

Urea, an organic compound, occurs naturally in animals and some plants. It was first identified over 200 years ago and was prepared synthetically in the laboratory in 1828. Industrial facilities to produce urea in large commercial quantities were developed early in this century. Urea is produced by reacting ammonia with carbon dioxide at many 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 percent nitrogen. It may also be sold as a 32 percent 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 potash is needed also, dry muriate of potash may be dissolved in this mixture to make a complete liquid fertilizer.

The tonnage of urea fertilizer sold in Kansas has increased markedly since 1981-82, largely because of the increase in dry urea sales. The total tonnage of nitrogen (both dry urea and ammonium nitrate) changed little from 1981-82 to 1985-86, but the proportion supplied as urea grew during this period from 31 to 79 percent. 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 percent nitrogen compared to 34 percent for ammonium nitrate. While the present cost advantages favor increased use of urea, questions are often raised about its availability to crops compared to ammonium nitrate and its potential for loss when applied to the soil surface and not incorporated by tillage. 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.

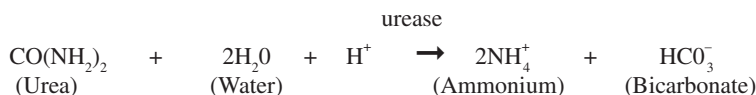
Reactions of Urea in Soil

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 always be greater from surface-banded urea, since the hydrolysis rate may be reduced (see 3 on next page).
- 2) The pH at the soil surface for the first 3 to 5 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 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 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 in the spring when temperatures begin to warm up. 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 one inch of sprinkler irrigation water was applied to a frozen soil (with air temperature about 35°F) just following application of urea and ammonium nitrate found that losses in runoff water were about equal for both sources, at 25

percent 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 0.5 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 percent 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. Other processes that reduce nitrogen fertilizer availability are also discussed.

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 will result 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 undecom-

posed 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 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.

In many cases, UAN solution may be mixed with herbicides and applied together preplant or sometimes after planting the crop. 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 a source of nitrogen such as ammonium nitrate, which does not lose ammonia when applied to neutral pH or acid soils. Such data from a 1986 study at the KSU Agronomy Farm are shown in Table 1. In this study, yields of grain sorghum averaged across nitrogen rates and tillage methods were 97 bushels per acre for surface-applied UAN solution, but 104 bushels per acre when ammonium nitrate was surface applied. Since ammonia is not lost from ammonium nitrate when applied to such an acid soil, the lower yields with broadcast UAN indicate that some ammonia may have been lost, thereby lowering crop yields. However, when UAN solution was knifed 5 to 6 inches below the surface on 30-inch centers, the yields were even higher than for broadcast ammonium nitrate (111 bushels per acre). The yields for the treatments correlate well with the percent nitrogen in the plant leaves. Higher nitrogen in leaves indicates better nitrogen nutrition in the plant because of better fertilizer availability. Similar results have been obtained at other study locations in Kansas and other states.

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. In the above study, the knifed UAN treatment was better than the broadcast UAN in part

because of less fertilizer nitrogen tie-up by decomposing crop residue. The amount of nitrogen fertilizer tied up by decomposing crop residue will depend on a number of factors, but two are especially important:

- 1) The nitrogen content in decomposing crop residue. The lower the nitrogen content, the greater the nitrogen fertilizer tied up.
- 2) The amount of crop residue per acre. The greater the amount of residue, the more nitrogen can be tied up.

Although the fertilizer nitrogen tied up through decomposition of residue may later be released for crop use, our studies indicate that it is released very slowly, and very little will be released in the same cropping season. In summary, nitrogen fertilizer banded below the soil surface will often be more available than surface-applied nitrogen, even with non-urea fertilizer sources.

An alternate 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 sys-

Table 1. Average yield of grain sorghum produced by fertilization with three nitrogen source/placement method combinations at the KSU North Agronomy Farm (1986).

N Source	Method	Yield	Flag Leaf N
		Bu/A	Percent
Ammonium Nitrate	Broadcast	104	2.19
UIAN	Broadcast	97	1.97
UAN	Knife	111	2.28

tems of these forage grasses, which are quite large and serve as storage reservoirs for much nitrogen.

Some forage fertilization studies have compared the production of bromegrass and fescue on plots receiving either urea or ammonium nitrate. In a study with brome, these two sources were applied to their respective plots for several years, and forage production was measured. In the second year of the study, forage production was better with ammonium nitrate than urea, but in the other years of the study, production was equal with the two sources. Total forage production for the seven years of the study also was about equal for the two sources of nitrogen. Other research has found better carry-over of nitrogen from urea fertilization than from ammonium nitrate for use by the next year's forage crop. In summary, 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 percent 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 application of urea fertilizers. If urea is surface-applied and not incorporated by tillage or does not receive one-half inch of rainfall or irrigation within 24 hours, there is some potential for ammonia loss. In Kansas, this potential is generally small for many of our 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.

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