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Bulletin

Soil Nitrate Testing as a Guide to Nitrogen Management for Vegetable Crops

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In-season soil nitrate testing is a diagnostic tool that can aid in predicting the sufficiency of the soil N (nitrogen) supply for a variety of annual crops. The testing procedure is often referred to as the presidedress soil nitrate test (PSNT). The PSNT was originally developed for use with field corn to predict need for sidedressing N. Its usefulness, however, has since moved beyond corn to an increasing number of vegetables. Approaches to using the PSNT or soil nitrate testing in general depend on the crop and soil system. This fact sheet will describe cropping systems where soil nitrate testing is most useful.

Matching supply of N from soil with plant demand for this nutrient is one of the nutrient management challenges of crop production. Striking a balance between having too little or too much N available from soil is important to yield, crop quality, farm profitability, and the environment. Nitrogen availability from soil can change rapidly, and soil testing for nitrate should be viewed as a snapshot in time of the soil's current N status which is reflective of the ability of the soil to supply available N to the crop. Crop demand for N uptake also changes during the course of the growing season. Thus, time of soil sampling is critical to the correct use and interpretation of soil nitrate test data. Appropriate use of soil nitrate testing should, therefore, be guided both by an understanding of the dynamic behavior of nitrate in soil and crop demand for nitrate uptake.

Factors Influencing Supply of Nitrate in Soil

When organic matter decomposes in soil, the mineral N that is released first appears in the form of ammonium. In warm soils with a favorable soil pH (6.0 to 6.5), ammonium-N (NH_4-N) concentrations are typically low because ammonium is rapidly converted to nitrate. Consequently, nitrate is the primary form of mineral N taken up by many crops. This explains why soil testing for NO_3-N is more useful than testing for NH_4-N to predict the sufficiency of soil mineral N supply to crops. Soil testing for NO_3-N, however, unlike testing for nutrients like P or K, which are relatively stable in soil, must be conducted and interpreted with consideration of the many environmental factors, such as rainfall and temperature, that can rapidly change the availability of NO_3-N.

Concentrations of soil NO_3-N are particularly susceptible to rapid change in regions of higher rainfall. Heavy rainfall can cause nitrate to leach below the depth of soil sampling or even below the root zone. When nitrate is leached from the surface layer but held in the lower profile, it remains available to deeply rooted crops, but this nitrate is not accounted for by the typical PSNT soil sampling depth. During extended periods of wet weather significant amounts of nitrate may be converted to gaseous forms of N and lost to the atmosphere by the process of denitrification.

By the end of winter, soils in regions of high rainfall typically have low concentrations of NO_3-N. Mineral N is released from soil organic matter slowly in the spring when soils are cool and more rapidly as soils become warm. In general, soil nitrate tends to accumulate in spring and decrease during summer due to crop uptake. At the end of the growing season, any nitrate that remains in the soil is vulnerable to leaching during winter unless cover crops are grown to capture it.

Coarse-textured soils and soils with low organic matter content generally have lower levels of soil test NO_3-N than fine-textured soils or soils with higher organic matter content. Fields where manure has been applied or where legumes are in the crop rotation generally have higher concentrations of soil test NO_3-N.

The quality of plant material, especially in terms of its carbon to nitrogen ratio, influences the rate of decomposition and the availability of N in soil. Plant materials such as straw have a high carbon to nitrogen ratio and its decomposition temporarily consumes available soil nitrate. Plant materials such as grass clippings have a low carbon to nitrogen ratio and cause soil NO_3-N concentrations to increase.

Demand for Nitrogen by Annual Crops

Soil nitrate testing is most suitable for use with annual crops which accumulate N rapidly within a single growing season. Typical patterns of biomass and N accumulation for annual crops are shown in Fig. 1. These patterns are similar, suggesting that the accumulation of biomass and N are closely linked. Thus, the rate of plant growth roughly approximates the rate of plant N accumulation or plant demand for N.

In annual crops, N accumulation more closely follows the pattern of dry matter accumulation during vegetative growth than during reproductive growth and maturation. This is because in the maturing crop, N uptake slows because much of the N already in the plant is remobilized from vegetative tissues to reproductive growth. The important point is that the pattern of N uptake by an annual crop is approximated by its pattern of growth, and that this pattern suggests the appropriate times for soil nitrate testing and N fertilization (Table 1).

A more detailed description of the pattern of cumulative N uptake over the growing season shows that it follows a sigmoid or 'S' curve that may be divided into three phases (Fig. 1b). A key time for soil nitrate testing is when a crop nears the end of the first phase and is about to enter the second phase of N uptake.

During the first growth phase, early plant growth and N uptake are relatively slow (Fig. 1). The use of a starter fertilizer at time of planting typically can satisfy this early demand for N uptake.

In the second growth phase (Fig. 1), there is a period of rapid N uptake, which corresponds with rapid vegetative growth. Demand for N during this growth phase is the highest of the growing season. As much as 50 to 85% of the total N uptake for the growing season is taken up during this growth phase. Producers can anticipate this growth phase by becoming familiar with the growth pattern of a particular annual crop. Any needed N fertilizer should be applied in advance of this growth phase to ensure that N is not limiting. The value of soil nitrate testing performed before the second growth stage is that the soil NO_3-N concentration can be used to predict whether the supply of N from soil is adequate to meet the demands of the second growth phase. Another consideration with regards to N fertilization is that the enlarging crop canopy may make later applications of N fertilizer difficult.

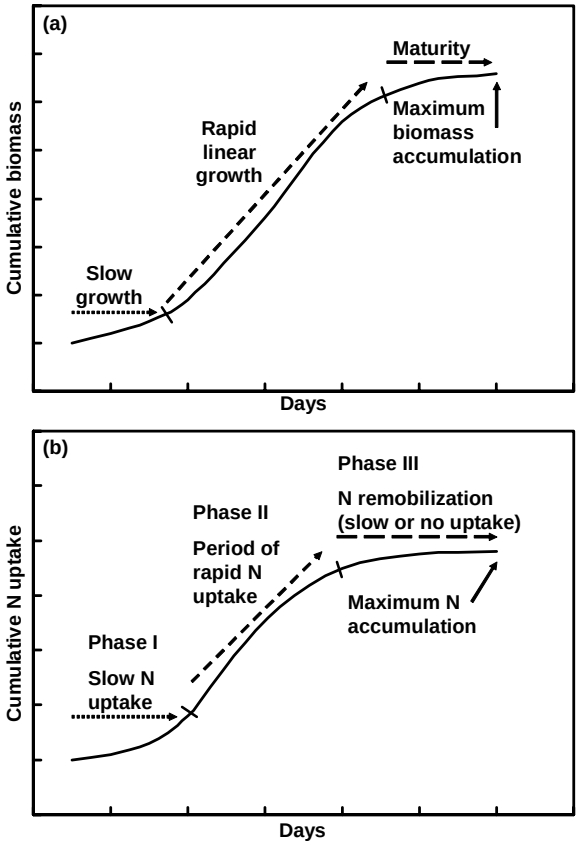

Figure 1. Typical biomass accumulation curve (a) and N accumulation curve (B) for annual crops.

In the third growth phase (Fig. 1b), vegetative growth (stems, leaves, etc.) has largely ended while reproductive structures (seed, fruit, tubers) are in development. As the crop approaches maturity, N is remobilized within the plant from vegetative to reproductive tissues. Nitrogen uptake from soil is slow. Applying N fertilizer during this final growth phase is seldom effective for increasing crop yields. Late applications of N may also slow maturation

and reduce crop quality. A possible exception where late N fertilization may be useful is on an indeterminate fruiting crop such as tomato.

Time of Sampling for Soil Nitrate Testing

The dynamic nature of soil nitrate concentrations and the changes in N demand during crop growth are key considerations in the effective use of soil nitrate testing. In general, soil sampling should be performed just prior to the period of rapid N uptake by the crop (Table 1). This allows the many environmental factors that influence soil NO_3-N concentration to operate as long as possible before the start of the crop growth period with the highest requirement for N uptake and before making a decision about N fertilization.

For certain crops, soil nitrate tests may be performed at other times. For example, multiple sidedressings of N fertilizer are often recommended for the production of vegetable crops such as celery, peppers, and tomatoes. In each case the decision as to whether any of these sidedressings are needed can be based on the results of a current soil nitrate test. However, if an earlier application of sidedress N was placed in a small zone (e.g. band), rather than uniformly over the field, then this may make the following soil sampling and soil nitrate test interpretation difficult or impossible.

Where to Use Soil Nitrate Tests

Time, labor, and costs of conducting soil nitrate tests limit the number of field sites that can be tested. Efforts should, therefore, be directed towards fields or cropping systems where soil nitrate testing can provide useful information. To prioritize fields for testing, one should consider the following:

Soil Type. Soils with a sandy texture or low organic matter content can be expected to have low soil NO_3-N concentrations. There is little useful information to be gained by performing soil nitrate tests on such soils, because crop need for N fertilizer is already predictable. It is generally better to focus efforts in soil nitrate testing on soils that have relatively high organic matter contents.

Manure or Compost. Fields that have received recent applications of manure, compost, or other N rich amendments are good candidates for soil nitrate tests. The soils in these fields will likely have elevated concentrations of NO_3-N. Questions remain, however, as to whether soil N availability will be adequate for crop production. This represents the classic example of where soil nitrate testing is especially useful in predicting whether or not supplemental N fertilizer is needed.

Table 1. Suggested times for soil sampling for use of in-season soil nitrate tests on various crops.

Crop	Time of soil sampling
Field corn Sweet corn	When plants are 6 to 10 inches tall.
Cabbage Cauliflower Broccoli Brussels sprouts	2 weeks after transplanting.
Celery	2 weeks after transplanting. Sample again in about 3 to 4 weeks.
Lettuce Endive and Escarole	2 weeks after transplanting or after thinning if direct seeded (2- to 4-leaf stage).
Beets Turnip Rutabaga	After thinning (2- to 4-leaf stages).
Pumpkin Winter squash Cucumber Muskmelon	When vines are 6 inches long.
Spinach	At 2- to 4-leaf stages. Sample again after cutting.
Irish potato	When plants are 6 inches tall.
Pepper Tomato Eggplant	At first fruit set. Sample again 3 to 4 weeks later.

Preplant Broadcast N. Fields that received broadcast applications of N fertilizer at the time of planting may also be appropriate for soil nitrate testing. The interpretation of soil nitrate tests in this instance may depend on the amount of rainfall received since the time of applying the broadcast N. When rainfall has been below normal, it is generally safe to assume that much of the N that had been broadcast is still available to the growing crop. However, when rainfall has been above normal, there is a concern about leaching and denitrification, and about whether enough N is still present to grow the crop. Because weather conditions continually influence N transformations in soil (mineralization, immobilization, denitrification, and leaching), soil nitrate testing is most useful for assessing the soils' current N status. When soil nitrate testing is performed at the proper crop growth stage the results of the test can help to predict if there is a need for additional N application.

Double Cropping. When cabbage and other vegetables are grown as a fall crop following the harvest of early season vegetables, such as sweet corn, peas, snap bean, or lettuce, in some cases enough carryover N from the early crop is available to grow the fall crop. Soil nitrate testing can be used to measure both the carry-over N and the release of N from the incorporation of the previous crop's residue.

Legume Cover Crops. When N-fixing crops are grown in the rotation and plowed down, soil nitrate testing can be used to predict if sufficient N has become available for the production of the non-legume crop that follows.

Organic Systems. Organic growers are challenged to provide optimal N fertility to crops from hard-to-quantify natural sources of N. The organic philosophy is to feed the soil rather than feed the crop during the growing season with sidedress N fertilizer. The function of soil nitrate testing in organic systems is not, therefore, to determine whether sidedress N fertilizer is needed. Rather, its function is to learn about the performance of the current organic fertility program that is in place and if that program needs adjustment for future growing seasons. Soil nitrate testing might help to indicate when excessive rates of N-containing materials have been applied which, upon mineralization, has the potential to leach N.

Procedures for Soil Nitrate Testing

In general, sample after crop establishment and just before the crop begins to grow and take up N rapidly. Some suggested sampling times are given in Table 1. Soil cores should be taken from the 12 inch depth, which is deeper than for a traditional soil fertility test. The deeper sampling helps to capture nitrate that is moving below the surface layer.

Areas having different soil types or management histories must be sampled and treated separately. Collect 15 to 20 soil cores from the area to be sampled and probe between the rows and away from any starter fertilizer band. For vegetable crops grown where all N fertilizer was broadcast and incorporated in the bed and covered with plastic mulch, sample from the bed by probing through the plastic. Thoroughly mix the soil and save about a cupful to carry out the analysis for NO_3-N.

Microbial activity can rapidly change the concentration of NO_3-N in warm, moist soil samples; therefore, the soil samples must be dried immediately after sample collection. The samples can be dried by spreading the soil in a thin layer on a sheet of plastic overnight. A microwave oven run at full power may also be used to dry soil samples more rapidly. One of several commercially available soil nitrate test kits can be used to determine the soil NO_3-N concentration in parts per million, or the samples can be sent by express mail to a university or commercial soil testing laboratory.

Interpretation of Soil Nitrate Test Results

The interpretation of soil nitrate tests is based on the findings of soil test calibration research conducted with a variety of crops grown in many regions of the USA. By far, the largest body of calibration data is for field corn collected from many states. These data have consistently

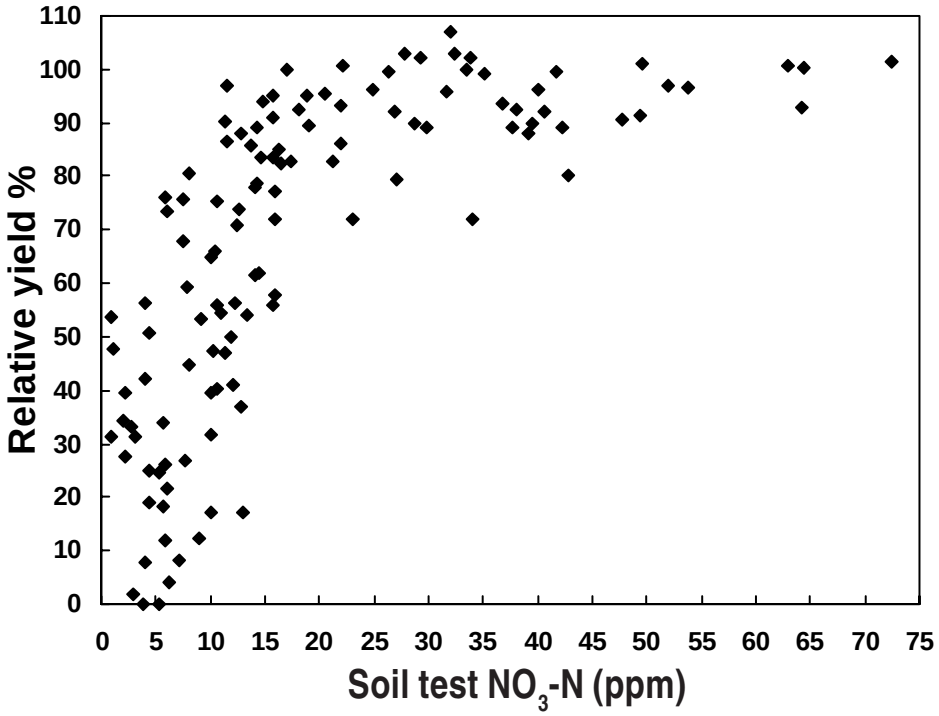

Figure 2. Relative yield of marketable cabbage heads as a function of soil nitrate (NO_3-N) concentration in surface 12 inches of soil sampled at 14 days after transplanting

shown that soil NO_3-N concentrations of 25 ppm indicate N sufficiency for field corn.

Research conducted on other crops such as sweet corn, celery, lettuce, cabbage, peppers, pumpkin, winter squash, and sugar beets suggests that sufficient soil N is available to grow these crops when the soil nitrate test is between or above 25 to 30 ppm NO_3-N. Some research has shown even lower concentrations were considered sufficient, but until additional research has been conducted, 25 to 30 ppm NO_3-N should be used as the generally recommended sufficiency level. In vegetable crops that set fruit, such as peppers, pumpkin, and squash, the application of sidedress N when the soil NO_3-N concentration is greater than 30 ppm may cause crop yields to decrease.

A typical display of soil test calibration data is shown in Fig. 2 for cabbage. A summary of suggested soil nitrate test interpretations is given in Table 2.

No soil test or system of providing N recommendations is always on target. Research on the PSNT, however, indicates that soil nitrate testing generally makes correct predictions as to whether applications of sidedress N are needed. The success of soil nitrate testing in improving N management in field corn, sweet corn, cabbage, celery, lettuce, beets, pumpkin, winter squash, pepper, and tomato crops has led to grower interest in extending the practice to other crops where research data are lacking. Soil nitrate testing is expected to also be useful on cauliflower, broccoli, Brussels sprouts, endive, escarole, turnip, rutabaga, cucumber, muskmelon, spinach, Irish potato, and eggplant, but growers should use the test with caution until more experience is obtained with these crops. In regions where soil nitrate testing research has been conducted, local Extension recommendations should be followed. Soil nitrate testing is not universally recommended for all crops and soils, but it is a useful tool when employed with knowledge and understanding of the N-cycle and the impacts of weather conditions on soil N availability.

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Table 2. Interpretation of in-season soil nitrate tests for annual crops.

Soil test NO_3-N (ppm)	Interpretation
Less than 20	Very likely N deficient, sidedress N is recommended.
20 to 24	May be sufficient for some crops. A low rate of sidedress N may be applied to ensure that N is sufficient.
25 to 30	Sufficient N is available for most crops. Sidedress N is usually not recommended.
Greater than 30	Sidedress N is not recommended.
Greater than 50	Excessive. Indicates excessive application of manure, compost, or other sources of N.

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