



Nitrogen fertilization of corn

Nitrogen (N), an element that literally surrounds us, changes in form and chemistry almost continuously and moves from one location to another without our notice. These changes, keys to the availability of N for uptake by crops, are illustrated in Figure 1. Discussion of their significance to the management of N fertility follows.

NITROGEN FORMS

Nitrogen makes up almost 80 percent of air, but that N may be used by the plant only after it is fixed, or taken from the air, industrially or by certain soil bacteria in association with legumes. The total amount of N in soil is large. In Pennsylvania, soil N averages about 0.14 percent, or about 2,800 lb/acre. Most of this (approximately 98 percent) is found in organic form. Organic N, because of its chemical composition, is very resistant to change and also unavailable for uptake by plants. The mineral forms of N, ammonium (NH_4^+) and nitrate (NO_3^-), make up the remainder of the N in the soil and are available to the plant. Only when converted to mineral ammonium-N by soil microbes (mineralization) does organic N become available for plant uptake. Subsequent microbial action (nitrification) converts ammonium N to nitrate N, the predominant form used by plants.

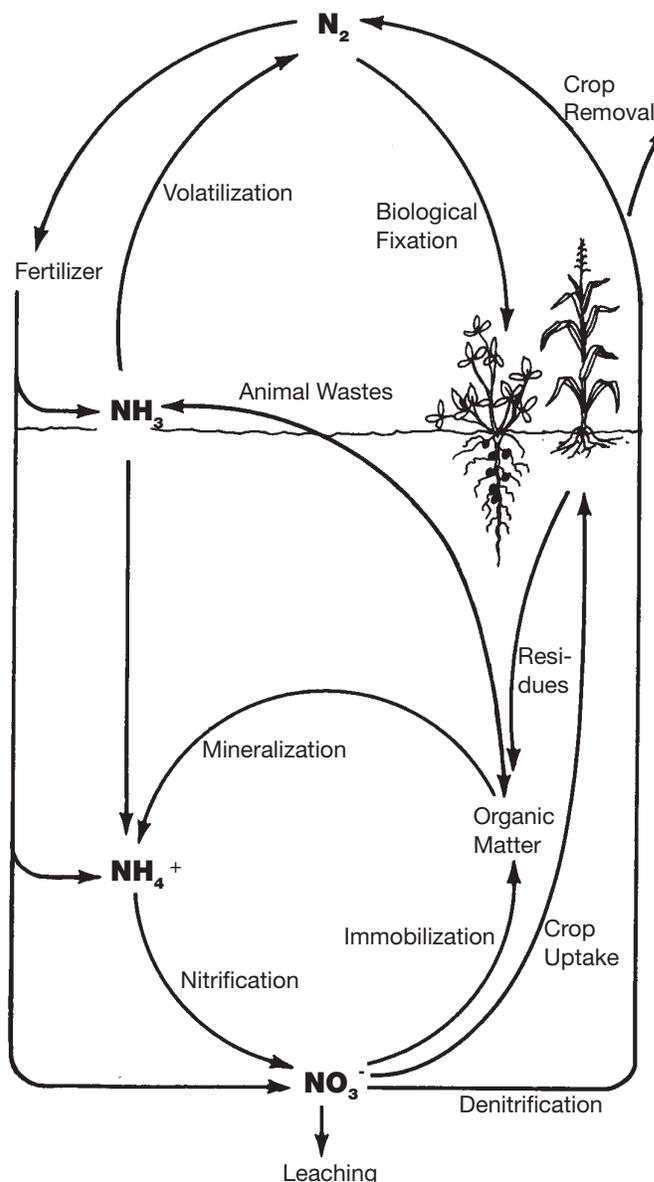
NITROGEN BEHAVIOR IN THE SOIL

In the soil, mineral N is vulnerable to a complex variety of processes brought about by the interactive effects of weather and soil microbes. Some of these processes may cause the loss of available N. Therefore, the quantity of mineral N in soil and the changes in availability are generally unpredictable. Potential routes of N loss are listed below.

Immobilization

Available N may be used by soil bacteria when there is abundant high-carbon, low-N organic matter such as corn stover. The bacteria need additional N and can tie up available N and temporarily prevent its use by plants or its loss by other means. This is most likely in no-till corn production where N fertilizer is surface applied and corn stover is left

Figure 1. Nitrogen cycle: Transformations between N forms.



from previous seasons. Since immobilization is temporary, there is no difference in the optimum N rate among different tillage or no-tillage methods of production. While immobilization can occur with very high rates of bedding added to the manure, this is usually not a problem at typical rates of bedding use.

Denitrification

Bacteria in a saturated soil (because of poor drainage, excessive rainfall, or a field depression where water tends to stand) use the oxygen from nitrate in place of the oxygen from air. As a result, the nitrate N is converted to nitrogen gases (N₂ and N₂O), forms unavailable to plants and easily lost to the atmosphere. Extent of N loss by denitrification is difficult to estimate, but significant losses can occur in less than a week of saturated conditions.

Leaching

Rain water, in excess of what can be held by well-drained soils, leaches down through the soil profile and will carry nitrate with it because nitrate is negatively charged and is not held by the like-charged soil particles. Ammonium has a positive charge and thus is held to soil particles, securing it from being leached. The potential loss of N by leaching is greatest in winter and spring months in well-drained soils.

Volatilization

The urea form of N, found in urea-containing fertilizers and in animal manure, converts to gaseous ammonia, NH₃, and is lost if exposed to the atmosphere by remaining on the soil surface. If the urea is incorporated, this loss is eliminated because the ammonia is converted to ammonium N and adsorbed to the soil particles. Table 1 lists estimates of ammonia volatilization and loss that may occur if incorporation is dependent on rainfall.

Table 1. Urea-N loss by volatilization versus time until incorporation by rainfall.

Rainfall (in)	Days after application	N loss (%)
1/2	2	0
1/2	3	<10
1/4-1/2	5	10-30
0	6	>30

Adapted from R.H. Fox and L.D. Hoffman, *Agron. J.* 73:891-895

Plant uptake

The major removal of any nutrient from soil, however, is through plant uptake, whether the plant is the desired crop or a weed. Uptake eliminates the chance of nutrient loss through any of the above processes. Some conservation of nutrients as well as of soil, therefore, can be achieved with the use of a winter cover crop.

CORN N REQUIREMENT

With so many processes potentially affecting the amount of N available to the crop, some measure of the N availability and the crop N need would help us manage N better. However, because mineral N is sensitive to environmental factors, a chemical analysis of soil before planting cannot indicate the N availability other than right at the time the sample was taken and, therefore, is unable to predict soil N availability throughout the growing season.

Research at Penn State has focused on the Pre-sidedress Soil Nitrate Test (PSNT) and the leaf chlorophyll meter test for corn. For the PSNT, soil samples are taken to a depth of 12 inches when the corn is 12 inches tall. From a measurement of the nitrate-N level in this sample, a sidedress nitrogen fertilizer recommendation can be made. This test is especially useful for confirming whether the N from organic sources of N such as manure are adequate to meet the needs of the corn crop. Details on using the PSNT and making improved sidedress N recommendations can be found in *Agronomy Facts 17, Nitrogen Soil Test for Corn in Pennsylvania*.

The chlorophyll meter test estimates the nitrogen status of the growing corn crop based on the color of the corn leaves. This test is also a pre-sidedress test, run at the critical time just before the major demand by the crop. The color of the leaves is read directly on the plant in the field with a handheld meter. Thus, no samples need to be collected and analyzed, and the results are available immediately. As with the PSNT, the chlorophyll meter test is most useful when there are organic sources of N such as manure in the system. Details on using the chlorophyll meter test and making recommendations based on the readings can be found in *Agronomy Facts #53, The Early Season Chlorophyll Meter Test for Corn*.

Penn State’s N fertilizer recommendations, which represent the most economical amount of nutrient to apply, are presented in Table 2 for several yield levels of corn grain and silage. Only N that returns its cost in increased yield is economical to apply. The amount varies with the yield potential of a site and the many other factors that affect N availability and N use by the plant.

Table 2. Penn State nitrogen recommendations for corn.

Corn for Grain					
Expected Yield (bu/A)	100	125	150	175	200
N Rec. (lb N/A)	100	130	160	190	220
Corn for Silage					
Expected Yield (ton/A)	17	21	25	29	33
N Rec. (lb N/A)	120	150	180	210	240

Yield potential is expressed as the “yield goal” on the soil test questionnaire. The N recommendation is made for the yield level you specify or for an average yield potential based on soil type if the yield goal is not indicated. Actual farm yields vary quite a bit from the average for a soil type, so the yield goal can help tailor recommendations to your farm conditions.

Recommendations may need to be adjusted. Adjustments to the N recommendation for the residual N from a legume are automatically made when a previous legume crop is indicated on the soil test questionnaire. If manure is applied, you will need to make adjustments in the N recommendation for the amount supplied by the manure. See the *Penn State Agronomy Guide* for details on these adjustments.

Over-application of N does not give extra yield; rather, it wastes your fertilizer dollars and becomes a potential source of nitrate pollution to ground and surface waters. Home and farm water supplies polluted with nitrate are a health hazard to infants and livestock. The consequences of that pollution may also become a legal liability. Therefore, apply only the amount of N the crop needs and use practices to conserve the N.

FERTILIZER N MANAGEMENT

Because of the potential losses of N, the amount of fertilizer N applied is not necessarily the amount that remains available to the crop. Nitrogen losses can, and should, be reduced by management decisions as to the form, timing, and method of N application. Expected losses of N should be considered when figuring the amount to apply.

Nitrogen fertilizer materials

Inorganic N fertilizers supply N in a readily available mineral form. Regardless of the form in which it is applied, the actions of soil bacteria convert mineral N to the nitrate form, beginning several days after application or when the soil temperature exceeds 50°F. If they are properly applied, the various N fertilizers are equally effective. Choice, therefore, can be based on the cost per unit of N and your fertilizer N management plan. (See *Agronomy Facts 6, Comparing Fertilizer Materials*, and the *Penn State Agronomy Guide* for more information.)

Incorporation

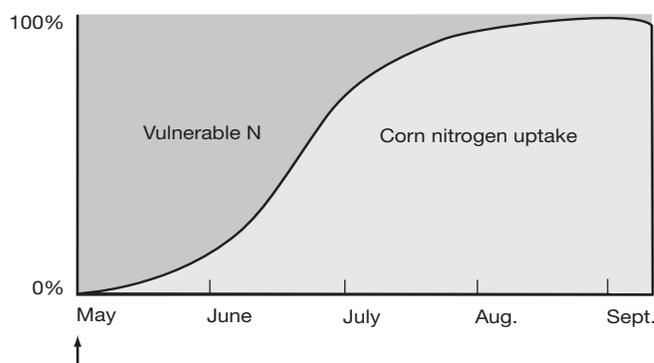
Use of urea fertilizer as an N source can result in N losses if the fertilizer is not incorporated. This includes urea and urea-ammonium nitrate solution fertilizer (UAN). Loss of urea N due to volatilization may be eliminated by immediate mechanical or rain incorporation (Table 1). Because of the volatilization problem, no-till corn production requires more attentive fertilizer management. Non-urea N fertilizers are not usually subject to volatilization under Pennsylvania soil conditions.

Timing

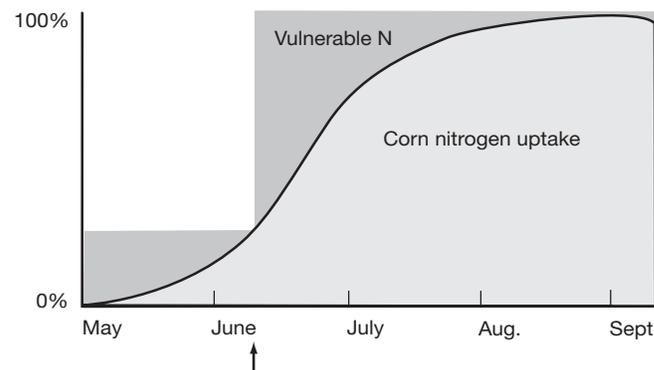
Leaching of nitrate out of the root zone and denitrification are processes that cannot be directly controlled. However, the potential for their occurrence can be reduced by waiting to apply N until the crop is ready to take it up, thereby reducing the time the N sits in the soil. While conditions for denitrification and leaching are greatest in the spring, corn uptake of N (Figure 2) is minimal until approximately thirty-five days after emergence, when a spurt of growth and N uptake occurs. Therefore 50 to 90 percent of the required N should be applied as a sidedress when the corn is 10 to 20 inches tall.

Figure 2. Relative vulnerability of applied N to loss by leaching and denitrification. There is less vulnerability to loss with delayed application.

A. All N applied preplant



B. Bulk of N applied as a sidedress



Note: Arrows indicate when fertilizer is applied.

Application methods

The same N materials available for preplant application are generally compatible with sidedress application. The materials and their associated methods of application each have certain limitations with regard to sidedressing.

Whether applied preplant or as a sidedress, anhydrous ammonia is an excellent source of N when proper soil conditions exist. However, if rocks or terrain cause the injection knives to come out of the soil, NH_3 will immediately be lost to the atmosphere. Soil moisture is chemically and physically important for effective application of anhydrous ammonia. The NH_3 reacts with water to form NH_4^+ and is adsorbed to the soil particles. Soil moisture also affects the closure of the soil slit behind the knife and thus the escape of NH_3 . Timing of sidedress NH_3 application, therefore, may be more critical than that of other materials.

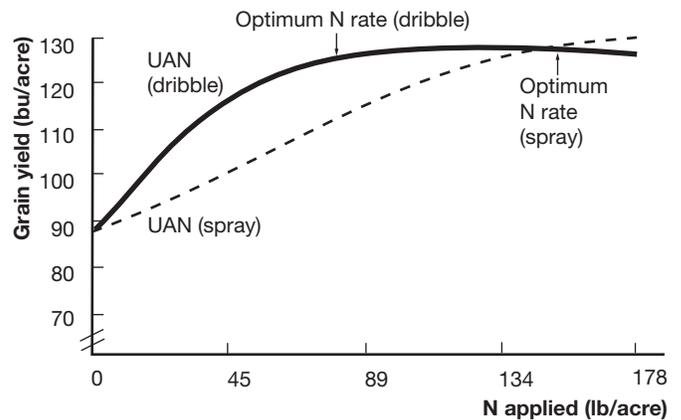
The presence of a crop does not prevent sidedress broadcasting of granular forms of N. Broadcasting is still probably the least time-consuming method of application, but leaf burn from the fertilizer is likely. However, plants recover within two weeks, apparently with no potential yield reduction. If urea is the N source used, surface application without incorporation by rain or cultivation can result in volatilization and loss of 30 percent or more of the applied N. If N is applied without incorporation, apply it to a dry soil surface, preferably just before a rain. Spinner spreader application inherently either covers field edges too lightly or wastes N beyond the field edges.

Solutions of urea and ammonium nitrate (UAN) are versatile, and their use, especially on no-till corn, has been increasing. Spray applications, either pre- or postemergence are often combined with herbicides in a "weed and feed" operation. Such an operation saves a trip through the fields, but spray application increases the susceptibility of urea N to volatilization and loss. In addition, corn leaf burn is generally worse than when broadcasting granular forms when sidedressing. Again, however, recovery without yield reduction is usually the case.

More efficient use of fertilizer N, in terms of total N availability, can be obtained with sidedress banding. Banding conserves the N applied and provides more uniform distribution of N across the field. A practical method for banding N is to apply UAN solution dribbled between the corn rows from hoses attached to the nozzles of a boom sprayer. Hoses should drag the ground to prevent them from swinging freely. The nozzle spacing should be close to that of the corn row spacing. Applying the N solution between alternate rows is adequate, in most cases, if the band placement is approximately midway between the two rows.

In a comparison of sprayed and dribbled applications of UAN at several rates of N, maximum yield was obtained at a much lower N rate with the dribbled application (Figure 3). Spraying, as compared to dribbling, exposes a larger propor-

Figure 3. Corn grain yield versus rate of urea-ammonium nitrate (UAN) solution applied either sprayed or dribbled. (Five rain-free days following application.) 1983



Source: R.H. Fox, The Pennsylvania State University

tion of the solution to the atmosphere and thus facilitates volatilization under certain conditions. Although the differences between the methods may not be this great (Figure 3) every year, the risk potential of dollars of yield lost favors dribbled application, even though it may be a slower operation.

Starter N

Starter fertilizer is generally recommended when planting corn. However, on soils with excessive nutrient levels or for late planting on soils with optimum or higher nutrient levels, a starter fertilizer may not be necessary. Recent research has shown that an N only starter such as ammonium sulfate also works well in these high fertility situations. Placement of soluble nutrients close to the seed is especially important in cold, wet soils in which nutrient availability and root growth are generally reduced. Early seedling vigor and subsequent grain yield are usually increased when nutrients are placed as a starter. Response to starter fertilization is generally greater in no-till corn fields because these fields tend to be colder and wetter than conventionally tilled fields at planting time.

Though most N sources are readily soluble, their suitability in a starter application varies greatly. Ammonium sources of N, compared to other N sources, increase P uptake. Ammonium phosphate materials are thus used regularly in starter formulations, and monoammonium phosphate (MAP) is an excellent material for this purpose. However, reactions producing free ammonia (NH_3) occur with diammonium phosphate (DAP). Ammonia is toxic to seedling roots, and this material is safe for starter use *only* when the rate is kept low and the material is placed two inches away from the seed. For this same reason, urea, which produces more free ammonia, should be used with caution in a starter fertilizer application.

Nitrogen in the starter fertilizer is important to meet most of the early N needs of the corn crop if the bulk of the N required is to be applied in a sidedress application. Normal starter rates are usually adequate to meet this need. Starter N rate may be safely increased if you want to apply more of the total N at planting. However, the rate and formulation of the starter fertilizer should never exceed that which would supply more than a total of 70 pounds N plus potash (K₂O) per acre, assuming it is placed no closer than two inches to the seed. If starter fertilizer is placed in the row with the seed, the safe rate drops to 10 pounds total N plus K₂O per acre. In this case neither DAP nor urea are acceptable materials! Subtract N applied in the starter from the total amount recommended.

MANURE N MANAGEMENT

Manure management needs to be more than just a plan to get rid of the stuff. Manure is a resource that can be a source of pollutants as well as of nutrients. The N of manure, like the N of soil, is in both organic and mineral forms. The mineral N can be lost through volatilization, denitrification, leaching, and runoff. The way you handle manure affects the extent of those N losses. Five practices that minimize losses of N from manure generally apply to reducing losses from N fertilizers as well.

1. Incorporate manure immediately after spreading. Much of the manure's mineral N is in the urea form, and surface application leaves it susceptible to volatilization. Incorporation eliminates that chance. Losses are directly related to length of time the manure remains on the soil surface. The organic N in the manure is neither immediately available to the plant nor susceptible to volatilization. If no-till is practiced, or if the manure is not incorporated within a week, 60 percent of the potentially available manure N can be lost.
2. Conserve the liquid portion of the manure. Approximately one-half of the N in animal wastes is found in the liquid portion. Therefore, it is very important that this liquid not be lost. Liquids can be conserved by using bedding to absorb them and/or water-tight storage.

3. Prevent loss of manure nutrients due to runoff. Flowing water from rain or melting snow can carry manure off your fields. It is especially important not to spread manure on frozen, steep hillsides.
4. Spread manure as near to the time of crop need as practical. Application just before spring plowing reduces the time that manure N is susceptible to losses due to leaching and denitrification. Apply manure only to fields for crops that will respond to the available N, such as corn and small grains.
5. Spread manure as uniformly as possible. Uneven spreading can result in some plants getting excess nutrients (waste) and other plants not getting enough nutrients. It is important to know the actual spreading rate so that the amount of nutrients applied in the manure are accurately accounted for when calculating supplemental nutrient requirements.

The availability of the nitrogen in manure to crops depends on how the manure is handled and applied. The main factors that determine N availability are incorporation and the time of year that the manure is applied. To estimate N availability for a given situation, multiply the N content of the manure by the appropriate factor in Table 3. Additional information on manure N is available in the *Penn State Agronomy Guide* and in *Agronomy Facts #55, Estimating Manure Application Rates*.

RESIDUAL N FROM LEGUMES

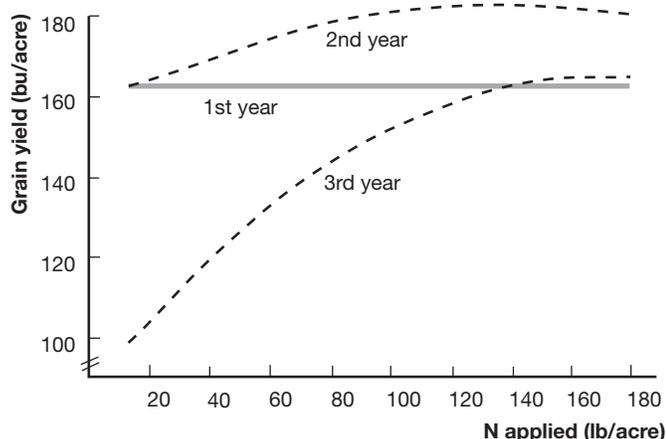
Dependence upon fertilizer N can be reduced by planning rotation of corn with legume crops. Although the amount of N that is available following a legume crop cannot be directly measured, research can show how much fertilizer N the residual N replaces. Yield response of corn following alfalfa to increased rates of fertilizer N is plotted in Figure 4. In the first year, there was no yield increase as a result of adding fertilizer N. All the N needs of the corn crop, apart from the starter application, were met by residual N from the alfalfa. In the second year, maximum yield was reached when only 80 lbs per acre of N was applied. The higher yield in this year can be attributed to different growing conditions.

Table 3. Examples of Manure N Availability in some common situations

Situation	Poultry	Swine	Other
	% N Available		
Manure applied in the spring for corn and immediately incorporated	75	70	50
Manure applied in the spring for corn and incorporated within 2 to 4 days	45	40	35
Manure applied in the spring for corn with no incorporation or significant rain for a week	15	20	20
Manure applied in the previous fall for corn the following year with a cover crop	50	45	40
Manure applied in the previous fall for corn the following year with no cover crop	15	20	50

The complete table of current N availability factors can be found in the *Penn State Agronomy Guide*.

Figure 4. Corn grain yield response to applied nitrogen for three years following alfalfa.



Source: R.H. Fox, The Pennsylvania State University

By the third year following alfalfa, a continuous corn situation is being approached and an N rate as recommended in Table 2 is required to obtain maximum yield. When you indicate on the soil-test questionnaire that your corn crop will follow a legume crop, the adjustment in the N fertilizer recommendation will be given.

SOIL ACIDITY FROM N SOURCES

In the microbial process that transforms all ammonium N sources to nitrate, acidity is produced. The lime required, on the basis of soil analysis, to neutralize soil acidity is given in the soil test report. In no-till corn production, fertilizer and manure N are concentrated on the soil surface. Acidity associated with N reactions is, therefore, also concentrated in the surface two inches of soil. Low surface pH reduces the activity of triazine herbicides. Therefore, soil sampling of a no-till field should include cores to less than two inches depth for pH analysis. If the surface pH is less than 6.2, apply one ton of lime per acre if no other lime is recommended on the basis of a normal 0-to-6 inch sample.

SUMMARY OF RECOMMENDATIONS FOR CORN N MANAGEMENT

1. If possible, plan corn production as part of a rotation with legumes. Take full advantage of the residual N by reducing fertilizer N.
2. Keep crop yield records for each of your fields.
3. Soil test every three years or when changing crops in a field.
4. Provide yield goal and previous crop information on soil test questionnaire for best N recommendation.
5. Account for available manure N for each field.
6. Don't waste fertilizer dollars by applying excess N.
7. Avoid N volatilization and loss, either by choice of N source or through incorporation.
8. Avoid denitrification and leaching losses of N by delaying application of the bulk of the N to be applied.
9. If UAN is your N source, apply it as a dribbled band rather than spraying it.
10. Use the PSNT on fields with a history of organic N additions.
11. Keep track of soil surface pH in no-till corn production.

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