

Section G

How to properly apply nitrogen fertilizer

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As previously discussed, implementation of the 4Rs of nitrogen management is essential for protecting groundwater quality. Proper nitrogen management includes applying the **Right** nitrogen rate, the **Right** source, at the **Right** time, and the **Right** placement. The primary goal of nitrogen best management practices is attaining high nitrogen use efficiency (greatest yield with least amount of nitrogen). This assures the most effective use of nitrogen fertilizer.

Good nitrogen management requires an understanding of:

- How nitrogen is used by the crop
- When nitrogen is used by the crop
- What environmental influences affect nitrogen use by the growing crop
- How management of nitrogen and irrigation water affect the leaching of residual nitrate

Corn nitrogen uptake across the growing season

The rate of nitrogen uptake depends on the stage of crop development. *Figure G-1* shows that early in the growing season the plant demand for nitrogen is low. During the late vegetative and early reproductive stage the demand for nitrogen is high. Application of nitrogen just before or during the time of most rapid nitrogen uptake assures the most efficient use of nitrogen by the crop.

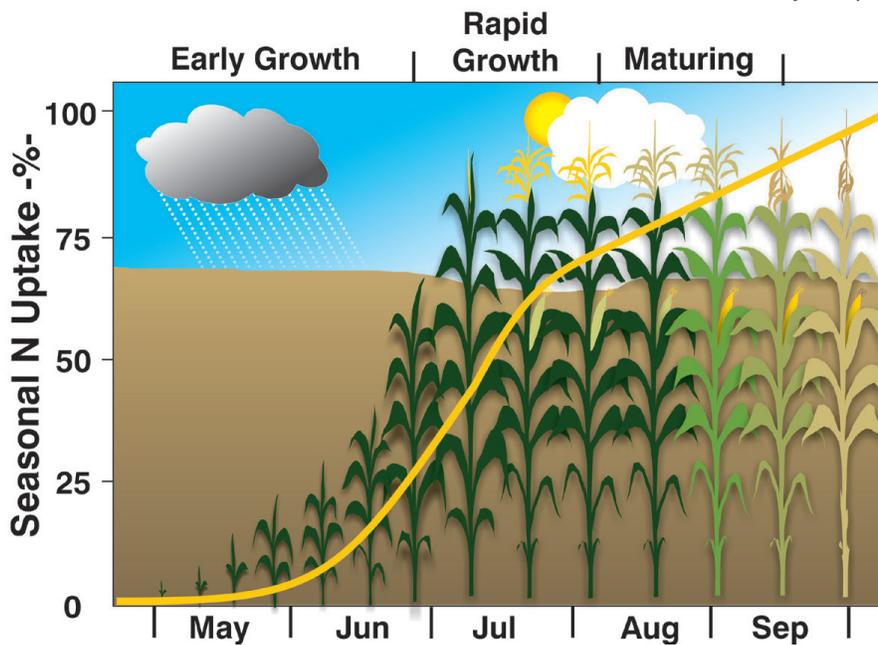


Figure G-1. Cumulative nitrogen uptake curve for a growing season.

The potential for leaching of nitrate by precipitation is greatest in the spring before the crops start growing rapidly (*Figure G-2*). On average, the highest precipitation in Nebraska occurs in May and June. During this time crop water use is low and very little nitrogen uptake occurs. If the water content of the root zone is at or near field capacity, the probability is high that at least part of the water entering the soil will move all the way through the root zone, taking nitrate with it. The potential for springtime leaching loss can be reduced by careful scheduling of the last irrigation of the previous season to leave the root zone drier over the winter, and by proper selection of nitrogen fertilizer type and timing of application. When the nitrogen fertilizer rate is below optimum, yield is lost. When the rate is above optimum, excess residual nitrogen can remain and be leached before the next growing season. Such losses contribute to groundwater contamination.

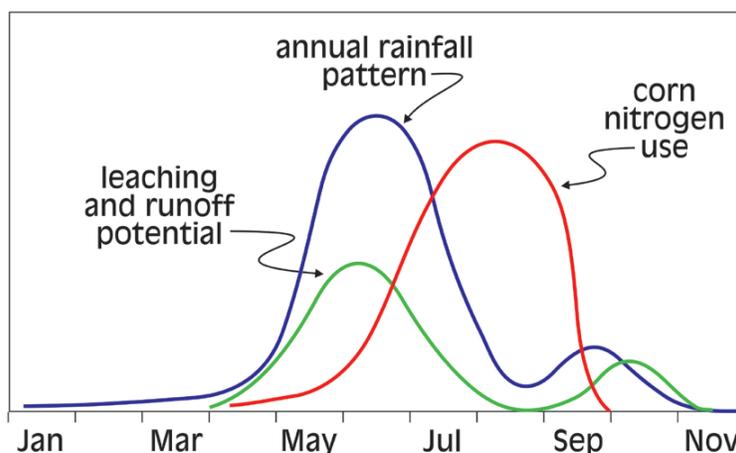


Figure G-2. Depiction of typical nitrogen uptake and the potential for nitrate leaching and runoff caused by precipitation during the growing season.

Nitrogen use efficiency

The amount of nitrogen applied has a very large effect on nitrogen use efficiency. Efficiency is a measure of the crop's ability to use applied nitrogen. **Nitrogen use efficiency is described in Section B as the bushel of grain harvested per pound of nitrogen applied.** High nitrogen use efficiency happens only when the nitrogen application is near the minimum needed to obtain optimum yield and is applied near or during the rapid uptake period. Low nitrogen use efficiency can result when nitrogen applications are applied well before the crop needs it and/or are excessive.

Figure G-3 shows a typical yield response of corn to nitrogen application. In this figure near-maximum yield and optimum nitrogen use efficiency are gained from rate B. Maximum profit is slightly to the left of B since fertilizer is not free. There is little increase in yield above this rate. If farmers reduce their nitrogen application to rate C, nitrogen use efficiency may be slightly higher than at point B, but there will be a moderate yield loss. With any nitrogen application (or even none) there is some level of soil residual nitrate. As nitrogen is added up to the point of maximum crop response to nitrogen, the residual soil nitrate level does not increase very much above where little or no nitrogen is applied. However, beyond the point of maximum response from applied nitrogen, soil residual nitrate increases rapidly and nitrogen use efficiency declines.

At nitrogen Rate A there is no gain in yield but there is a significant rise in the residual nitrate and a large decrease in nitrogen use efficiency. This extra nitrogen residual over and above the point of optimum use efficiency and will leach if water passes through the soil.

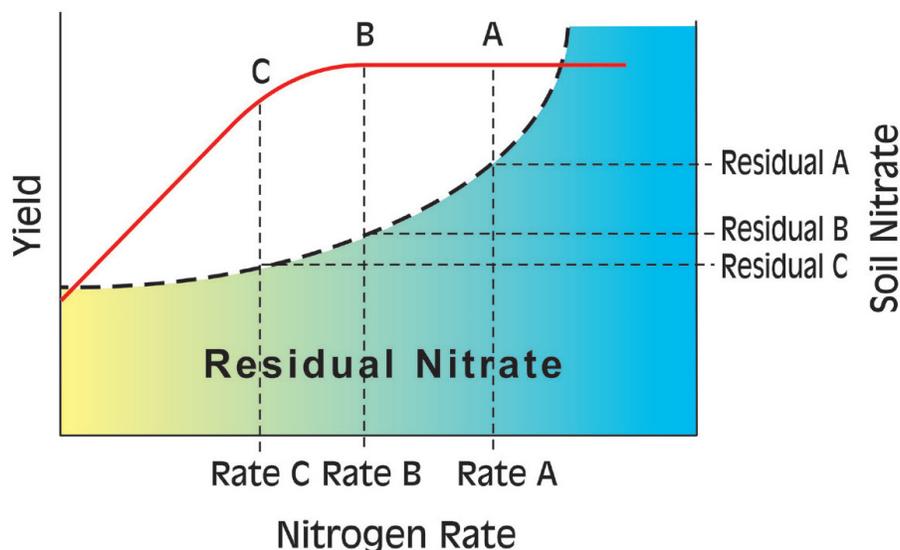


Figure G-3. Impact of excessive nitrogen application rate on soil residual nitrogen.

Example: Five-year average of nitrogen applied, yield, and residual soil nitrogen.

Point	Nitrogen applied lb/acre	Yield bu/acre	Residual soil nitrate-nitrogen, lb/acre
C	90	168	73
B	140	176	76
A	190	176	104

In this example presented above, the yield for the 90 lb/acre average nitrogen application corresponds to point C in *Figure G-3* with a yield of 168 bu/ac and residual nitrate-nitrogen was 73 lb/ac. When the nitrogen application was increased from 90 to 140 lb/ac, the grain yield increased by 8 bu/acre and the residual nitrate-nitrogen increased by 3 lb/ac. This corresponds to point B in *Figure G-3*. A further increase in nitrogen applied resulted in no additional yield, but the residual nitrate-nitrogen went up. This corresponds to point A in *Figure G-3*.

Timing

Crops have their greatest daily nitrogen use rate between the V6 and VT growth stages (*Figure G-1*). During this time the crop takes up at least half of its total nitrogen requirement. Nitrogen applications during this period will generally be more efficient because there is a short time between application and uptake. This limits exposure of the nitrogen to leaching by excess precipitation or irrigation. The relative ranking of nitrogen use efficiency for different application

timings is summarized in *Table G-1*. These rankings are correct for irrigated production. In rainfed areas that lack adequate moisture in late May and June, waiting to apply nitrogen may decrease nitrogen efficiency. Decreased efficiency results since nitrogen will not move to the roots in dry soil.

Table G-1. Nitrogen use efficiency according to timing of application.	
Highest	Sprinkler applied during rapid growth
↓	Sidedress just before rapid growth
↓	Postplant incorporated
↓	Preplant incorporated
Lowest	Fall application for next year's crop

Any nitrogen application made long before the rapid growth period will have a higher probability of loss and, consequently, there will be less available for uptake by the crop. Fall application and early spring application in some years on any soil, or in most years on sandy soils can be a poor choice. In these situations nitrate-nitrogen has a lot of time to be leached from the root zone or to be denitrified.



Figure G-4. Average soil temperature in the fall at Clay Center, NE.

As the soil temperature decreases in the fall, the activity of soil microorganisms declines. At a temperature of 50°F in the top few inches of the soil, the rate of nitrification of ammonium drops to about 20% of its maximum rate in a warm soil. As long as the soil stays cold, only a limited amount of the ammonium will nitrify and be subject to leaching. Figure G-4 shows that, on average, a soil temperature of 50° F is reached around Oct. 15 in South Central Nebraska. For this reason, it is recommended that fall applications of anhydrous ammonia wait until after Oct. 15. However, it is best to check local soil temperatures first. Check the UNL

CropWatch site for soil temperature progression in your area (cropwatch.unl.edu/web/cropwatch/cropwatchsoiltemperature). Of course, as the soil warms in the spring, nitrification rate increases again so fall applied nitrogen is subject to leaching by spring precipitation and therefore it is best to avoid fall applications if possible.

Sandy soils have a greater leaching potential during the growing season than finer textured soils. Under sprinkler irrigation on sandy soil one of the best choices for nitrogen fertilizer timing is to use a small amount of nitrogen as a starter, with the bulk of the nitrogen applied either as sidedress, or through the sprinkler irrigation system.

Placement

Nitrogen placement can affect nitrogen use efficiency. Below are some points to help make wise placement decisions.

- Subsurface or incorporated nitrogen has a lower opportunity for surface runoff losses than surface broadcast application.
- Surface-applied fertilizer should be incorporated with irrigation to reduce surface runoff and volatilization.
- If nitrogen is surface applied, banding reduces potential volatilization loss. Using a urease inhibitor will also reduce volatilization loss.
- Nitrogen applied with the planter will provide early season nitrogen but caution needs to be exercised to avoid salt injury and/or ammonia toxicity.
- With furrow-irrigated ridge-till, placement in a band on the side of the ridge, at least 6 in from the row, can reduce downward percolation of nitrogen.
- Small consecutive applications of nitrogen through the sprinkler system can improve nitrogen use efficiency.
- If the total nitrogen applied is greater than crop needs, nitrogen use efficiency will be reduced and potential nitrate loss to groundwater will be increased, regardless of timing or placement.

Selecting nitrogen sources to protect groundwater quality

Environmental concerns related to nitrogen fertilizer sources are based on leaching potential. Nitrate-nitrogen will move with the soil water that passes through the root zone. Ammonium sources will attach to soil and organic matter and resist leaching. However, nitrification will change ammonium forms to nitrate quite rapidly. Some leaching potential can be overcome by the use of nitrification inhibitors. Inhibitors are substances added to nitrogen fertilizer that slow the conversion from the non-mobile ammonium form to the mobile nitrate form. When nitrification inhibitors are used, significant leaching of applied fertilizer may be reduced or prevented if a heavy precipitation event occurs close to application. Inhibitors will not prevent the leaching of residual nitrate that is already in the soil at the time fertilizer is applied.

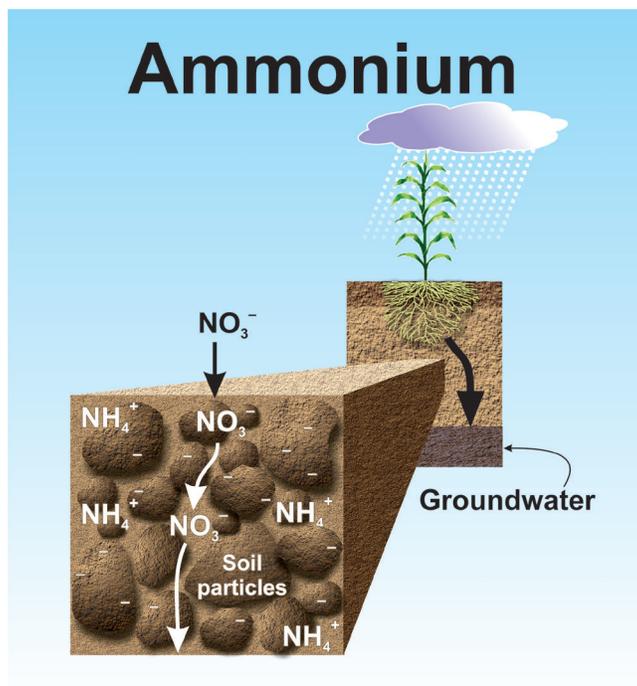


Figure G-5. Depiction of the attachment of positively charged ammonium molecules to negatively charged soil particles, which prevents leaching of N in the ammonium form while allowing leaching in the nitrate form.

Both the ammonium and nitrate forms of nitrogen are available to the crop. However, anhydrous ammonia is the only form of nitrogen fertilizer that is totally nonleachable immediately after application. Urea and nitrate can leach right after application but urea will be converted to ammonium in a very few days. A potential for volatilization loss exists from surface applied nitrogen and runoff from heavy rains can transport nitrogen that has not been mixed into the soil. Incorporation of nitrogen and timely applications will provide good crop nutrition from all nitrogen sources. (Details in Section D.)

Enhanced efficiency fertilizers

Decisions on which fertilizer to use, when to apply it, and how much to apply interact with which nitrogen source is chosen. Making a nitrogen management plan to reduce risks that threaten the nitrogen use efficiency will contribute to profit and environmental protection. The choices for a nitrogen source have expanded over the last few years because of several technologies designed to improve nitrogen use efficiency by addressing various sources of potential nitrogen losses. These are collectively called Enhanced Efficiency Fertilizers (EEF). However, many of them have different modes of action so it is important that they be understood so they can be used under the appropriate situations.

As discussed several times in this publication, nitrate is the form of nitrogen that has the most potential for loss in the soil, and urea on the surface of the soil has the potential for volatilization with ammonia being lost to the atmosphere. Most of the products available address the need to

slow the availability of nitrate, or protect urea from the process called hydrolysis, which frees the ammonia molecule from the urea compound.

Table G-2 lists the many compounds and the nitrogen process affected by the use of the chemical. Section D discusses these processes in detail. The major concept critical for effective use of these products is that there has to be risk of loss. Split applications and timing when corn needs the nitrogen are excellent management strategies. Table G-3 lists some of the situations that might benefit from the use of the materials in Table G-2.

Nitrogen Products*	Common Product Names	Process Affected
Dicyandiamide (DCD)	Guardian®	Nitrification
2-chloro-6 (trichloromethyl) pyridine (Nitrapyrin)	N-Serve®, Instinct®	Nitrification
N-butyl-thiophosphoric triamide (NBPT)	Agrotain®	N volatilization
NBPT + DCD	Agrotain®Plus, SuperU®	Nitrification, N volatilization
Triazone + NBPT	N-Pact®	N release, volatilization
Malic+ itaconic acid co-polymer with urea	Nutrisphere®,	Nitrification, N volatilization
Polymer-coated urea (PCU)	ESN®, Polyon®, Duration®	N release
Sulfur-coated urea (SCU)	SCU	N release
Polymer + SCU	Tricote, Poly-S®	N release
Urea formaldehyde	Nitroform®	N release
Methylene urea	Nutralene®, CoRoN®, NFusion®	N release
Triazone	N-Sure®	N release
Methylene urea + triazone	Nitamin®, Nfusion®	N release

Situation	Risk	Approaches
Fall application to silt loam or clay loam soil	Denitrification, leaching	NH ₃ injection with nitrapyrin
Preplant application to silt loam or clay loam soil	Denitrification, leaching, runoff, volatilization	NH ₃ with nitrapyrin; PCU; Urea with NBPT; Methylene urea; UAN knife in
At-planting surface application with no-till	Volatilization, runoff, denitrification	Urea with NBPT; PCU; Methylene urea; UAN with NBPT
Sidedress application or fertigation	Wet weather preventing timely application	Preplant or at-planting knife application, using inhibitors or slow/controlled release formulation

Real time N adjustments

It is well known that improving N use efficiency reduces the amount of N that can potentially leach into groundwater supplies. However, management of N is a major challenge because of the unknown factors related to weather such as air temperature and precipitation levels. To minimize the risk associated with having the necessary amount of N available to the crop, researchers have worked to develop tools that can be used to help make N management decisions during the growing season. Handheld chlorophyll meters and multispectral sensors mounted in aircraft or on high clearance equipment can provide in-season measures of N sufficiency. These tools provide the potential to fine-tune N management decisions by reacting to changing crop and weather conditions during the growing season.

Leaf chlorophyll meters

Research over the past decade indicates a close link between leaf chlorophyll content and leaf N content in corn, which makes sense because the majority of leaf N is contained in chlorophyll molecules. Chlorophyll meters (*Figure G-6*) enable field managers to quickly and easily measure potential photosynthetic activity, which is closely linked to leaf chlorophyll content, crop N status, and leaf greenness. Essentially, the meter exposes a small portion of the leaf to abundant light and measures how much was reflected by chlorophyll in the leaf. The chlorophyll meter records the reflection of light in the photosynthetically active waveband of plant leaves and can be used to monitor crop N status and potentially increase N use efficiency.



Figure G-6. Handheld chlorophyll meter used to monitor nitrogen status of corn plants.

The chlorophyll meter has several advantages over other tissue testing methods. Samples don't need to be sent to a laboratory for analysis, saving time and money. The use of the chlorophyll meter is nondestructive and permits repeated measurements throughout the growing season. Plants produce as much chlorophyll as possible until something else becomes limiting. As such, luxury consumption of N does not increase leaf chlorophyll content. This causes meter readings to reach a plateau when N availability is adequate, regardless of how much extra N is taken up by

the plant. Using a chlorophyll meter to monitor leaf greenness throughout the growing season can signal the approach of a potential N deficiency early enough to correct it without reducing yields. This approach makes chlorophyll meters especially useful where additional N can be applied through sprinkler irrigation systems (fertigation) or with high-clearance equipment such as a sprayer.

Many factors affect chlorophyll meter readings. Variety or hybrid differences can greatly affect meter readings in that some adequately fertilized corn and sorghum hybrids are darker green than others. The stage of growth can affect leaf greenness, as can recent environmental conditions such as temperature, moisture stress, and sunlight. Plant diseases, nutrient deficiencies, and nearly any other kind of plant stress can affect the plant's ability to produce chlorophyll, thus affecting leaf greenness. Because the chlorophyll meter is affected by so many things, it is impossible to say that a given meter reading indicates sufficient N. Meter readings mean very little by themselves and must be calibrated for each field, soil, hybrid, and environment to make use of the readings. The best way to calibrate the meter is to create a set of adequately fertilized reference strips in each field every year.

The chlorophyll meter enhances a producer's ability to make N management decisions but does not replace other aspects of good N management. Environmentally and economically sound N management must begin with a representative soil sample and a realistic value for expected yield. It is suggested that at least one-half to three-quarters of the total N fertilizer be applied to the entire field prior to the six-leaf stage to ensure the chlorophyll meter technique is effective. If a corn plant experiences moderate to severe N stress in the early growth stages, the size of the ear and number of kernels may be limited, so additional N fertilizer applied later will not allow full recovery of grain yield.

The chlorophyll meter technique allows fine-tuning N management to field conditions and reduces the risk of yield limiting N deficiencies. The meters can also help prevent the over-application of N fertilizers, thereby reducing potential leaching. Producers should recognize this as another tool that may complement, but does not replace, other aspects of sound N management.

Additional information on how to specifically use chlorophyll meters use can be found in UNL NebGuide G1632, *Using a Chlorophyll Meter to Improve N Management*.

Crop canopy sensors

Recent advances in precision agriculture technology have led to the development of ground-based remote sensors (or crop canopy sensors). These sensors essentially measure the amount of light reflected off of the crop canopy. Light reflectance has been used for some time to gauge crop status in terms of nutrient and water stress. However, ground-based sensors are novel in that they have their own light source (active sensor) instead of relying on sunlight (passive sensor). Previously reflectance was collected via airborne or satellite sensors. These had several limitations, including expense and weather-related issues such as cloud cover that could greatly limit the effectiveness of these sensing techniques. Active sensors have their own source of light energy and allow for the determination of reflectance measurements at specific times and locations throughout the growing season without need for ambient illumination or flight concerns.



Figure G-7. Onboard plant chlorophyll sensors used to adjust nitrogen fertilizer application.

Crop canopy sensors are relatively small in size and operate by directing sensor produced visible light (VIS) as well as near infrared (NIR) light at the plant canopy of interest (some sensors are configurable allowing for other wavelengths of light to be used as well). The amount of VIS and NIR light that is reflected off the plant canopy is measured and specific indices can be calculated depending on the variable of interest (i.e. N stress). The visible light reflectance is primarily dependent on the chlorophyll contained in the palisade layer of the leaf and the NIR reflectance depends on the structure of the mesophyll cells and the cavities between these cells.

A strong relationship exists between leaf chlorophyll concentration and leaf nitrogen (N) concentration. Therefore, greater leaf area and green plant biomass levels result in higher reflectance and higher subsequent sensor readings. Because these variables are directly related to the N content of the plant, higher values relate with higher plant N content. These properties allow sensors to be a valuable tool in determining the relative plant N status by comparing the plants with sufficient N to plants with an N deficiency.

Crop canopy sensors are used much in the same way as the aforementioned chlorophyll meters. However, the crop canopy sensors do not need to be directly attached to the leaf. The crop canopy sensors are placed approximately 2 feet above the canopy (depending on manufacturer recommendations) and collect data as the sensor moves through the corn (usually attached to a high clearance tractor). This allows the crop canopy sensors to cover a lot of ground in a short amount of time, thus recommendations for supplemental N fertilizer can be made on a field scale in relatively short order.

Generally the sensors would be used at the V10-V12 corn growth stages (high clearance equipment is needed for effective crop canopy sensor use). Readings would first be collected on an area of the field where crops exhibit no visual deficiencies due to N. This is called the reference strip and is set up by the producer early in the growing season by applying N in quantities that will not be limiting to the corn by the V10-V12 growth stages. Next, sensor readings are collected on the area of the field where side-dress is needed (usually called the target area). Sensor readings from the reference area and target area are then put into an algorithm (several are available depending on sensor type, use, etc.) that calculates a recommended N rate. This process can be done on the fly where sensor readings and calculations are made rapidly and variable rate N fertilizer is applied all in the same pass.

Research has shown that crop canopy sensors can significantly reduce the amount of N that is applied while still maintaining yields. This can greatly increase nitrogen use efficiency and has the potential to greatly reduce potential leaching of N into groundwater. Unfortunately, the process has been shown to be site-specific and the sensors are still relatively expensive. However, there are several co-ops and custom applicators now offering this method of N application to farmers. It is expected that the use of crop canopy sensors will increase as they become more cost effective over time. As with the chlorophyll meters, producers should recognize crop canopy sensors as a tool that can complement sound N management.

Nitrogen fertilizer cost

Cost per pound of nitrogen, availability, supplier services, application cost, storage cost, and transportation all influence the crop grower's decision on which nitrogen fertilizer to buy and from which supplier. Cost per ton can be converted to a price per pound of nitrogen by a quick calculation (prices continually change, numbers given are just an example).

Example: Converting fertilizer cost/ton to nitrogen cost/lb

82-0-0, anhydrous ammonia (82% nitrogen) costs \$315/ton

$$82\% \times 2000 = 1640 \text{ lb nitrogen/ton of anhydrous}$$

$$\$315 \div 1640 \text{ lb} = \$0.19/\text{lb}$$

28-0-0, Urea ammonium nitrate solution (28% nitrogen) costs \$135/ton

$$28\% \times 2000 = 560 \text{ lb nitrogen/ton}$$

$$\$135 \div 560 \text{ lb} = \$0.24/\text{lb}$$

**The most profitable nitrogen application rate is dependent on the price of corn and cost of nitrogen. Adjustments based on these prices are described in EC117, Fertilizer Suggestions for Corn*

More Extension Publications (available at ianrpubs.unl.edu)

EC117, Fertilizer suggestions for corn

EC163, Site-specific nitrogen management for irrigated corn

G1632, Using a chlorophyll meter to improve N management

For More Information

Hergert, G.W., R. Ferguson, C. Wortmann, C. Shapiro, and T. Shaver. 2011. Enhanced efficiency fertilizers: Will they enhance my fertilizer efficiency? *In: 2011 Crop Production Clinics Proceedings*. Pg. 145-148.