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Best Management Practices for Minimizing Ammonia Volatilization from Fertilizer Nitrogen Applications in Idaho Crops

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Introduction

NITROGEN (N) FERTILIZATION is a primary factor influencing agronomic and economic returns in Idaho cropping systems. Nitrogen is needed for photosynthesis in crops and is required for production of amino acids that combine to form proteins crucial for plant growth. Plants take up N from the soil in the inorganic forms of ammonium (NH_4) and nitrate (NO_3). While many fertilizers contain inorganic forms of N, organic fertilizer sources such as urea ($CO(NH_2)_2$) must be converted to these inorganic forms before crops can use them. As NH_4 is derived from the fertilizer, one result is that gaseous NH_3 (ammonia) can be lost to the atmosphere. Thus, NH_4 and NH_4-forming fertilizers are susceptible to N loss via ammonia (NH_3) volatilization. In this bulletin, “ammonia losses” refers to loss of N through NH_3 volatilization. See Understanding Factors Controlling Ammonia Volatilization from Fertilizer Nitrogen Applications (University of Idaho Extension Bulletin 926) for details of the processes related to ammonia volatilization from fertilizer N applications.

Successful management of crops, soils, and the surrounding environment in an agricultural production system involves trade-offs between maximizing crop yield and providing efficient and sustainable use of farm resources. Thus, best management practices (BMPs) which are crop-specific, economically viable, and environmentally sustainable must be identified and practiced to reduce ammonia losses. For instance, adoption of the most appropriate method and timing of fertilizer application should be chosen to address crop demands, weather conditions, and favorable soil conditions to minimize ammonia volatilization. While each fertilizer application situation is unique, the following BMPs provide guidance to help producers evaluate and choose strategies most suitable for their farming operation.

By adopting BMPs, growers can enhance their ability to maximize crop production efficiency, while reducing ammonia volatilization losses.

Best management practices to reduce ammonia volatilization

Ammonia volatilization can be minimized by following BMPs related to fertilizer rate, source, and type, as well as the time and method of fertilizer application. Understanding potential issues that may arise with each is key to minimizing these losses.

Fertilizer Management

Proper management of urea and other NH_4-forming fertilizers is critical for minimizing ammonia volatilization. Urea-based fertilizers are highly susceptible to ammonia volatilization, so the majority of this publication will focus on urea management, but the BMPs are applicable to other NH_4 or NH_4-forming fertilizers as well. The primary management goal is to move urea and NH_4-forming fertilizers into the soil profile so they can be taken up by the crop, while minimizing ammonia losses.

Fertilizer rates

University of Idaho Extension recommendations for fertilizer N applications are crop specific but are primarily based on realistic yield goals, existing soil inorganic N values, and estimates of conversion of soil organic N to inorganic N (that is, mineralization of N). Northern and southern Idaho also have different recommendations for individual crops based on yield and quality expectations of the cropping system. Determination of proper N application rates depends on accurate soil testing protocols and analysis. Protocols for soil sampling and fertilizer management are detailed in University of Idaho Extension Bulletin 915 (Walsh et al. Forthcoming).

Fertilizer sources

Choice of fertilizer N source can significantly influence the resulting susceptibility to ammonia volatilization (Table 1). Anhydrous ammonia is particularly susceptible to volatilization losses since it becomes a vapor during injection; it must be placed 4 to 8 inches below the soil surface to prevent loss to the atmosphere (IPNI 2016). Urea has a high potential for ammonia losses since it increases soil pH around fertilizer particles during hydrolysis, following application to the soil. Ammonium sulfate is intermediate in terms of ammonia losses, with higher volatilization rates occurring in alkaline calcareous soils as compared to acidic soils, due to sulfate dissolving calcium carbonate resulting in a pH increase (Jones et al. 2013). Urea ammonium nitrate (UAN) solution contains only 50% urea, and has a lower ammonia volatilization risk as compared to urea.

Specific compounds have been investigated and found to inhibit urease activity to reduce ammonia volatilization from urea. For example, the urease enzyme inhibitor (N-[n-butyl] thiophosphoric triamide; NBPT) delays the conversion of urea to NH_4 and can result in decreased ammonia volatilization from urea.

In a study conducted in Aberdeen, Idaho in 2016 on a Declo-loam soil, an approximately 80% reduction in ammonia losses from surface applications to moist soil were measured when urea was coated with NBPT. Ammonium sulfate also reduced ammonia volatilization, compared to applying untreated urea

Table 1. Common sources of N-containing fertilizers susceptible to ammonia volatilization.

Fertilizer source	Chemical formula	Nitrogen content (%)	Fertilizer type	Potential risk of NH_3 volatilization
Urea	$CO(NH_2)_2$	46	Dry Granular	High
Anhydrous ammonia	NH_3	82	Compressed Gas	High
Ammonium nitrate	NH_4NO_3	28	Dry Granular	Low
Ammonium sulfate	$(NH_4)_2SO_4$	21	Dry Granular	Intermediate
Urea ammonium nitrate (UAN)	$CO(NH_2)_2 + NH_4NO_3$	28	Liquid	Intermediate

to the soil surface (Fig. 1). Further, a study conducted in Montana reported approximately a 66% reduction in ammonia losses when urea was coated with NBPT (Engel et al. 2011; Jones and Engel 2012). Use of various controlled release or slow-release fertilizers (e.g. polymer-coated urea) has shown as high as 35 to 40% reduction of ammonia losses (Knight et al. 2007; Vaio et al. 2008; Rochette et al. 2009); however, timing of release of N from these sources to meet crop demand in Idaho is not well documented and is a factor that must be considered if using these sources.

Methods of fertilizer application

Fertilizer application and land management practices may be the most cost effective and impactful options for reducing ammonia volatilization when considering the recovery of N to ensure maximum crop production. Surface broadcasting of urea and other NH_4-forming fertilizers prior to seeding is a common practice, although this method of N fertilization carries the greatest risk of ammonia losses. In contrast, sub-surface banding, direct injection, and incorporation immediately after application of fertilizer N all help to reduce ammonia losses.

Sub-surface banding has been reported to conserve more N than surface broadcasting on alkaline calcareous soils. However, a higher volatilization rate was reported in poorly buffered acidic soils (pH < 7.0) when urea was applied as surface or sub-surface bands in comparison to surface or incorporated broadcast applications (Sommer et al. 2004; Rochette et al. 2009). Increased emissions from banding in this scenario are primarily due to an increased rate of hydrolysis and a locally concentrated soil pH increase surrounding the band.

Limitations exist for specific fertilizer application methods. For example, subsurface fertilizer injection is less efficient in soils with high moisture content or compaction. The potential root damage from the action of the injectors may cause reduced yields as well as increased application time and costs. Injection may not be practical on stony soils or sloped land and, consequently, surface application might be the only viable option. Additionally, the injection method can be more expensive than broadcast application due to the time and equipment needed to inject the fertilizer N. On the other hand, the injection method helps to significantly reduce ammonia losses, thereby potentially increasing crop production and farm profit. Best results in terms of reduction of ammonia volatilization are seen when urea or other NH_4-forming fertilizers are applied in a subsurface band on alkaline calcareous soils at least two inches below the surface or when surface-broadcast fertilizer N is incorporated using either tillage, irrigation, and/or rain to infiltrate N into the soil (Jones et al. 2013).

Time of fertilizer application

One of the primary ways to reduce ammonia volatilization is to apply fertilizer N at the appropriate time. Timing of fertilizer application and subsequent N availability should correspond to the time of maximum crop demand for N. Synchronizing N availability with plant N uptake improves N uptake efficiency and minimizes ammonia losses.

Depending on environmental conditions, ammonia volatilization can occur soon after application of fertilizers, hence, incorporation should occur as soon as possible after fertilization by either a tillage operation, or irrigation and/or rainfall.

Ammonia volatilization can be minimized by applying NH_4-forming fertilizers in dry and cool weather and by avoiding application on warm, humid, or windy days. For best retention of N fertilizer, surface applications should be made on dry soil followed by rainfall events (>0.5 inches) or irrigation (>0.5 inches) within a couple of days of application. Also, tillage operations (>2 inches deep) performed shortly after broadcast applications can be used to incorporate fertilizer and thereby, reduce ammonia volatilization (Jones et al. 2013). Therefore, the most effective practice to substantially reduce ammonia losses from urea or other NH_4-forming fertilizers is application onto cool/dry soil when precipitation, irrigation, or tillage are available to incorporate N shortly after fertilization (Table 2).

Soil Management

Soil factors and management significantly affect the potential for ammonia volatilization. For example, soils with a high CEC (such as with greater clay content) are able to hold more charged NH_4 ions in the soil.

A general recommendation is to apply N fertilizers when soil temperatures are not high—although cool soil temperatures alone do not ensure lower volatilization risk. Surface soil moisture also plays

Table 2. Best management practices (BMPs) to minimize NH_3 (ammonia) volatilization from urea and NH_4- or NH_4-forming fertilizer N application to soils.

Delay application under high-risk conditions, including moist soil, high-soil temperature, or frozen soil surface.
Incorporate surface-applied fertilizer within one to two days following application, by : • Tillage (> 2 in) • Irrigation (> 0.5 in) • Rainfall (> 0.5 in single event)
Apply as a subsurface band (> 2 in) in poorly buffered, low pH soils (pH < 7.0). (There can be increased risk of loss, particularly if surface- or shallow banded.)
For surface-applied urea, consider a urease inhibitor (i.e., NBPT), particularly when conditions are sub-optimal.
Consider an alternate N source to urea, particularly when conditions are sub-optimal.

Adapted from Jones et al. (2013)

an important role in ammonia volatilization losses, particularly when urea or other NH4-forming fertilizers are surface broadcast. In a Montana study, an almost 25% loss of N via ammonia volatilization was observed when urea was surface applied at near freezing temperatures in soils covered with snow (0.6 inches in December–January; Jones et al. 2013).

Ammonia losses of 30 to 40% have been reported when urea was applied to wet or snow-covered soil surfaces followed by drying with little or no rainfall. In contrast, 10 to 20% ammonia loss was observed when urea was surface applied to dry soils followed by scattered rainfall (<0.33 inches) and <10% when applied to a dry soil followed by 0.75 inches of rainfall within two weeks (Jones et al. 2013).

Conventional tillage has advantages over reduced or no-tillage in reducing ammonia volatilization from surface applications of fertilizer N because of options for incorporation into the soil. Application of urea and other NH_4-forming fertilizers without incorporation with no-tillage is likely to increase susceptibility to ammonia losses. However, incorporation through irrigation, rainfall, direct injection, or banding can mitigate this increased risk on reduced or no-tillage systems. Research in Aberdeen, Idaho, in 2016 on a Declo loam soil measured a 64% reduction in volatilization when urea was incorporated to a depth of approximately 2 inches, as opposed to surface applied onto a moist soil (Fig. 1).

In irrigated systems, appropriate timing and rates of irrigation can incorporate urea or other NH_4-forming

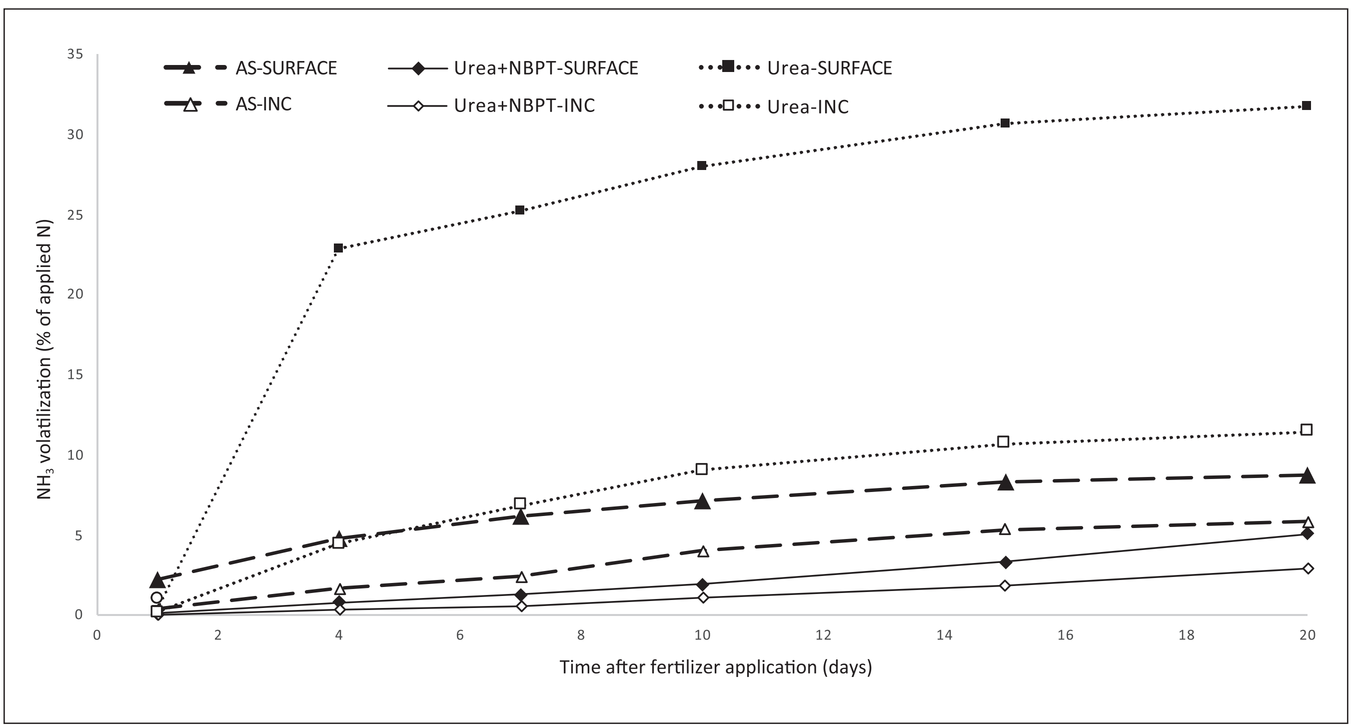

Figure 1. The effects of N-fertilizer sources and application methods on ammonia volatilization losses (%) from fertilizer N applications in Aberdeen, Idaho, on a Declo-loam. Ammonium sulfate (AS), urea + N-[n-butyl] thiophosphoric triamide (NBPT), and urea fertilizer sources applied either broadcast on the surface or incorporated (INC) in the soil to a depth of approximately 2 inches.

fertilizers into the soil and reduce ammonia volatilization. Furrow irrigation favors the dissolving of urea granules and can increase ammonia losses due to evaporation rather than moving the urea into the soil, which, in turn, hastens ammonia volatilization from the field (Jones et al. 2013).

Environmental Management

Some environmental conditions such as cool soil temperature, low wind speed, and sufficient rainfall for soil incorporation reduce the risk of volatilization when applying urea or other NH_4-forming fertilizers. Since we cannot manage or change environmental conditions such as soil temperature, wind speed, etc., we must manage our practices around them.

It is recommended not to apply fertilizers to a frozen soil, especially on slopes, since this will restrict the ability of the fertilizer N to effectively move into the soil. While rainfall can help fertilizer N to infiltrate into the soil, application onto already saturated or wet soils can increase ammonia volatilization.

Summary

Nitrogen fertilizer applications in areas of intensive agricultural production of Idaho are likely to result in loss of N via ammonia volatilization. However, effective use of BMPs can minimize that loss and improve fertilizer use efficiency. Adopting BMPs improves on-farm utilization of fertilizer inputs by minimizing applications in high-risk conditions (Table 2) and minimizing ammonia volatilization losses. Best management practices can lead to more efficient N fertilizer utilization, providing a potential financial boost to growers. Soil conditions that provide a lower risk of ammonia volatilization include inherent soil properties like lower soil pH, higher CEC, and higher soil organic matter. Environmental conditions associated with lower N loss risk due to ammonia volatilization are cooler soil temperatures, little or no wind, and a dry soil surface at the time of fertilizer application. Understanding environmental risk factors and using BMPs will improve on-farm N use efficiency, which can lead to improved agronomic and economic returns for Idaho growers.

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