soil Nitrogen

Soil Quality Kit – Guides for Educators

United States Department of Agriculture
Natural Resources Conservation Service

Nitrogen (N) is the most abundant element in the atmosphere and is usually the most limiting crop nutrient. Nitrogen cycles through soil in various processes and forms. Some processes are necessary to convert N into forms which plants can use. Some processes can lead to N losses such as leaching or volatilization. Nitrogen is added to soil naturally from N fixation by soil bacteria and legumes and through atmospheric deposition in rainfall. Additional N is typically supplied to the crop by fertilizers, manure, or other organic materials. Soil nitrate-N is an excellent indicator of N-cycling in soils, whether carryover nitrogen was used by the previous crop and whether additional nitrogen is needed.

Inherent Factors Affecting Soil Nitrogen

Inherent factors such as soil drainage, soil texture, and slope steepness impact N-transport and N-transformation processes that limit availability to crops or lead to losses. Inherent factors such as rainfall and temperature; and site conditions such as moisture, soil aeration (oxygen levels), and salt content (electrical conductivity/EC) affect rate of N mineralization from organic matter decomposition, nitrogen cycling, and nitrogen losses through leaching, runoff, or denitrification. Organic matter decomposes releasing N more quickly in warm humid climates and slower in cool dry climates. This N release is also quicker in well aerated soils and much slower on wet saturated soils.

Nitrogen can readily leach out of the root zone in nitrate-N form. The potential for leaching is dependent on soil texture (percentage of sand, silt, and clay) and soil water content. Water moves more quickly through large pore spaces in a sandy soil than it does through small pores in a clayey soil and water holding capacity is much lower in sandy soils, making them especially vulnerable. Soils that have poor drainage and are ponded or saturated with water causes denitrification to occur resulting in loss of N as a gas which can result in emission of potent greenhouse gases, yield reduction and increased N fertilizer expense.

Nitrogen Management

Management factors, such as N-rate, N source, N placement method, timing of application, irrigation management, residue management, crop type, etc. all can affect how efficiently N is used by crops and amount of N losses. Nitrogen management on sandy soils is important because of high potential for leaching losses. Selecting appropriate N rate is the primary management consideration. However, nitrogen source, timing N application close to plant uptake, and method of application such as injecting N to avoid losses are also important. Management measures that increase organic matter and avoid compaction are also important to stabilize crop N supply, increase aeration, and to limit N losses due to denitrification occurring in saturated soils.

Nitrogen rates should be based on amount needed to optimize yield based on agronomic economic and environmental considerations. When planning N-fertilizer or manure application rates appropriate N-credits should be accounted for including; soil test residual nitrate-N, soil organic matter mineralization, legume credits, manure or other organic amendments, irrigation water nitrate-N, residue decomposition and natural N sources.

Time N fertilization to provide adequate amounts of N when plants are actively growing and using N rapidly. Losses of applied N from fertilizer can be reduced by delaying application until the crop has emerged (side dressing). Split N applications, where some N is applied prior to crop emergence and the balance after emergence can increase crop N-use efficiency.

Fertilizer source is important to increase N recovery by crops, avoid N-loss from volatization and be matched to the type of placement method to reduce losses and maximize recovery by crops. Anhydrous ammonia is usually the least expensive N source, but this material must be handled safely, and must be injected/knifed in with ideal soil moisture conditions. Urea and urea containing materials should be injected to reduce loss from ammonia volatilization. Surface applied urea N fertilizers, should not be applied during warm humid conditions, or on wet residues because of high potential for N losses from volatization. Manure or organic amendments can be an effective N-fertilizer. However, care must be taken to apply manure uniformly at a known rate, and account for mineralization rate.

Placement of N-fertilizer can be accomplished by several methods. Typical methods include, side dress applications after crop emergence, knifed application placing a band of fertilizer below the soil surface, broadcast applications that uniformly distribute N, and through sprinkler irrigation systems. Each placement method has its advantages, and must be matched to type of fertilizer or manure that will be applied.

Irrigation scheduling is important. The goal is to supply enough water to optimize yield while avoiding excess irrigation which can increase costs and leach N below the root zone.

Keys to managing N in most efficient manner include these strategies:

1) Apply recommended rate based on realistic yield
2) Time N application just before peak crop demand
3) Select an ammonium containing fertilizer which provides greater N recovery by crops
4) Inject N if possible to avoid ammonia or volatization losses
5) Use N-inhibitors when N is applied outside of growing season
6) Credit all sources of N
7) Irrigate wisely
8) Monitor crop nitrogen needs by scouting
9) Regular soil testing for nitrate (including deep samples), and soil salt content (EC)

Yellow coloration in a “V” shaped pattern is symptomatic of nitrogen deficiency (Figure 1). This pattern progresses from leaf end to leaf collar and from lower to upper leaves. Lower leaves often die when nitrogen deficiency is severe.

Figure 1. Nitrogen deficient corn characterized by yellow coloration in V-shaped pattern.

Nitrogen Cycle

Besides nitrogen (N2) gas within soil pore space, nitrogen is found in both organic and inorganic forms in soil. Organic forms occur in soil organic matter which consists of three primary parts including small (fresh) plant residues and small living soil organisms, decomposing (active) organic matter, and stable organic matter.

Predominate inorganic forms of N in soils are ammonium (NH_4) and nitrate (NO_3), which are both useable by plants. The nitrogen cycle (Figure 2) illustrates reactions that various inorganic and organic N compounds undergo in soil. The nitrogen cycle typically begins with nitrogen in its simplest stable form, dinitrogen (N_2) in air, and follows it through the processes of fixation, mineralization, nitrification, leaching, plant assimilation, ammonia volatilization, denitrification, and immobilization.

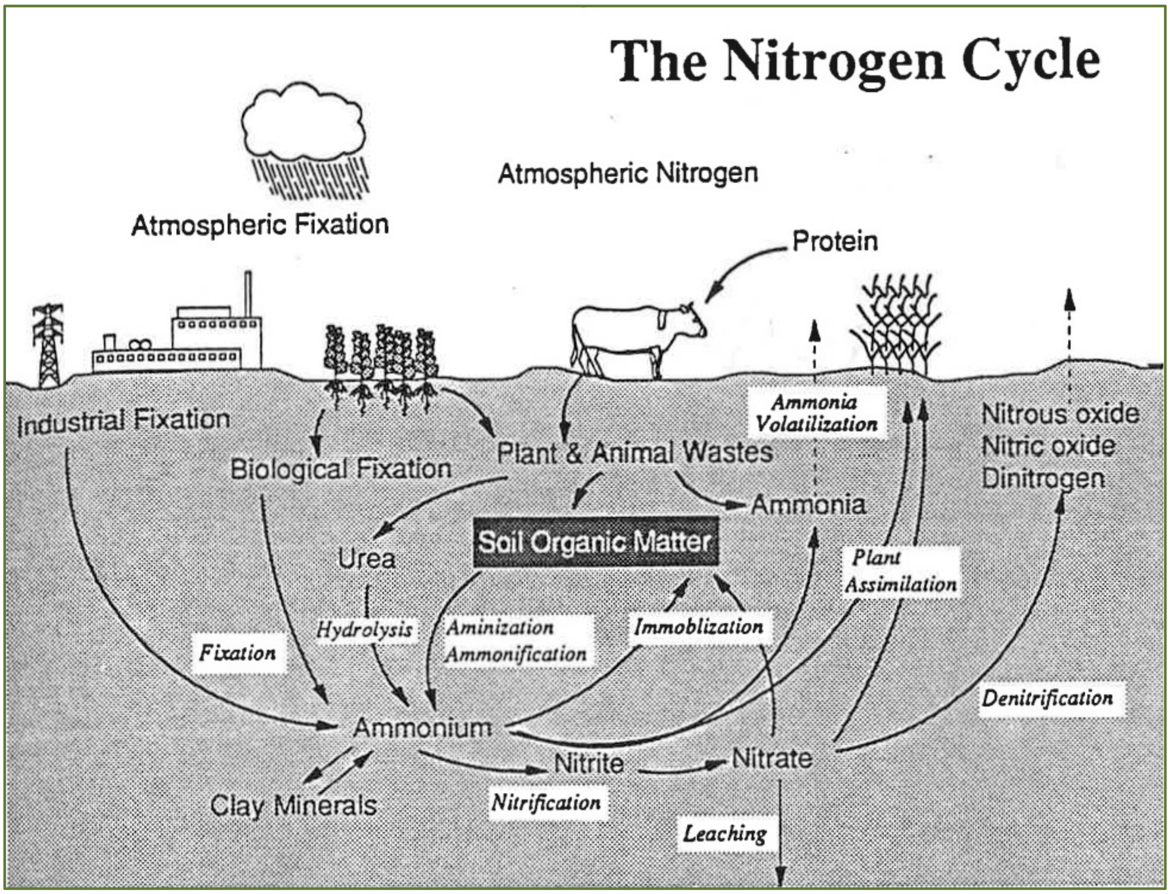

Figure 2. Nitrogen cycle ("Soil as a Plant Sees It", University of Nebraska, 1991).

What management measures being used do you predict will affect N losses from leaching volatization, etc.?

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Do you expect soil Nitrate-N levels to be high or low and why?

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Measuring Soil Nitrate/Nitrite

Materials Needed to Measure Nitrate/Nitrite

____ Plastic bucket and probe for gathering and mixing soil samples

____ Nitrate/nitrite test strips

____ 1/8-cup (29.5 mL) measuring scoop

____ Calibrated 120-mL shaking vial with lid

____ Squirt bottle

____ Distilled or rain water

____ Pen, field notebook, sharpie, & zip lock bags

Considerations – Electrical conductivity (EC) measurements should always be measured first, before measuring nitrate or nitrite on same sample. Soil phosphate and soil pH can also be measured using the following steps.

In-Field Quick Hand Test

1. <u>Soil Sampling:</u> Soil nitrate-N level is highly variable, depending on management history, field location and time of year. For example; erosion rates, soil texture, organic matter content, and applications of manure or fertilizer. Using a soil probe gather at least 10 small samples randomly from an area that represents soil type and management history to a depth of 8 inches for the surface and a depth up to 3 feet for subsurface and place in a small plastic bucket. Do not include large stones and residue in sample. Repeat this step for each sampling area.

2. Neutralize hands by rubbing moist soil across your palms and discard soil, then place a scoop of mixed soil in the palm of your hand and saturate with “clean” water (distilled or clean rain water).

3. Squeeze soil gently until a water slurry runs out into the cup of your hand on the side.

4. Touch nitrate test strip tip directly to soil water slurry such that the tip is barely wet so solution is drawn up at least 1/8 to 3/16" (Figure 3).

5. After 1 to 2 minutes, measure nitrate by comparing color of wetted test strips to color picture scale on container test strips were stored (Figure 4). The color that most closely matches test strip is the amount of nitrate in water saturated soil.

6. For nitrite the procedure is repeated after nitrate test pad on the end of the strip is cut off to expose the nitrite test strip to the soil slurry.

Figure 3. Nitrate-N quick hand test.

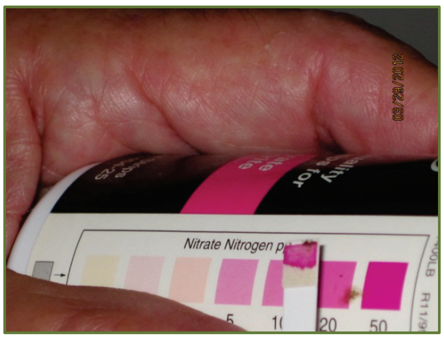

Figure 4. Nitrate color scale.

<u>1:1 Soil-Water Soil Nitrate/Nitrite Test in Classroom</u>

1. <u>Soil Sampling</u>**:** Same as step 1, shown in "In Field Hand Test" above.

2. Add one sampling scoop (29.5 ml) of mixed soil that has been tamped down during filling by striking carefully on a hard level surface. Then add one scoop (29.5 ml) of water to the same vial resulting in a 1:1 ratio of soil:water, on a volume basis.

3. Tightly cap the vial and shake 25 times, let settle for 1 minute, remove cap, and decant 1/16" of the soil water 1:1 mixture carefully into lid.

4. After setting for 2-3 minutes in the lid, immerse end of nitrate test strip 1/16" into 1:1 soil water mixture until liquid is drawn up at least 1/8 to 3/16" beyond area masked by soil (Figure 5).

5. After 1 to 2 minutes, measure nitrate by comparing color of wetted test strips to color picture scale on container test strips were stored (Figure 4). The color that most closely matches test strip is the amount of nitrate in water saturated soil.

6. For nitrite the procedure is repeated after the nitrate test pad on the end of the strip is cut off to expose the nitrite test strip to the soil slurry.

Figure 5. 1:1 soil water test for nitrate.

Interpretations

Soil nitrate-N is an excellent indicator of N-cycling in soils, whether carryover nitrogen was used by the previous crop and whether additional nitrogen is needed. High nitrate-N levels also signal potential for excessive nitrogen applied in the past, high rates of organic N mineralization, and potential for losses from denitrification, leaching, or volatilization.

Typically, an early season measurement of **20 ppm** nitrate-N in topsoil (30 cm) is sufficient to produce a good corn yield and most other high N-use crops, whereas a value of only **14 ppm** is sufficient where animal manure is applied or where corn or other high N use crop follows a legume crop. A very high soil nitrate-N value above **40 ppm** in topsoil will turn off the ability of bacteria and legumes to fix nitrogen. Therefore, nitrogen applications should be managed to keep nitrate-N levels below this value. Nitrate-N levels must be adjusted for soil bulk density and moisture content of the soil as shown in Table 1.

Table 1. Average bulk density for soil minerals (texture) and organic matter (Rawls 1983).

Class (texture, organic matter)	Average Bulk Density (g/cm^3)
Organic Matter	0.22
Sand	1.56
Loamy Sand	1.54
Sandy Loam	1.50
Loam	1.45
Silt Loam	1.20
Sandy Clay Loam	1.63
Silty Clay	1.55
Clay Loam	1.45
Silty Clay Loam	1.40

Soil Nitrate-N Calculations Necessary to Complete Table 2:

Ex. 1 Data: Silty Clay Loam texture, 8 inch sample depth; 2% organic matter estimate from soil color chart; no bulk density (BD) measurement (BD based estimated values from Table 1).

Sampling depth conversion: Sampling depth in centimeters (cm) = inches (sampling depth) x (2.54cm/in)

*Ex. 1: 8 inch (sampling depth) x 2.54 = **20 cm sampling depth***

Subsample Soil water content (g/g) = (weight of moist soil – weight of oven dry soil) / (Weight of oven dry soil)

*Ex. 1: (41.0g – 32.5g) / 32.5 g = **0.262 g of water/g of soil***

Dry weight of soil = (weight of soil in scoop) / (1+ soil water content(decimal))

Ex. 1: (41.0gr / (1 + .262g/g) = **32.5g**

Volume (weight) of water = water added to soil in grams + (dry weight of soil x soil water content g/g)

(1ml water = 1g)

*Ex. 1: 29.5g + (32.5g x .262g/g) = **38 g***

Adjusted ppm soil Nitrate-N = (ppm NO_3-N of 1:1 mix) x (volume of water content in extract & soil) / dry weight of soil extracted

*Ex. 1: (20ppm x 38.0g) / 32.5g = **23.4 ppm (adjusted)***

Estimated Bulk Density (refer to bulk density educator guide to calculating actual bulk density or use estimate from Table 1 as shown below)

$$\text{Est. Bulk Density (Table 2)} = \frac{100}{\text{\% organic matter/organic Matter BD}) + ((100 - \text{\% organic matter})/\text{avg soil BD}))}$$

Ex. 1: $$\frac{100}{(2.0/0.22\ g/cm3) + ((100 - 2)/1.40\ g/cm3)}$$ = ***1.26 g/cm3 (estimated bulk density (BD))***

Lbs of nitrate-N/ acre/depth sampled = (adjusted ppm NO_3-N) x (cm depth soil sampled/10) x estimated soil bulk density x 0.89 (conversion factor)

Ex. 1: 23.4 ppm NO_3-N X (20 cm/10) x 1.26 g/cm3(estimated BD) x 0.89 = ***52.5 lbs/Nitrate Nitrogen/20cm sampling depth***

Table 2. Soil nitrate nitrogen (based on sampling depth).

Site	*Sample Depth (inches or cm)	Nitrate-N (ppm) From test strip	*Adjusted Nitrate-N (ppm)	*Bulk Density (g/cm3)	*Lbs of nitrate-N/ acre/depth sampled	**Nitrite-N (ppm) from test strip	Notes:
Ex1	8" or 20cm	20ppm	23.4 ppm	1.26	52.5 lbs	NA	Spring N-test just prior to planting

** Follow soil nitrate calculation steps based on sampling depth (Ex. 1 is based on 8 inch sample depth).*

*** When nitrate-N exceeds 40 ppm, or EC exceeds 0.6 ds/m nitrite should also be measured.*

Water Nitrate or Nitrite Content

Water nitrate and nitrite levels can be estimated for drinking water, irrigation water, and other water sources. Cloudy samples, such as runoff or water from ponds, will need to be filtered first before testing. Drinking water treatment should be considered if nitrate levels exceed 10 mg/l Nitrate-N (ppm) is considered the maximum contaminate level (MCL) by EPA. Consult your local health officials and be aware that nitrate levels in groundwater may vary seasonally. If your water tests high or borderline high, retest your water every three to six months. Nitrates in irrigation water can be credited for N supplied to crops using the formula footnoted in Table 3.

1. Collect water sample in small plastic container.
2. Filter water sample (if cloudy).
3. Place 1 or 2 drops of water on nitrate/nitrite test strip.
4. After 30 seconds, compare the color to nitrite scale on the bottle and record nitrite (ppm).
5. After 60 seconds compare the color to nitrate scale on the bottle and record nitrate in ppm on Table 3.

Table 3. Water nitrate and nitrite nitrogen.

Site	Nitrate-N (ppm) from test strip	Nitrite-N (ppm) from test strip	Irrigation Water Applied (inches/ac pumped)	Irrigation Water N Credit lbs of N/acre
Ex1	20ppm	NA	12”	54 lbs N/ac

**(Pounds of N/acre credited = (inches pumped x ppm nitrate X 2.7) ÷ 12)*

Are soil nitrate levels adequate for crops being grown?

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Does the total amount of nitrate-N in the soil appear too high or too low based on N application rates, methods, and timing of application?

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Do you expect nitrate nitrogen to be lost to leaching, volatization, denitrification, or other losses? Why or why not?

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If you tested drinking water for nitrate or nitrite-N, do levels exceed 10 mg/l Nitrate-N (ppm) which is considered the maximum contaminate level (MCL) by EPA? If so what steps should you consider?

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Glossary

Ammonification – Production of ammonium (NH_4) from SOM decomposition, and other sources.

Ammonium – Form of nitrogen expressed as NH_4, which is a plant available form of N that occurs as part of the N-cycle in soil. Occurs from soil organic matter (SOM) decomposition and other sources.

Bulk Density – Weight of dry soil per unit of volume, more compacted soil with less pore space will have a higher bulk density.

Denitrification – Conversion and loss of nitrate nitrogen to various nitrogen gases shown in Figure 1. when soil becomes saturated with water.

Immobilization – The temporary "tieing up" of inorganic N by soil microorganisms decomposing plant residues is not strictly a loss process. Immobilized N will be unavailable to plants for a time, but will eventually become available again as residue decomposition proceeds.

Leaching – Loss of nitrogen in the form of Nitrate-N which is a water soluble, mobile form, with excess water that moves below the root-zone, or to drainage tile.

Mineralization – Organic matter decomposition which releases nutrients in a plant available form (e.g., phosphorus, nitrogen, and sulfur).

Nitrate-N – Form of nitrogen expressed as NO_3, which is a plant available form of N that occurs as part of the N-cycle in soil. Nitrate is the form of N most susceptible to leaching loss.

Nitrification – Part of the nitrogen cycle where soil organisms convert ammonia and ammonium to nitrite and next to nitrate-nitrogen which is available to plants.

Soil Nitrogen Fixation – Conversion of nitrogen in the air to organic N-forms, which occurs either by soil organisms or in association with legumes.

Volatilization – Ammonia nitrogen loss from N-fertilizers and other sources. Loss can be especially high when N-fertilizers containing urea are surface-applied directly on moist residue.