A2519

Understanding Plant Nutrients

Soil and Applied Nitrogen

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The atmosphere contains about 78% nitrogen gas (N_2). This is the equivalent of more than 30,000 tons/a. However, most plants cannot use nitrogen as it exists in the atmosphere. It must first be converted through biological or chemical fixation.

1. Biological fixation—Rhizobia and other bacteria that live in the roots of legumes take nitrogen from the air and fix it in a form that plants can use. This mutually beneficial relationship between microorganisms and plants is called symbiosis.

2. Chemical fixation—In the manufacture of chemical nitrogen fertilizer, atmospheric nitrogen (N_2) is combined with hydrogen (H_2) to form ammonia (NH_3). Ammonia can be sold for direct application, or it can be used to manufacture other forms of nitrogen fertilizer such as ammonium nitrate (NH_4NO_3) or urea ($CO(NH_2)_2$).

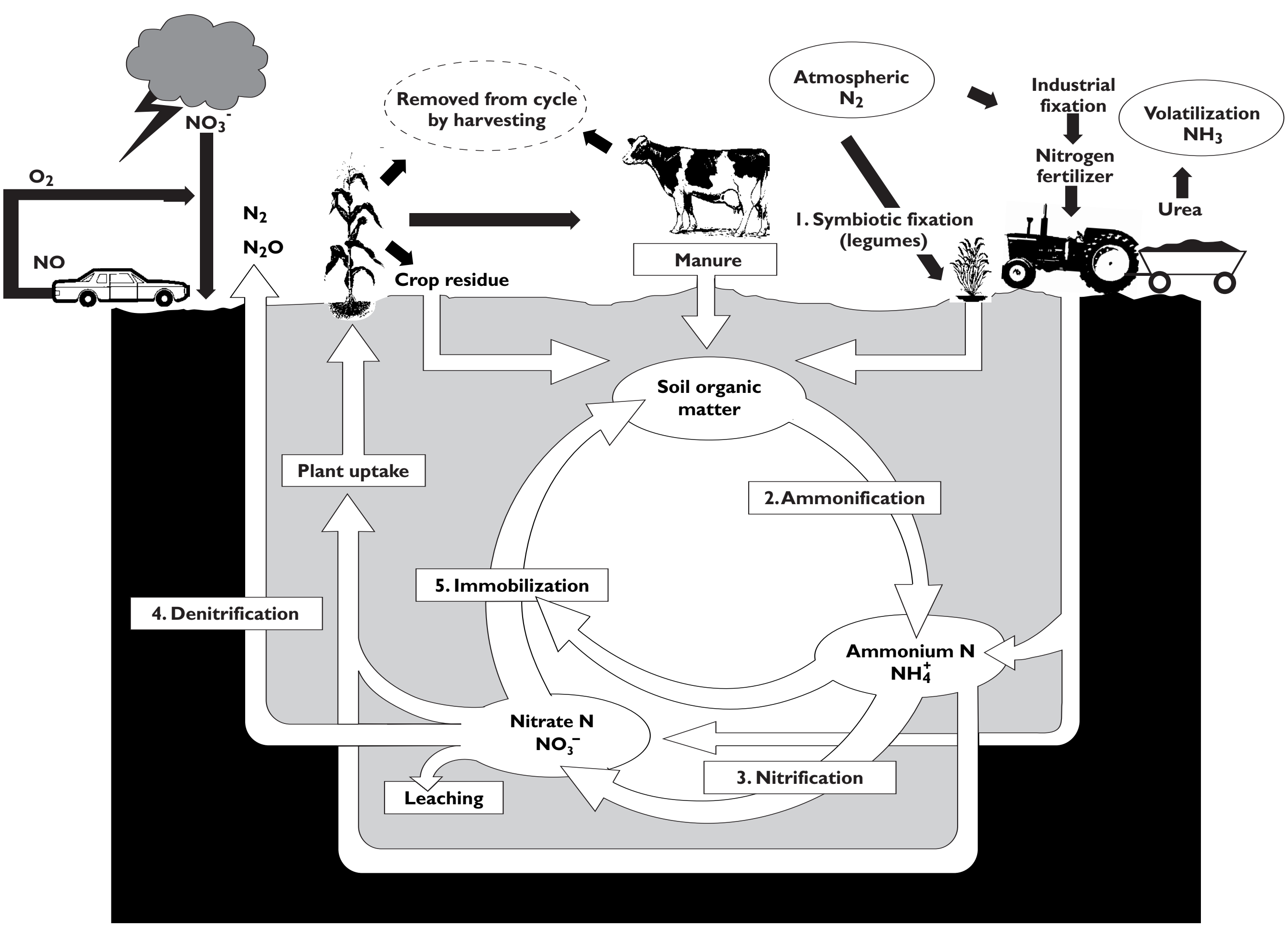
Nitrogen exists in many different forms. Several physical, chemical, and biological processes affect its availability to plants. Collectively, these transformations make up the nitrogen cycle, illustrated in Figure 1.

NITROGEN REACTIONS IN SOILS

Biological Transformations

Symbiotic fixation. Legumes inoculated with the proper strain of nodule-forming bacteria use atmospheric nitrogen (Reaction 1 in Figure 1). Most legumes fix all the nitrogen they need and do not need nitrogen fertilizer. In addition, many legumes supply substantial amounts of nitrogen to the succeeding crop.

Figure 1. The nitrogen cycle. Biological transformations of nitrogen in soil are numbered and explained under "Nitrogen Reactions in Soils."



Ammonification. This is the conversion of organic nitrogen into ammonium by soil microbes (Reaction 2 in Figure 1). Plants can use ammonium nitrogen, and it is not lost by leaching. Negatively charged particles of clay minerals and soil organic matter hold the positively charged ammonium ion (NH_4^+). This greatly restricts its movement by percolating water.

Nitrification. This is the conversion of ammonium nitrogen to nitrate nitrogen by soil bacteria (Reaction 3 in Figure 1). Nitrate ions (NO_3^-) are readily available to plants. However, their negative charge causes them to remain in solution in the soil, and they can be leached below the root zone by percolating water.

Nitrification occurs rapidly in warm, well-aerated, and properly limed soils (pH of 6.5–7.0). When conditions are favorable, the ammonium form of nitrogen in fertilizers is changed to the nitrate form within 1–2 weeks after application.

Denitrification. In poorly aerated, water-logged soils, soil bacteria change available nitrate nitrogen into unavailable atmospheric nitrogen (Reaction 4 in Figure 1). Decomposable organic matter must be present as a source of energy for denitrification to occur. This energy requirement often limits denitrification deep in the subsoil or in groundwater.

Denitrification takes place very rapidly. If water stands on the soil for only 2–3 days during the growing season, most of the nitrate nitrogen will be lost through denitrification. Yellowing of corn and other crops grown on poorly aerated soils is often due to a nitrogen deficiency.

Immobilization. Carbon-rich crop residues, such as straw or corn stalks, can cause temporary nitrogen deficiency because the bacteria that decompose the residues temporarily immobilize or "tie up" available ammonium or nitrate nitrogen (Reaction 5 in Figure 1). Most of the nitrogen immobilized as microbial protein becomes part of the soil organic matter and is slowly released in a plant-available form as the organic matter decomposes.

The addition of nitrogen fertilizer sometimes is recommended to hasten decomposition of crop residues. However, most well-managed soils contain enough nitrogen to break down the crop residue. The size of the residue particles usually is more important than the amount of nitrogen in determining how fast residues will decompose in soil: small particles decompose much more rapidly than large particles. For rapid decomposition, chop or shred corn stalks and other crop residues.

NITROGEN LOSSES

Leaching

Leaching of nitrate nitrogen can be a serious problem, especially on sandy soils. Because sandy soils retain only about 1 inch of water per foot of soil, relatively small amounts of rain or irrigation water readily move nitrate below the root zone. Well-drained silt and clay soils retain about 3 inches of water per foot of soil, so rapid leaching occurs in these soils only when rainfall is abnormally high.

Ammonium nitrogen is held on soil particles and is essentially non-leachable. Nitrate nitrogen is not held by soil particles and can be leached below the root zone. This does not mean that ammonium nitrogen is more effective than nitrate nitrogen. Ammonium nitrogen quickly changes to nitrate nitrogen under optimum soil conditions. As a result, nitrogen loss through leaching can occur even where nitrogen is initially applied as ammonium.

Volatilization

When manure, urea fertilizer, or solutions containing urea are surface applied and not worked into the soil, some nitrogen can be lost as ammonia gas. Direct loss of ammonia from anhydrous ammonia occurs if the material is not properly injected into the soil. Proper injection of solutions containing ammonia and immediate incorporation of manure and urea-containing fertilizer eliminate volatilization losses. A light rainfall (0.1–0.2 inches) within 1–2 days after surface application of urea-containing fertilizers will greatly reduce or eliminate ammonia volatilization. Little ammonia loss will occur when ammonium nitrate, ammonium sulfate, or ammonium phosphate are surface applied on acid or neutral soils. Incorporate ammonium sulfate or ammonium phosphate on high-pH soils. (See also "Urease Inhibitors" on page 4.)

Denitrification

As previously noted, most of the available nitrate nitrogen in soil converts to unavailable atmospheric nitrogen when soils are poorly aerated. It is important, therefore, to provide adequate surface or subsoil drainage on soils that tend to be poorly drained.

SOURCES OF NITROGEN

Organic Matter

Soils often contain 2,000–6,000 lb/a of organic nitrogen, but almost all of this nitrogen is combined in stable organic matter (humus) that decomposes very slowly. Mineral soils in Wisconsin supply only about 25–75 lb/a of available nitrogen annually. Nonlegume crops usually require additional nitrogen from fertilizer, previous legumes, or manure to achieve optimum yields.

Nitrogen Fertilizers

Many different chemical and physical forms of nitrogen fertilizer are available. If properly applied, the various forms are equally effective, although one form may have an advantage over another under certain conditions. Table 1 lists the general characteristics of the important fertilizer sources of nitrogen.

Table 1. Nitrogen fertilizers.

FERTILIZER	CHEMICAL FORMULATION	ANALYSIS ($N-P_2O_5-K_2O$)	PHYSICAL FORM	METHOD OF APPLICATION
Ammonium nitrate	NH_4NO_3	33-0-0	dry prills	Broadcast or sidedress. Can be left on the soil surface.
Ammonium sulfate	$(NH_4)_2SO_4$	21-0-0	dry granules	Broadcast or sidedress. Can be left on the soil surface.[a]
Anhydrous ammonia	NH_3	82-0-0	high-pressure liquid	Must be injected 6–8 inches deep on friable[b] moist soil. Excessive loss will occur from wet soils.
Aqua ammonia	NH_4OH	20-0-0 to 24-0-0	low-pressure liquid	Must be injected 2–3 inches deep on friable[b] moist soils. Excessive loss will occur from wet soils.
Calcium nitrate	$Ca(NO_3)_2$	15.5-0-0	dry granules	Broadcast or apply in the row. Can be left on the soil surface.
Diammonium phosphate	$(NH_4)_2HPO_4$	18-46-0	dry granules	Broadcast or apply in the row. Can be left on the soil surface.[a]
Low-pressure nitrogen solutions	$NH_4NO_3 + NH_3 + H_2O$	37-0-0 41-0-0	low-pressure liquid	Must be injected 2–3 inches deep on friable[b] moist soils. Excessive loss will occur from wet soils.
Potassium nitrate	KNO_3	13-0-44	dry granules	Broadcast or apply in the row. Can be left on the soil surface.
Pressureless nitrogen solutions	NH_4NO_3 + urea + H_2O	28-0-0 32-0-0	pressureless liquid	Spray on surface or sidedress. Incorporate surface applications to prevent volatilization loss of NH_3 from urea.
Urea	$CO(NH_2)_2$	45-0-0	dry prills or granules	Broadcast or sidedress. Incorporate surface applications to prevent volatilization loss of NH_3 from urea.

[a]*Incorporate on high pH soils.*

[b]*Friable soils are those which are easily crumbled or pulverized.*

Timing of application. The timing of nitrogen fertilizer applications can markedly affect their efficiency and the potential for nitrogen losses. Supplying the needed nitrogen just prior to the crop's greatest demand maximizes the efficiency of nitrogen applications. For spring-planted crops, sidedress and spring preplant applications provide greater nitrogen efficiency than fall applications, which are usually 10–15% less effective in increasing crop yields.

Fall applications are most effective on medium-textured, well-drained soils, where nitrogen loss through leaching and denitrification is usually low. They are *not* effective on sandy soils, shallow soils over fractured bedrock, or fine-textured, poorly drained soils. Price and convenience advantages frequently associated with fall-applied nitrogen must be weighed against the possibility of lower effectiveness and nitrate nitrogen losses.

Sidedress nitrogen applications during the growing season are effective on all soils. Proper timing of these applications is essential to provide available nitrogen during the period in which the crop uses nitrogen rapidly. Benefits from using sidedress instead of preplant applications are greatest on sandy soils or on fine-textured, poorly drained soils.

Spring preplant applications are usually as effective as sidedress treatments on medium-textured, well-drained soils, because the risk of leaching or denitrification on these soils is low.

Nitrification inhibitors. Using a nitrification inhibitor such as nitrapyrin (N-Serve) or dicyandiamide (DCD) with ammonium forms of nitrogen fertilizer can reduce nitrogen losses on soils where leaching or denitrification is likely. Nitrification inhibitors slow the conversion of ammonium to nitrate by soil organisms (Reaction 3 in

Figure 1). Because leaching and denitrification occur through the nitrate form of nitrogen, maintaining fertilizer nitrogen in the ammonium form should reduce nitrogen losses through these processes.

Nitrification inhibitors are likely to increase crop yields when used with spring preplant nitrogen applications on sandy soils or fine-textured, poorly drained soils. Yield increases are also likely from inhibitor use with fall-applied nitrogen on medium-textured, well-drained soils. However, spring-applied nitrogen fertilizer is usually more effective than fall-applied nitrogen even with use of a nitrification inhibitor. Using nitrification inhibitors with spring preplant nitrogen on medium-textured, well-drained soils or with sidedress applications on any soil type is not likely to improve yields.

Urease inhibitors. Use of urease inhibitors such as NBPT (Agrotain) with surface-applied urea-containing fertilizers can reduce ammonia losses and improve nitrogen efficiency. However, they do not consistently increase yields. The decision to use a urease inhibitor will depend on the risk of nitrogen loss that could be controlled, the cost of using the inhibitor, and the cost and convenience of other nitrogen sources or placement methods that are not subject to ammonia loss. Alternatives include injecting or incorporating the urea-containing fertilizers or using non-urea nitrogen sources.

Nitrogen management recommendations. To minimize leaching or denitrification losses, follow these general recommendations.

1. Sandy soils—Apply nitrogen as a sidedress treatment. Fall or spring preplant treatments result in excessive losses on sandy soils. If you must use spring preplant applications, apply ammonium forms of nitrogen treated with a nitrification inhibitor. For irrigated crops, apply part of the nitrogen through the irrigation water.

2. Well-drained silty or clayey soils—Spring preplant or sidedress applications can contain any form of nitrogen. If you must make fall applications, use ammonium forms of nitrogen with a nitrification inhibitor.

3. Poorly drained soils—Use sidedress applications or apply nitrification inhibitors with spring preplant treatments.

Legumes

Legumes can supply substantial amounts of nitrogen to the succeeding crop. Table 2 indicates the nitrogen credit that should be given to various legume crops. For additional information, see Extension publication *Using Legumes as a Nitrogen Source* (A3517).

Table 2. Nitrogen credits for previous legume crops.[a]

LEGUME CROP	NITROGEN CREDIT	EXCEPTIONS
Forages		
First-year credit		
Alfalfa	190 lb/a N for a good stand[b] 160 lb/a N for a fair stand[b] 130 lb/a N for a poor stand[b]	Reduce credit by 50 lb/a N on sandy soils.[c] Reduce credit by 40 lb/a N if plant regrowth was less than 6–10 inches prior to tillage or plant death.
Birdsfoot trefoil, red clover	Use 80% of alfalfa credit.	Same as alfalfa.
Second-year credit		
Fair or good stand	50 lb/a N	No credit on sandy soils.[c]
Green manure crops		
Alfalfa Red clover Sweet clover	60–100 lb/a N 50–80 lb/a N 80–120 lb/a N	Use 40 lb/a N credit if field has less than 6 inches of growth before tillage.
Soybean	40 lb/a N	No credit on sandy soils.[c]
Leguminous vegetable crops		
Pea, lima bean, snap bean	20 lb/a N	No credit on sandy soils.[c]

[a] *Legume credits to a following corn crop can be confirmed by using the presidedress nitrogen test (PSNT) when corn is 6–12 inches tall.*

[b] *A good stand of alfalfa (>70% alfalfa) has more than 4 plants/ft^2; a fair stand (30–70% alfalfa) has 1.5–4 plants/ft^2; and a poor stand (<30% alfalfa) has less than 1.5 plants/ft^2.*

[c] *Sandy soils are sands and loamy sands.*

Table 3. Nitrogen content and first-year credits for solid and liquid manure.

TYPE OF MANURE	% OF TOTAL N AVAILABLE IN FIRST YEAR	APPLICATION METHOD	NITROGEN CONTENT OF MANURE			
			SOLID (lb/ton)		LIQUID (lb/1000 gal)	
			TOTAL	N CREDIT	TOTAL	N CREDIT
Beef	25%	Surface	14	4	40	10
	30%	Incorporated[a]	14	4	40	12
Dairy	30%	Surface	10	3	28	8
	35%	Incorporated[a]	10	4	28	10
Poultry	50%	Surface	25	13	70	35
	60%	Incorporated[a]	25	15	70	41
Swine	40%	Surface	10	4	55	22
	50%	Incorporated[a]	10	5	55	28

[a]*Injected or incorporated within 72 hours of application.*

Adapted from: USDA-SCS. Wisconsin Field Office Technical Guide. Sec. IV. Spec. 590.

Manure

Manure contains substantial amounts of nitrogen, but much of the nitrogen is in the organic form and is not all available in the first year following application. The amount of manure nitrogen available to a crop depends on the type of manure, the application rate, the method of application, and the consecutive years of application. Reduce or eliminate fertilizer nitrogen applications when you apply manure. Table 3 lists first-year nitrogen credits for solid and liquid manure. For additional information, see Extension publication *Guidelines for Applying Manure to Cropland and Pastures in Wisconsin* (A3392).

Precipitation

In rural areas in Wisconsin, precipitation accounts for about 10 lb/a of available nitrogen (ammonium + nitrate nitrogen) annually. This is a small addition on a per-acre basis, but it is a significant contribution to the total nitrogen budget for the state.

DIAGNOSTIC TECHNIQUES

Deficiency Symptoms

Lack of nitrogen first appears as a light green coloring of the plant. As the deficiency becomes more severe, leaves turn yellow and may "fire." Nitrogen deficiency first appears on the plant's lower leaves and gradually progresses up the plant. On corn, this yellowing starts at the midrib of the leaf with the edge of the leaf remaining green. Corn, small grains, and forage grasses all require relatively high amounts of nitrogen and show deficiency symptoms whenever nitrogen is in short supply. Yellowing of the bottom few leaves as corn plants approach physiological maturity is normal and usually does not indicate a nitrogen deficiency.

Soil Analysis

Nearly all nitrogen in the soil is in the unavailable organic form. The amount of organic nitrogen that soil bacteria convert to an available form depends on such environmental factors as temperature, rainfall, and soil oxygen levels. Soil organic matter content provides a general indication of the soil's nitrogen-supplying capability, and nitrogen recommendations in Wisconsin take this source of nitrogen into account.

Soil nitrate testing allows nitrogen fertilizer recommendations to be adjusted for field-specific conditions that can influence crop nitrogen needs. Two nitrate tests, a preplant soil nitrate test and a presidedress soil nitrate test, are available for improving the efficiency of nitrogen fertilizer applications. These tests offer economic and environmental benefits. Economically, tailoring nitrogen applications to crop needs saves fertilizer dollars. Environmentally, avoiding over-application of nitrogen reduces the potential for nitrate movement to groundwater.

A preplant soil profile nitrate test (PPNT) is useful for predicting site-specific nitrogen fertilizer needs, particularly for corn production. Soil samples, taken in 1-foot increments to a depth of 2 feet, are used to measure residual nitrate nitrogen in the crop root zone in early spring. The factors that influence the amount of residual nitrate nitrogen in the soil include October-to-April precipitation, soil texture, crop sequence, and repeated manure applications. The PPNT is likely to be most beneficial when corn follows corn on medium- and fine-textured soils and when October-to-April precipitation is normal or below normal. Even in years of above-normal winter precipitation, the test is likely to be beneficial in second-year corn following alfalfa, in continuous corn, and in fields with a history of manure applications. The test is not useful on sandy soils because potential nitrate nitrogen carryover is almost always low in these soils.

Table 4. Nitrogen plant analysis interpretations for common Wisconsin field crops.

CROP	PLANT PART SAMPLED	TIME OF SAMPLING	INTERPRETATION DEFICIENT	LOW	SUFFICIENT	HIGH
			% N			
Alfalfa[a]	Top 6 inches	Early bud	<1.25	1.25–2.50	2.51–3.70	>3.70
Barley, oat, wheat	Top leaves	Boot stage	<1.50	1.50–2.00	2.01–3.00	>3.00
Corn	Ear leaf	Silking	<1.75	1.75–2.75	2.76–3.75	>3.75

[a] *First crop.*

A presidedress soil nitrate test (PSNT) allows adjustments to nitrogen recommendations based on the soil's nitrate content. Soil samples, taken to a depth of 1 foot, are collected after planting is completed. This test measures the amount of nitrogen released from previous legume crops, manure applications, and soil organic matter as well as part of the nitrogen carried over from the previous growing season. The PSNT is a beneficial tool for confirming nitrogen contributions from fall, winter, and spring manure applications and from forage legume crops preceding first-year corn. This test is not recommended on sandy soils. For more information see Extension publication *Soil Nitrate Tests for Wisconsin Cropping Systems* (A3624).

Plant Analysis

Although plant tissue analysis can indicate whether a plant is deficient in nitrogen, it is difficult to detect small differences in nitrogen availability with a tissue sample alone. Many environmental factors such as moisture stress, light intensity, and time of day can affect the amount of nitrogen in plant tissue. In addition, the amount of total nitrogen (crude protein) in a plant decreases as the plant grows. It is important to specify the stage of growth when sampling a crop for nitrogen analysis. Table 4 gives an approximate interpretation of nitrogen plant analyses for the major agronomic crops grown in Wisconsin. For additional information about plant analysis, see Extension publication *Sampling for Plant Analysis: A Diagnostic Tool* (A2289).

ENVIRONMENTAL EFFECTS

Excessive nitrate in drinking water can cause human and animal health problems. Nitrate and other nitrogen compounds also can hasten deterioration of lakes and streams by promoting excessive growth of weeds and algae. The following recommendations can minimize these adverse environmental effects.

- Use recommended rates of nitrogen fertilizer; give credit to nitrogen from manures and legumes and to residual nitrate nitrogen as measured by the Wisconsin preplant soil profile nitrate test.
- When possible, time the application of nitrogen fertilizer with nitrogen uptake by the crop, especially on irrigated sandy soils.
- Practice good conservation to minimize erosion losses.
- Maintain a rotation that includes a deep-rooted crop, such as alfalfa.
- Eliminate winter and fall applications of fertilizer.
- Avoid winter application of manure when feasible.
- Locate rural wells as far as possible from farm lots and other areas where manure accumulates.

For additional information on the environmental effects of nitrogen see Extension publication *Nitrate in Wisconsin Groundwater: Sources and Concerns* (G3054).

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