Soil Quality Indicators

Soil Nitrate

Nitrate (NO_3^-) is a form of inorganic nitrogen (N) naturally occurring in soils. Sources of soil NO_3^- include decomposing plant residues and animal manure/compost, chemical fertilizers, exudates from living plants, rainfall, and lightning. Eventually, nitrate ions immobilized by microorganisms (nitrate taken up by microorganisms) are converted into organic forms and released back to the soil in plant-available forms when dead soil organisms are fed upon or decompose. In well drained soils, ammonium (NH_4^+) and ammonia (NH_3) are converted into NO_3 by very specific populations of aerobic bacteria. This process is known as nitrification.

Another biological N transformation is denitrification, which is the conversion of NO_3^- into nitrous oxide (N_2O), nitrogen dioxide (NO_2), and nitrogen gas (N_2) that often occurs in anaerobic soils, such as waterlogged soils and wetlands. Even when nitrifying bacteria are very active in the outer parts of aggregates in well aerated soils, denitrification may still occur in anaerobic microsites inside the aggregates. Nitrate is very soluble in water and can be easily transported by runoff and other surface and subsurface flows to rivers and lakes or moved downward to ground water.

Factors Affecting

Inherent — Soil texture influences NO_3^- mobility: the coarser the soil texture (sandy), the faster NO_3^- leaches through the soil profile because NO_3^- ions do not bind to sandy particles and water infiltration rates are typically very high in sandy soils. Under heavy rain, NO_3^- in those soils can eventually leach and contaminate the ground water. Less weathered types of clay minerals (e.g., montmorillonite, illite, vermiculite) have lower NO_3^- retention than very weathered clay minerals (e.g., kaolinite) found in tropical and subtropical soils. Soils with a high CEC do not retain NO_3^-. These soils, such as those in the Mississippi River basin, have major leaching issues. Climate (temperature and precipitation) affects the rate of nitrification; the optimum temperature is between 86 and 95 degrees F. Poor soil drainage creates an ideal biochemical environment for denitrification and the release of gaseous NOx into the atmosphere, which is exacerbated in carbon-rich soils (e.g., wetlands or plugged tile drains). Soil NO_3^- is sensitive to seasonal fluctuations and crop presence. Figure 1 shows that that the amount of NO_3^- increases as the soil warms in temperate regions (May and June) and then, because of NO_3^- leaching during the rainy season, sharply decreases in autumn.

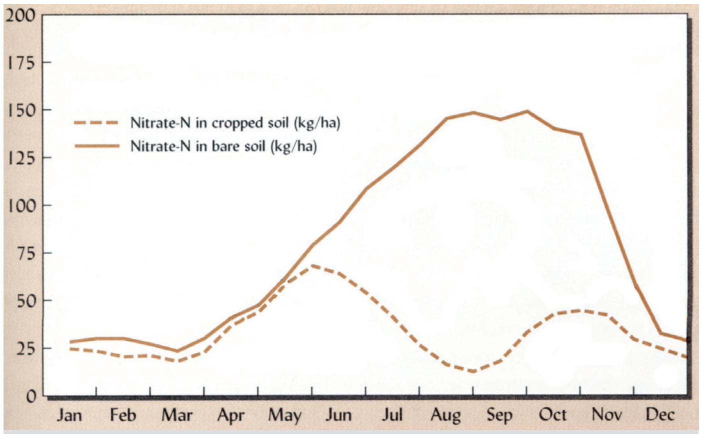

Figure 1. Typical seasonal pattern of nitrate concentration in representative surface soil layers with and without growing plants for soils typical in humid temperate regions that have cool winters and rainfall uniformly distributed throughout the year (based on Brady and Weil, 1996).

Dynamic — Nitrate is usually deficient in acid soils because low soil pH (<5.5) reduces nitrification. Nitrification ceases at pH <4.5, and the optimum pH is between 6 and 8. Because organic matter is an important source of NO_3^-, accumulation may correlate with organic matter content patterns across the landscape. Moreover, nitrification depends on microorganisms, which proliferate in the presence of organic matter. Residues with high C:N ratio (>24/1) slow down the release of NO_3^- from organic matter; microorganisms initially immobilize all available NO_3^--N from soil for their growth. This delays the decomposition of organic matter and the associated nitrification.

Relationship to Soil Function

The primary function of NO_3^- is to serve as a source of nitrogen for the nutrition and growth of plants and soil microorganisms.

Problems with Poor Activity

Denitrification results in nitrogen loss from soil and produces some forms of intermediate gaseous nitrogen (e.g., N_2O) that are harmful to the environment. Problems associated with high NO_3^- concentration include the pollution of ground water and surface water and an increased risk of eutrophication that threatens the survival of aquatic life. Nitrification can potentially result in soil acidification by hydrogen ions (H^+) released during the process.

Improving Management

In a study conducted at the University of Maryland Research Center, soil NO_3^- concentrations at any depth (except 0-30 cm) have been found to be consistently lower in no-till plots than in conventional-till plots (see Figure 2) and were related to the amount of N fertilizer applied. The explanations by the authors of the study include: (i) the lack of a winter cover crop on the conventional till plots affected the soil N content in the root zone and the subsequent rates of nitrate leaching; (ii) the no-till plots had higher rates of denitrification compared to the conventional-till plots (i.e., higher populations of denitrifying organisms in no-till); (iii) crops in no-till plots used N more efficiently (removal of more N from soil); and (iv) the conventional till plots had an accumulation of nitrate from the plant residues of previous years.

The following practices add nitrate:

- Crop rotations with legumes
- Addition of organic residues, manure, and compost
- Conservation tillage and field strips or no-till with a winter cover crop
- Split applications of fertilizer that match crop growth stages

The following practices prevent nitrate loss:

- Autumn applications of ammonium-based fertilizer on frozen soils
- Application of materials that slowly release nitrogen
- Planting cover crop species that use residual NO_3^-
- Planning the timing and rates of irrigation according to site water content
- Keeping the soil well drained
- Additions of green manure with a high C/N ratio

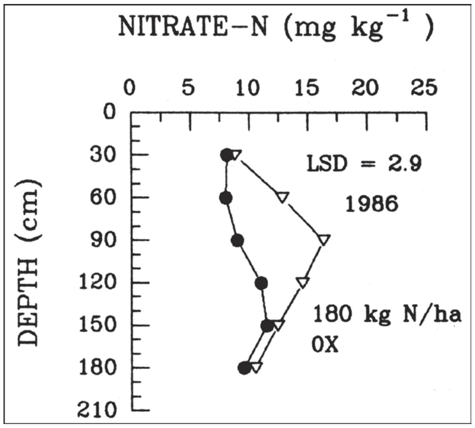

Figure 2. The effects of ammonium nitrate and tillage (●=no-till; Δ=conventional-till; 0X=no manure) on nitrate concentrations of soil collected to a depth of 210 cm during the spring of 1986 (after Angle et al., 1993).

Measuring Nitrate

Soil NO_3^- is measured in the field using a test strip as described in the *Soil Quality Test Kit Guide*. Measurement takes just 15 minutes. The test strip has two pads, one to measure nitrite (NO_2^-) and the other to measure NO_2^-/NO_3^- combined. This is not intended to be a substitute for a fertilizer recommendation but is an indication of potential management remediation needs.

References

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