

Urea, an organic compound, occurs naturally in animals and some plants. It was first identified more than 200 years ago and was prepared synthetically in the laboratory in 1828. Commercial production of large quantities of urea takes place by reacting ammonia with carbon dioxide at ammonia manufacturing facilities that use natural gas as feedstock. Carbon dioxide is a by-product of ammonia production at these facilities.

Urea fertilizers range in composition from pure, dry, granular urea (46-0-0) to products that are mixtures of urea and other sources of nitrogen and/or phosphate and potash. The most common mixture of urea with other nitrogen fertilizers is the liquid urea-ammonium nitrate solution (UAN), which in Kansas is most often sold as a solution containing 28% nitrogen. It also may be sold as a 32% nitrogen solution. Approximately half of the nitrogen in UAN is urea. Dry urea may be blended with dry phosphate and potash products such as diammonium phosphate (18-46-0) and muriate of potash (0-0-60) to supply total nutrient needs. For a liquid program, UAN is often blended with liquid ammonium polyphosphate (10-34-0). In cases where other nutrients are needed, liquid sources of sulfur and micronutrients can be added to the mixture to make a complete liquid fertilizer.

The tonnage of urea fertilizer sold in Kansas has increased in recent years. The increased use of urea is likely to continue in the near future, since urea is less expensive to produce and transport because of its higher concentration of nitrogen. Urea contains 46% nitrogen compared to 34% for ammonium nitrate. While the present cost advantages favor increased use of urea, questions are often raised about its availability to crops compared to other nitrogen sources and its potential for loss when applied to the soil surface and not incorporated by tillage or irrigation. Chemical reactions of urea and ammoniacal nitrogen (ammonia and ammonium) in soil, and soil, climate, and management factors that affect the performance of urea need to be understood for proper use.

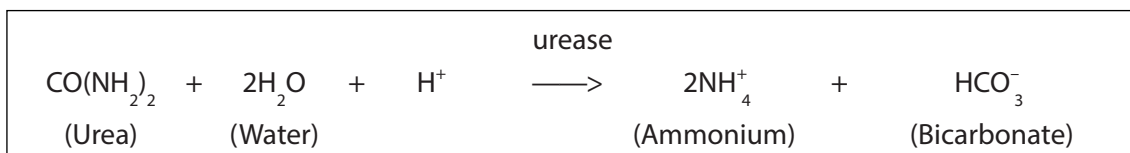
Reactions of Urea in Soil

Urea applied to the soil reacts with water and the soil enzyme urease and is rapidly converted to ammonium. This conversion, shown with the chemical reaction below, is called urea hydrolysis.

In this reaction, hydrogen ions (H^+) are consumed, causing the soil pH near the fertilizer to rise. If the pH rises above 7, a significant amount of gaseous ammonia can form in soil for a few days following urea application. When urea is surface-applied, the formation of ammonia at the soil surface from urea hydrolysis may allow some ammonia to be lost, and if urea is banded with the seed, some plant damage may occur because of ammonia toxicity. The severity of both processes depends largely on the concentration of ammonia formed in the soil.

The concentration of ammonia in the soil from urea hydrolysis depends on a number of factors. The most important are:

- 1) The rate of urea applied. Larger urea applications generally result in more hydrolysis and higher ammonia concentrations in soil. Band applications also concentrate the urea in smaller volumes of soil, which can result in more ammonia formation at the site of fertilizer placement; however, this does not mean that ammonia loss will be greater from surface-banded urea, since the hydrolysis rate may be reduced (see number 3).
- 2) The pH at the soil surface for the first three to five days following urea application. The higher the pH during this time, the more ammonia will be formed. Soils vary in their ability to resist the increase in pH due to the amount of hydrogen ions they contain. Soils with relatively large amounts of clay and organic matter, and low pHs before urea is applied have relatively large amounts of hydrogen ions. Less ammonia will be formed on these soils. At the other extreme, soils that are sandy and low in organic matter, especially those with a high



pH, allow more ammonia to be formed from urea hydrolysis.

- 3) The speed (rate) of urea hydrolysis in soils. Fast urea hydrolysis reduces the time available for urea and ammonium (and any gaseous ammonia) to diffuse deeper into the soil when surface-applied (or away from the seed in case of seed-placed urea). When the time for diffusion into the soil is reduced, the ammonium will be more concentrated at the surface, the pH will be higher, and more ammonia will form. The factors affecting the rate of hydrolysis that are most likely to change from field to field include the amount of urease enzyme in the soil, soil temperature, and soil moisture. Since band application reduces the contact between fertilizer and soil urease, this method slows the rate of urea hydrolysis.

The combination of large amounts of urease, high temperature, and moist soil favors fast urea hydrolysis, which results in more ammonia formation. Each of the three factors affecting ammonia formation will be discussed in more detail below.

Weather Conditions at the Time of and Shortly after Application

Two weather-related factors, temperature and moisture, greatly affect urea hydrolysis rates and ammonia loss from surface-applied urea fertilizers. Knowledge of how these two factors affect loss of ammonia can be used to the farmer's advantage in making fertilizer application decisions.

If a choice is possible, apply urea fertilizers when temperatures are cool. Wheat and cool-season grasses can be fertilized in late winter to good advantage, rather than late spring when temperatures begin to rise. Even though losses are usually not large with later application, the early application is preferred.

Although application under cool or cold conditions is preferred, there is potential for loss of fertilizer in storm runoff should an unusual winter rainstorm or quick snowmelt occur when soils are frozen. Poor fertilizer performance has been observed in a few instances when these somewhat rare weather events occurred. A study of nitrogen loss in runoff when 1 inch of sprinkler irrigation water was applied to a frozen soil (with air temperature about 35 degrees Fahrenheit) just following application of urea and ammonium nitrate found that losses in runoff water were about equal for both sources, at 25% of the fertilizer applied. Therefore, it is best to avoid application of fertilizer to frozen soils, if there is a high probability of rapid warming conditions with rainstorms and

runoff. If the surface soil is partially thawed at fertilizer application time or if it thaws soon after application, the fertilizer will dissolve and diffuse into the soil within a day or two. If storms and runoff then follow, losses will be small.

Application is also better under dry surface soil conditions than under wet conditions to avoid ammonia loss. Usually, the surface of a well-drained soil dries quickly in Kansas weather. Soils with high water tables, however, may stay moist near the surface for longer periods of time. Lower parts of a field that stay wet for long periods of time may also experience some problems with ammonia loss, whereas well-drained areas of a field may not. Somewhat higher rates of application on these wetter areas could increase production by offsetting some nitrogen loss.

Management Practices Affecting Ammonia Loss

When urea fertilizers are top-dressed to winter wheat in late winter or broadcast and incorporated for production of any crop, studies have shown good crop performance and little or no loss of ammonia. Low losses from urea top-dressed to wheat are due largely to the low soil temperatures typical at the time when top-dressing is usually done. For other crops, incorporation of urea by tillage on the day of application or leaching of the fertilizer into soil by $\frac{1}{2}$ inch or more of rain or irrigation water will generally eliminate ammonia loss. Even when conditions are considered ideal for ammonia loss (lots of urease, warm temperatures, and moist soil), losses are unlikely to exceed 20% of the surface-applied urea. Injection of urea-containing fertilizer solutions into irrigation water also results in little ammonia loss. The effectiveness of this method of fertilizer application depends on how uniformly the water (and therefore the urea) can be applied across the field. The following describes some cases in which ammonia loss from urea fertilizers may be a problem and suggests practices to reduce losses.

No-Till Crop Production: Ammonia loss from surface-applied urea is likely to be greater for no-tillage than for conventional tillage systems. Continued no-till crop production results in a layer of crop residue on the soil surface that can enhance ammonia loss from surface-applied urea or UAN solution. A layer of partially decomposed or undecomposed crop residue can increase loss because: 1) The urease activity of this residue layer is higher than in underlying soil. 2) Undecomposed crop residue may reduce diffusion of fertilizer into the soil. 3) Crop residue at the surface often increases the water content of the surface soil

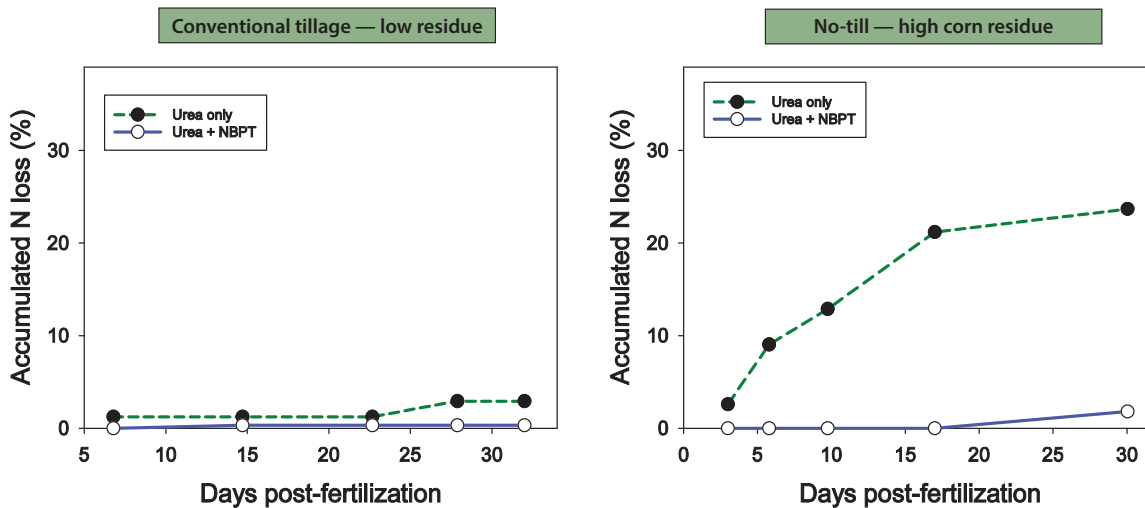


Figure 1. Cumulative nitrogen loss from surface urea application during a period of 30–35 days with no precipitation in the winter. Data from Manhattan, Kansas (Perin et al.).

layer, which can increase ammonia loss as discussed earlier. The layer of partially decomposed crop residue can tie up nitrogen temporarily, making it less available to the crop as discussed below.

Cumulative nitrogen loss by volatilization can be significant even under low temperatures, as shown in a 2020 study in Kansas (Figure 1). These types of losses occur in smaller increments but extended over time with the lack of precipitation to incorporate the nitrogen. This study showed the effect of tillage and the presence of heavy residue on ammonia volatilization. Also, urease inhibitors (NBPT) reduce urease activity and minimize volatilization. Urease inhibitors can delay the process of urea hydrolysis, providing an opportunity for rainfall to incorporate the nitrogen into the soil.

In many cases, UAN solution may be mixed with herbicides and applied together preplant or sometimes after planting. The loss of ammonia from this mixture after application will not be affected by the herbicide and will still be determined by the factors discussed here for urea-containing fertilizers applied alone.

No-till row crops fertilized with surface-applied urea or UAN solution have sometimes yielded less than crops fertilized with other nitrogen sources, which do not lose ammonia when applied to neutral pH or acid soils. However, sufficient evidence has been collected to show that the differences in crop response to the various nitrogen sources are not always due to differences in ammonia loss from the various fertilizers. Decomposing crop residue can tie up surface-applied nitrogen (making it unavailable to crops), whereas nitrogen placed below the decomposing crop residue is not as susceptible to this problem. Therefore, nitrogen fertilizer banded below the soil surface will often be

more available than surface-applied nitrogen, even with non-urea fertilizer sources.

An alternative method of applying liquid nitrogen sources with little or no tillage is to apply the fertilizer in surface bands or strips. When differences occur, this method of placement provides better nitrogen availability to row crops or small grains than surface broadcast applications, but not as good as fertilizer injected below the soil surface.

Cool-Season Grass Fertilization: Grasses such as brome grass or tall fescue cover the soil surface with a layer of partially decomposed litter. These residues are comparable to no-till cropland with regard to the amount of organic litter on the soil surface. When urea fertilizers are applied to these grass sods, they are potentially subject to ammonia loss much the same as when urea fertilizers are applied in no-till crop production. They are also subject to nitrogen tie-up in this decomposing litter. Other non-urea sources of nitrogen may also be tied up in this litter.

When urea fertilizers are not used efficiently by forage grasses, it is difficult to determine in traditional soil fertility studies whether poor use of the applied nitrogen is due to ammonia loss or nitrogen tie-up. An additional complication is the root systems of these forage grasses, which are quite large and serve as storage reservoirs for much nitrogen. However, in most cases there is little ammonia loss from urea surface-applied to cool-season grasses on well-drained soils in Kansas. Over several years of fertilization, the production of forage using urea will be the same as that from using ammonium nitrate, when applied during the recommended time from November through early March.

When UAN solution is used as the nitrogen source, it has resulted in better performance (about 15% more forage production) when it is applied in surface bands rather than broadcast. If surface bands are used, however, they should be spaced no more than 10 to 12 inches apart in order to obtain maximum forage production.

Summary

Ammonia can form in soils following the application of urea fertilizers. If urea is surface-applied and not incorporated by tillage or does not receive ½ inch of rainfall or irrigation within 24 hours, there is some potential for ammonia loss. In Kansas, this potential is generally small for many surface-applied urea fertilizers. Urea may be safely applied for the following conditions when tillage is not possible:

- a) Wheat top-dressed in winter when soil temperatures are cool or cold;

- b) Cool-season grasses fertilized during cool weather from November through March on well-drained soils;
- c) Early spring application for summer crops on clean-tilled fields.

Enough ammonia loss to reduce crop yields can sometimes occur under the following conditions:

- a) No-till crop production when urea is applied to a warm and moist soil surface heavily covered with crop residue. Little loss occurs if the surface is dry.
- b) Soils kept wet by water tables near the soil surface. These are most likely to be lower-lying areas of fields following very wet weather.

References

Perin, V., Santos, E.A., Lollato, R., Ruiz Diaz, D.A., Kluitenberg, G.J. 2020. Impacts of ammonia volatilization from broadcast urea on winter wheat production. *Agronomy Journal*. 2020; 112: 3758–3772. <https://doi.org/10.1002/agj2.20371>

Dorivar Ruiz Diaz

Soil Fertility and Nutrient Management Specialist
Department of Agronomy

Brand names appearing in this publication are for product identification purposes only. No endorsement is intended, nor is criticism implied of similar products not mentioned.



Publications from Kansas State University are available at: bookstore.ksre.ksu.edu

Publications are reviewed or revised annually by appropriate faculty to reflect current research and practice. Date shown is that of publication or last revision. Contents of this publication may be freely reproduced for educational purposes. All other rights reserved. In each case, credit Dorivar Ruiz Diaz, *Management Practices Affecting Nitrogen Loss from Urea*, Kansas State University, June 2021.

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Director of K-State Research and Extension, Kansas State University, County Extension Councils, Extension Districts.