension

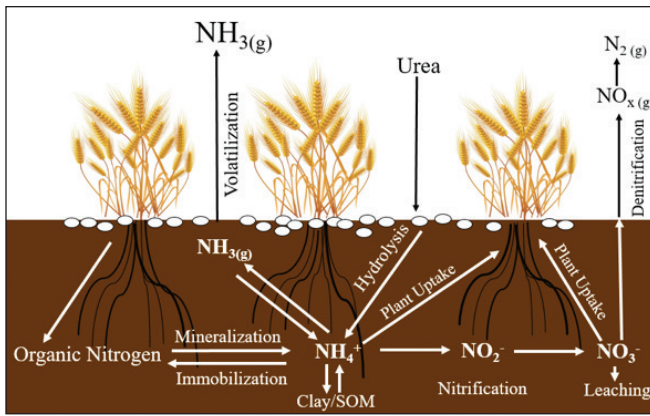


Figure 1. Schematic of nitrogen cycling including ammonia volatilization in the soil–plant–atmosphere environment.

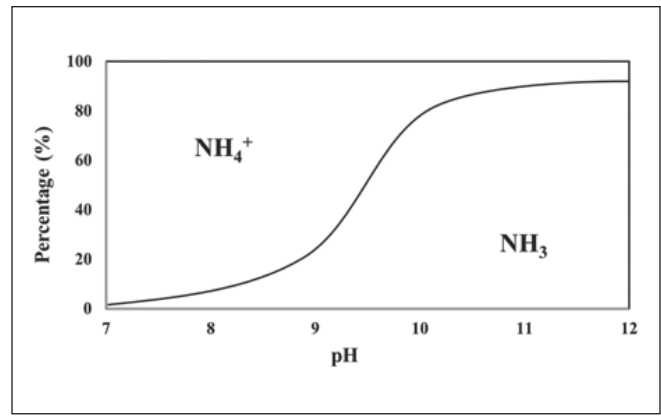


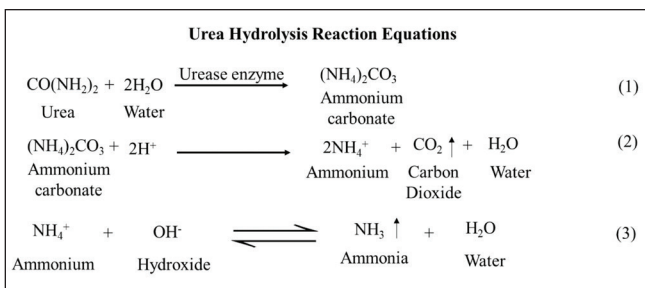
Figure 2. Change in ammonia (NH₃) and ammonium ion (NH₄⁺) concentration ratio as a function of pH.

Sources of ammonia volatilization

Ammonium or NH₄-forming fertilizers such as urea (46-0-0), ammonium sulfate (21-0-0-24), ammonium nitrate (34-0-0), and urea ammonium nitrate (UAN, 28/32-0-0) are susceptible to NH₃ volatilization losses. Agricultural systems are estimated to account for approximately 89% of total NH₃ volatilization in North America (FAO 2014). Although animal production accounts for the major share of the total agriculture-related NH₃ volatilization, N loss from fertilized fields also plays a pivotal role in NH₃ volatilization.

Ammonia volatilization occurs as NH₄ is converted to NH₃ gas at the soil surface and transported to the atmosphere. Urea accounts for about 50% of the total world N fertilizer consumption and is the primary N fertilizer used in agriculture throughout the United States (FAO 2014). The pathway by which ammonia volatilization occurs from urea is shown in Equations 1–3.

When either granular or liquid urea is applied to the soil, it hydrolyzes and is converted to ammonium carbonate by the urease enzyme naturally occurring in soils. Then, a portion of ammonium is converted into ammonia gas which can be lost to the atmosphere.



Factors affecting ammonia volatilization

Nitrogen losses via ammonia volatilization following surface application of NH₄ or NH₄-forming N fertilizers are controlled by various soil, environmental, and fertilizer management factors as discussed in the following sections.

Soil factors

The extent of NH₃ volatilization is influenced by soil pH, type (or texture), cation exchange capacity (CEC), soil organic matter (SOM), temperature, and moisture content of the soil.

Soil pH

In general, alkaline soils (pH >7.0) are more susceptible to NH₃ volatilization, while neutral to acidic soils (pH 5.0–7.0) result in reduced NH₃ volatilization losses. During urea hydrolysis, the initial soil pH increases surrounding the fertilizer. The ratio of NH₄ to NH₃ is largely dependent on pH (Fig. 2), thus increased pH above 7.0 promotes NH₃ volatilization. Fertilizer N sources such as urea can result in elevated pH conditions at the site of fertilizer contact with the soil even in neutral to acidic soils, increasing NH₃ volatilization risk. The ability of a soil to resist an increase in pH (that is, its buffering capacity) affects the amount of NH₃ loss because of the buffering capacity's effect on the ratio of NH₃ to NH₄ (Fig. 2).

Soil physical and chemical properties

Ammonia volatilization largely depends on the texture of a soil along with its buffering capacity. Generally, soil texture is an important indicator of

CEC since clay content is positively correlated with CEC. A soil with a higher buffering capacity (because of high CEC, high clay content, high SOM, or a combination of those) has a reduced rate of NH₃ loss because rapid pH change is restricted or because of increased adsorption of NH₄ to clay particles. For instance, sandy soils with lower CEC and SOM, low pH, low buffering capacity, and greater magnitude of pH changes can lead to greater NH₃ volatilization loss as compared to silty or clay soil with a higher CEC, SOM, and thus, buffering capacity.

Soil temperature

Increased soil temperature increases the solubility of urea and thus, the rate of NH₃ volatilization. Generally, the risk of NH₃ volatilization is increased at soil temperatures over 70°F. However, the rate of NH₃ volatilization can still be substantial at near-freezing temperature. Specifically, a study from Montana revealed that significant NH₃ losses (almost 40% of applied N) from surface-applied urea can occur even when soil temperatures are cold (<5°F) (Jones et al. 2013). Another study by Engel et al. (2011) reported that approximately 12% of applied N was lost within 5 weeks of application when the soil temperature was 30°F even when the soil was covered with snow in December. Therefore, soil surfaces can be subject to NH₃ volatilization losses even if cold or frozen at the time of fertilizer N application.

Soil moisture

Soil moisture plays a critical role in determining the fate of applied fertilizer N. For example, urea applications to a wet soil surface result in increased NH₃ volatilization as the rate of hydrolysis is increased and movement into the soil is decreased due to the amount of water-filled pore spaces. Similarly, prolonged contact of fertilizer granules with a damp soil surface promote N loss. The increased NH₃ volatilization is related to urea being highly hygroscopic (that is, it absorbs water from both liquid water and water vapor in the air). As a result, granular urea dissolves when in contact with moisture and can be lost via volatilization shortly after hydrolysis occurs following surface applications (Wahl et al. 2006). On the other hand, the application of fertilizer N to a dry soil with low relative humidity reduces NH₃ volatilization losses.

Research from Montana reported less than 10% NH₃ volatilization losses occurred within 2 weeks of surface application of urea to a dry soil. Additionally, a wet soil surface can result in greater risk for NH₃ loss even at a low soil temperature (i.e., 25 to 40°F). This particular situation may prevail especially during late fall, winter, and early spring fertilizer applications in Idaho.

Fertilizer management factors

Ammonia volatilization is affected by fertilizer source, type, time, and method of application. Surface application of urea or other NH₄-forming fertilizers is a predominant cause of NH₃ volatilization from Idaho cropping systems. Broadcast urea and other granular or liquid-N fertilizers without incorporation increases the susceptibility to NH₃ loss. This results from greater exposure of the fertilizer to the combination of environmental conditions conducive to NH₃ volatilization. Conversely, sub-surface fertilizer banding helps to minimize NH₃ volatilization risk on calcareous soils.

Environmental factors

Urea needs to be hydrolyzed before NH₃ can be volatilized and the rate of the hydrolysis process can be affected by certain environmental conditions such as soil temperature and humidity. Weather conditions such as rainfall, snowfall, or fog directly affect NH₃ volatilization loss from a soil. Fertilizer application should occur onto a dry soil surface where incorporation into the soil can occur, and ½ inch of rain should be sufficient to incorporate surface-applied fertilizer N (Jones et al. 2013). This will reduce NH₃ volatilization substantially as compared to surface applications without incorporation.

The loss of NH₃ from surface-applied N fertilizers increases in windy conditions, when NH₃ is moved into the atmosphere as the surface of the soil dries (Cornell Univ. Coop. Ext. 2013). Generally, higher air temperature (>70°F) also increases NH₃ volatilization risk due to the increased speed of hydrolysis of urea, and thus, greater NH₃ volatilization occurs under warm, windy conditions. Fluctuations in volatilization potential have also been noted throughout the day—the risk is generally greater during the warmer part of the day compared to the night.

Summary

Urea and other NH_4 -forming fertilizers are commonly used to optimize crop production, but are susceptible to losses as NH_3 gas, particularly when left on the soil surface after application. Ammonia volatilization results in loss of applied nutrients, which can negatively impact farm economy and the environment. Ammonia volatilization loss from urea and other NH_4 -forming fertilizers is controlled by diverse soil properties such as pH, soil type/texture, temperature, and soil moisture content. Environmental conditions in combination with soil and crop management factors (fertilizer sources, time and methods of application, etc.) make NH_3 volatilization difficult to predict in the field.

In general, higher pH, warmer temperatures, and greater soil moisture content increase the potential for volatilization, while soil incorporation via rainfall, irrigation, or tillage after application decreases volatilization potential. Further, soils with a higher CEC, buffering capacity, and cool environmental conditions during fertilizer application have a reduced potential for NH_3 volatilization.

Understanding the factors and the mechanisms that influence volatilization will allow growers to select the best management practices (BMPs) that minimize NH_3 volatilization in their operations. Please see “Best Management Practices for Minimizing Ammonia Volatilization from Fertilizer Nitrogen Applications in Idaho Crops” (University of Idaho Extension Bulletin 927) for details of BMPs to minimize ammonia volatilization from fertilizer applications to Idaho crops.

References

- Cornell University Cooperative Extension. 2013. Urea Fertilizer. Agronomy Fact Sheet Series; Fact sheet #80. Cornell University Cooperative Extension. Cornell, NY.
- Eckard, R.J., D. Chen, R.E. White, and D.F. Chapman. 2003. Gaseous Nitrogen Loss from Temperate Perennial Grass and Clover Dairy Pastures in South-Eastern Australia. *Aust. J. of Agril. Res.* 54:561–570.
- Engel, R., C. Jones, and R. Wallander. 2011. Ammonia Volatilization from Urea and Mitigation by NBPT Following Surface Application to Cold Soils. *Soil Sci. Soc. Am. J.* 75:2348–2357.
- International Plant Nutrition Institute (IPNI). 2016. Nitrogen Notes: Ammonia Volatilization, Bulletin #6. Available from [http://www.ipni.net/publication/nitrogen-en.nsf/0/B219184650778DB985257DD60005826A/\\$FILE/NitrogenNotes-EN-6.pdf](http://www.ipni.net/publication/nitrogen-en.nsf/0/B219184650778DB985257DD60005826A/$FILE/NitrogenNotes-EN-6.pdf).
- Jones, C., B.D. Brown, R. Engel, D. Horneck, and K. Olson-Rutz. 2013. Nitrogen Fertilizer Volatilization. Montana State Univ. Extension - EB0208. Bozeman, MT.
- Lightner, J.W., D.B. Mengel, and C.L. Rhykerd. 1990. Ammonia Volatilization from Nitrogen Fertilizer Surface Applied to Orchardgrass Sod. *Soil Sci. Soc. of Am. J.* 54:1478–1482.
- Hamid, A., and R.L. Mahler. 1994. The Potential for Volatilization Losses of Applied Nitrogen Fertilizers from Northern Idaho Soils. *Comm. Soil Sci. Plant Anal.* 25:361–373.
- Wahl M.R., U. Kirsch, S.T. Brockel, and M. Bottlinger. 2006. Caking of Urea Prills. *Chem. Eng. Technol.* 29:674–678.
- FAO. 2014. FAOSTAT. Available from <http://faostat.fao.org>. Accessed Nov. 6, 2017.

ALWAYS read and follow the instructions printed on the pesticide label. The pesticide recommendations in this UI publication do not substitute for instructions on the label. Pesticide laws and labels change frequently and may have changed since this publication was written. Some pesticides may have been withdrawn or had certain uses prohibited. Use pesticides with care. Do not use a pesticide unless the specific plant, animal, or other application site is specifically listed on the label. Store pesticides in their original containers and keep them out of the reach of children, pets, and livestock.

Trade Names—To simplify information, trade names have been used. No endorsement of named products is intended nor is criticism implied of similar products not mentioned.

Groundwater—To protect groundwater, when there is a choice of pesticides, the applicator should use the product least likely to leach.