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## A review on management of urea fertilizer to minimize losses of nitrogen from rice fields

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### Abstract

Volatilization of  $\text{NH}_3$  from urea and other N fertilizers is controlled by a number of diverse soil properties and environmental conditions that make losses difficult to predict in the field. In general, higher pH, temperature, crop residue, and moisture conditions increase the potential for volatilization, while increased incorporation depth from tillage, rain, or irrigation decrease volatilization potential. Due to soil characteristics such as high Cation Exchange Capacity and buffering capacity, substantial inputs of bicarbonates and Ca on irrigated land, and generally cool conditions during major fertilizer application periods, the potential for substantial urea volatilization in many cropping systems of the is likely relatively low. Nevertheless, the lack of direct field measurements of  $\text{NH}_3$  volatilization is coupled with the complexity of fertilizer management practices for the many diverse crops grown in the area is reason to exercise caution and use good urea management practices. Understanding the factors that influence volatilization will allow urea users to select management practices that minimize volatilization.

**Keywords:** Volatilization of  $\text{nh}_3$ , crop residue, high cation exchange capacity and buffering capacity

### Introduction

Urea was introduced in 1935, is now the primary source of dry nitrogen (N) fertilizer due to its relatively high N content, easy handling, and price. Acceptance of urea was delayed in part due to its greater potential for N loss via ammonia volatilization (conversion from dissolved ammonia to ammonia gas). While all top-dressed ammonia- and ammonium-based N fertilizers can volatilize, the potential is greatest with urea and fluids containing urea such as urea-ammonium nitrate. Volatilization losses of nitrogen under worst-case conditions can be substantial, with proper management losses can be negligible. With reduced availability of ammonium nitrate and increased reliance on urea, recent increases in N prices, and increasing environmental concern over atmospheric ammonia emissions, it should prove helpful to review conditions that affect ammonia volatilization and recommend ways to use urea effectively. Rice is the principal crop of India. About 90 per cent of rice grown in world is produced and consumed in Asian region. India has largest area among rice grown countries and ranks second in production after China. India produces 104.32 million tonnes of rice from an area of 43.38 million hectares with a productivity of  $2404 \text{ kg ha}^{-1}$  (2015-16). Rice occupies 42 per cent area under cereal and contributes 42 per cent area under food grain production in the country. Nitrogen is the most essential nutrient for rice production. Nitrogen contributes about 20% of the rice yields out of total application of Nitrogen, Phosphorus and Potassium fertilizers. Most of the nitrogen applied through fertilizer is lost from soil in many ways. There is hardly 30% recovery of applied nitrogen. Knowledge on processes of nitrogen loss from rice field can generate the means of preventing its loss and thus boosting the rice yield. The purpose of this paper is to summarize wide-ranging research on urea use across a range of cropping systems and environmental conditions so farmers can manage urea to minimize volatilization losses and maximize efficiency.

### Factors Influencing volatilization losses

All  $\text{NH}_4^+$  and  $\text{NH}_3$  based fertilizers have the ability to volatilize. Topdressed urea fertilizers generally have the greatest potential for  $\text{NH}_3$  volatilization. The most significant  $\text{NH}_3$  volatilization from applied urea typically occurs during a two to three week period after application, assuming it is not incorporated by tillage, rain, or irrigation.

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The rate of  $\text{NH}_3$  volatilization depends on the rate of urea hydrolysis (urea's conversion to  $\text{NH}_4^+$ ), weather conditions and soil properties. Multiple and often interrelated factors make volatilization variable and difficult to predict under field conditions.

### Soil Moisture and Depth of Urea in Soil

Volatilization of top-dressed urea increases linearly as soil water content increases (Kanani *et al.* 1991) [3]. Again, volatilization decreases as urea is moved below the soil surface, either through incorporation or movement by rainfall or irrigation. Specifically, in a study with a pH 6.5 silt loam soil at 75°F, only 5% of the urea-N that was incorporated into the upper 1.5 inches of soil volatilized compared to 17% for surface applied urea (Ernest *et al.* 1960) [2].

### Soil Temperature and pH

High soil pH and high temperature cause higher rates of  $\text{NH}_3$  volatilization because they increase soil concentrations of  $\text{NH}_3$  dissolved in soil water ( $\text{NH}_3$ ). This is one reason why applying urea during periods with forecasted cool temperatures is recommended to reduce volatilization, especially on high pH soils. Other reasons are that urea hydrolysis rates are higher at higher temperatures, and  $\text{NH}_3$ (gas), like all gases, is more volatile at higher temperatures. The pH at which the percentage of  $\text{NH}_3$  becomes noticeably higher than 0 is higher than the surface pH of the majority of soils in our region. However, pH in the vicinity of a urea granule or fluid droplet can be substantially higher than the surrounding soil because urea hydrolysis raises pH by removing hydrogen ions ( $\text{H}^+$ ) from the soil solution. Urea is not the only N fertilizer that raises pH; anhydrous ammonia, aqua ammonia (ammonium hydroxide), and UAN can similarly raise the pH of soil around the fertilizer; ammonium sulfate (AS), ammonium nitrate (AN), and diammonium phosphate can also have the same effect, but only in calcareous soils (soils containing lime). The pH increase resulting from urea hydrolysis is temporary because  $\text{NH}_4^+$  is converted relatively quickly to  $\text{NO}_3^-$  (nitrification), or  $\text{NH}_3$ ; processes that lower pH by releasing  $\text{H}^+$  ions. Although volatilization has been measured from fields with even lower soil pHs, these fields had a stubble or sod surface cover, which likely had a higher pH than the underlying soil (Keller *et al.* 1986, Lightner *et al.* 1990) [6]. Volatilization can also occur at soil pHs below 6.5 if the soil buffering capacity is low. As this research shows, caution is warranted when surface applying urea, as well as other  $\text{NH}_3$ -based N fertilizers, on warm, high pH soils.

### Cation Exchange Capacity, Soil Buffering Capacity, and Calcium Concentrations

Due to the large effect of pH on pH changes will decrease  $\text{NH}_3$  volatilization from urea. These include high clay, organic matter, and/or bicarbonate contents. A high cation exchange capacity (CEC) will lower the  $\text{NH}_4^+$  concentration in solution, decreasing the  $\text{NH}_4^+$  available for conversion to  $\text{NH}_3$ , and thereby reducing volatilization. Irrigated soils receive annual inputs of Ca and bicarbonate, which should also reduce the potential for volatilization.

### Soil Organic Matter and Residue

High concentrations of soil organic matter and crop residues increase urea hydrolysis rates (Kissel *et al.* 1988, Torella *et al.* 1983) and volatilization. This is largely because the urease enzyme, which is necessary for hydrolysis, is produced by

microorganisms that are more active in the presence of organic material than in mineral soil. Residue may also prevent urea and its hydrolysis product ( $\text{NH}_4^+$ ) from entering the soil. As a result, perennial sod and no-till systems have higher surface hydrolysis rates than bare soil and conventional tillage systems, respectively (Torella *et al.* 1983).

### Management of urea

#### Source

Urea is found in three common fertilizer formulations: dry granular urea (46-0-0), UAN (28-0-0 or 32-0-0), and liquid urea (see Liquid Urea side bar). All three urea sources have similar potentials to volatilize; therefore, the decision on which source to use should be based primarily on cost per unit of N, equipment available to apply the material, and convenience of application.

#### Placement

Urea-based fertilizers can be broadcast, subsurface banded, or surface banded. Broadcasting urea without incorporation increases the potential for  $\text{NH}_3$  volatilization and should be avoided, if possible, under high-risk conditions. If this is unavoidable then delaying the application, applying prior to an irrigation or a rain event, or banding beneath the surface should be considered. In perennial grass systems, subsurface placement of urea by drilling or knifing reduces  $\text{NH}_3$  volatilization (Raczowski *et al.* 1989) [7], but may not be feasible or may cause excessive stand disturbance. Alternatively, surface banding fluid UAN in perennial grass systems may result in lower volatilization than spraying UAN on the surface (Touchton *et al.* 1982) [9]. In wet soil conditions may preclude deep banding, and the soil above the deep band may dry out preventing germination until a precipitation event. In addition, draft requirements increase when fertilizer is deep banded in the same pass as seeding. At higher risk, either delay application, subsurface band, or incorporate with: Tillage (> 2 inches deep), Irrigation (> 0.5 inches) and Rainfall (when > 0.5 inches is expected). Incorporation should take place within 1 to 2 days. If incorporation is not possible within that period, and application cannot be delayed, consider using a coated urea product or urease inhibitor. At lower risk surface broadcast or Subsurface band/incorporate to further minimize the potential for volatilization.

#### Liquid Urea

Dry urea can be mixed with water to produce a fluid containing 15 to 23% N by weight. Dissolution is slow and should be done in a large tank with an external source of heat. The final solution may recrystallize depending on urea concentration and temperature. An even mixture of urea and water by weight (e.g. 5000 lb of urea and 625 gal of water) results in a 23% N solution which will recrystallize below 60°F, whereas a 15% N solution will recrystallize below 10°F. The final product must also be filtered (40 mesh) to prevent nozzle plugging. The primary advantage of a liquid urea compared to a UAN solution is that it produces less leaf burn when applied as a foliar spray (Brown *et al.* 1988) [1]. Liquid Urea Dry urea can be mixed with water to produce a fluid containing 15 to 23% N by weight. Dissolution is slow and should be done in a large tank with an external source of heat. The final solution may recrystallize depending on urea concentration and temperature. An even mixture of urea and water by weight (e.g. 5000 lb of urea and 625 gal of water) results in a 23% N solution which will recrystallize below 60°F, whereas a 15% N solution will recrystallize below 10°F. The

final product must also be filtered (40 mesh) to prevent nozzle plugging. The primary advantage of a liquid urea compared to a UAN solution is that it produces less leaf burn when applied as a foliar spray, (Brown *et al.* 1988) <sup>[1]</sup>. However, because the percentage of N in liquid urea is lower than UAN, transportation costs are normally higher per unit of N.

### Inhibitors

Chemical compounds are also added to urea fertilizers to inhibit transformations of N. Urease inhibitors are one class of compounds that prevent the conversion of urea to  $\text{NH}_4^+$ . Inhibitors can delay the hydrolysis of urea for 2 to 10 weeks. In general, the longevity of urease inhibitors declines as soil temperature and moisture content increase. Inhibitor formulations are available to treat both dry and liquid forms of urea. Inhibitors have met with varied success because they affect only one reaction (hydrolysis) in the process of  $\text{NH}_3$  volatilization from urea, depend on rainfall (or irrigation) to move the urea into the soil before hydrolysis begins and, similar to coatings, may delay the availability of N to the crop.

### Coatings

Coatings slow down the rate that granules dissolve, and hence reduce losses. The oldest and most common coating is elemental sulfur. Once applied, soil bacteria oxidize the sulfur coating, allowing the granule to dissolve and undergo hydrolysis. Nitrogen release from sulfur-coated urea depends on soil moisture and temperature and therefore is somewhat unpredictable. Substantial N may not be released until later in the season, creating problems for high N demand crops like potatoes and sugarbeets. Polymer coatings also control the release of N but use a different mechanism than sulfur coatings. Polymers act as a semi-permeable membrane that permits water to move in through the coating and dissolved urea to move out. The permeability of polymer-coated products depends primarily on soil temperature. A variety of polymer coatings are available to match release rates to specific crop N needs. In the past, the cost of coated urea products has limited their use to intensively managed horticulture crops and turf. In the last ten years, however, new technology has made these coatings less expensive. For example, current polymer coatings may add 20% to the cost of urea fertilizer compared to 100% or more as little as 10 years ago. As a result, coated urea is being targeted for lower value crops and environmentally sensitive situations.

### Conclusions

Since soil and climatic factors affect urea volatilization so it is nearly impossible to predict how much urea will be lost in a given field application situation. By understanding how soil and climate factors influence volatilization, farmers, crop producers and their advisers can avoid applying urea in situations that may promote volatilization, or adopt best management practices to minimize the potential for loss. Management practices include incorporating urea with equipment, irrigation, or rainfall; top dressing urea when temperatures and soil moisture levels are low; and avoiding top-dress applications under high risk conditions unless there is an opportunity to incorporate the urea within one to two days of application.

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