MARYLAND COOPERATIVE EXTENSION
UNIVERSITY OF MARYLAND
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Fact Sheet

Fact Sheet 559

Nitrogen Recommendations for Corn Using the Pre-Sidedress Nitrate-Nitrogen Soil Test

Corn is one of the most important agronomic crops grown in Maryland. With approximately 550,000 acres planted annually, corn generates the largest demand for nitrogen fertilizer of any crop. Each year Maryland growers purchase over 50,000 tons of commercial nitrogen fertilizers, a large percentage of which is applied to corn.

Nitrogen (N) is one of the most expensive fertilizers to manufacture because of its dependency on petroleum as a source of hydrogen in the production of ammonia and the high energy requirements for this process. Thus, if nitrogen fertilizer is improperly managed, the cost can strain growers' budgets. Additionally, excessive nitrogen fertilizer applications can pose a threat to water quality. A dependable nitrogen soil test, combined with other best management practices, can be a valuable tool in improving profit margins for farmers and reducing the threat of nitrogen enrichment to Maryland's surface and groundwater.

Routine and Nitrogen Soil Tests

The best way to estimate available soil nutrients and soil pH (acidity) is through use of a scientifically calibrated soil test. Soil testing has become accepted as a routine practice by many growers for custom designing lime and fertilizer recommendations for more efficient crop yields. Having soil tested for pH, phosphorus (P_2O_5), potassium (K_2O), magnesium, and numerous other secondary and micronutrients has been routine procedure for decades. But until recently, routine soil testing excluded nitrogen. Without having a reliable nitrogen soil test available, crop growers had to base nitrogen recommendations entirely on careful estimates of plant needs and the amount of nitrogen supplied by the soil, previous crops, and manure applications.

The laboratory procedure for testing soil nitrogen is no more difficult than testing for most other nutrients. Analytical procedures have been available for decades for analyzing soil, plants, and other materials for total nitrogen and even the plant-available nitrate nitrogen (NO_3-N) and ammonium nitrogen (NH_4-N) forms. However, what complicates testing for available soil nitrogen is that the amount of available nitrogen in soil constantly changes with time as N is released from soil organic matter. Most soil nitrogen is tied up in organic matter and is unavailable to plants. Although some is in the NH_4-N form, most plant-available nitrogen occurs as NO_3-N, a negatively charged ion that is completely soluble and mobile in the soil. There is usually relatively little available nitrogen (NO_3-N or NH_4-N) in the soil at any given time. The process of nitrogen mineralization (converting organic nitrogen to plant-available NO_3-N and NNH_4-N) is carried out by various soil microorganisms. The activity of these microorganisms depends heavily on soil moisture, temperature, aeration, pH, and a variety of other factors.

Unlike P_2O_5 and K_2O, plant-available nitrogen is more subject to loss from the root zone through leaching, denitrification, and volatilization, as well as by plant uptake. Available soil nitrogen levels are in a relatively dynamic state during the growing season, in contrast to a comparatively static state for most other nutrients. The nitrogen soil test can only be used to estimate how much available nitrogen is present at the time of sampling.

In contrast to nitrogen, soil P_2O_5 and K_2O are nonmobile and persist in the soil profile. Leaching and other physical or chemical processes do not rapidly change the quantity of available P_2O_5 and K_2O in the plow layer. Thus, a P_2O_5 or K_2O soil test can be performed at almost any time of the year and still be useful as the basis for a reliable prediction of any P_2O_5 and K_2O fertilizer needs for the coming season. But because the soil's available nitrogen content (NO_3-N and NH_4-N) is much more dynamic, applying conventional soil test procedures to nitrogen has been difficult. The task of interpreting NO_3-N soil test results from samples taken at times other than rigidly specified times is very difficult (if not impossible).

Pre-Sidedress Nitrate-Nitrogen Soil Test

For a nitrogen soil test (in this case, a pre-sidedress NO_3-N soil test) to be useful for predicting crop needs for additional nitrogen fertilizers or manure, the test procedure must be accurately calibrated for each specific crop and carried out at a specific stage of growth. The pre-sidedress NO_3-N soil test can only provide a snapshot of changing soil nitrate levels during a brief, well-defined time that is specific for year, field conditions, and previous crop history. Based on field calibration data, this snapshot must then be interpreted to develop a nitrogen fertilizer recommendation for a specific set of growing conditions.

Utilizing what is currently known about the relationship of time to the mineralization of soil organic matter and to the nutrient uptake pattern of corn, an appropriate time for applying the pre-sidedress NO_3-N soil test has been established—when corn is 12 inches tall. This test procedure was first developed at the University of Vermont and has subsequently been tested and modified at numerous other USDA and state agricultural experiment stations.

The first important step before testing soil for nitrogen is to obtain a representative, well-mixed soil sample. Experience shows that the minimum number of soil cores required to assure that the sample represents the field is about double that for a routine soil test. Thus, if 10 to 15 soil cores are considered satisfactory for a routine soil sample in a uniform 10-acre field, then 20 to 30 cores would be a minimum for the pre-sidedress NO_3-N soil test. Air-dry the soil sample immediately to stop microbial formation of additional nitrates. Run the analysis for NO_3-N as soon as possible after the soil is air-dried.

Because soil nitrogen is mobile and all the available nitrogen in the soil is not necessarily located in the top 6- to 8-inch layer, and because plant roots normally extend much deeper than 6 to 8 inches, the most accurate procedure to use to sample soil for available nitrogen would be to sample the entire root zone, which is 3 to 4 feet deep in many soils. However, to routinely sample soil at this depth would obviously be impractical. To be realistic, take soil samples from a shallower depth. For the pre-sidedress NO_3-N soil test, a sampling depth of 12 inches is used as a compromise between the need to sample beyond the plow layer and the impracticality of deep sampling.

The information provided by the pre-sidedress NO_3-N soil test will have limitations because of the relatively shallow sample depth compared to plant rooting depth. However, most soil organic matter (a major source of nitrate production) is located in the top 12 inches. If soil sampling is made at the proper time, most of the soil NO_3-N should be found in this zone. But it must be recognized that the results from an otherwise properly taken soil sample might be interpreted as needing additional nitrogen when in fact sufficient nitrogen is available in the root zone below the 12 inches represented by the sample. This characteristic will occasionally result in a higher-than-needed nitrogen recommendation. But the net result of regularly using the pre-sidedress NO_3-N soil test has shown less use of nitrogen overall than had the pre-sidedress NO_3-N soil test not been used.

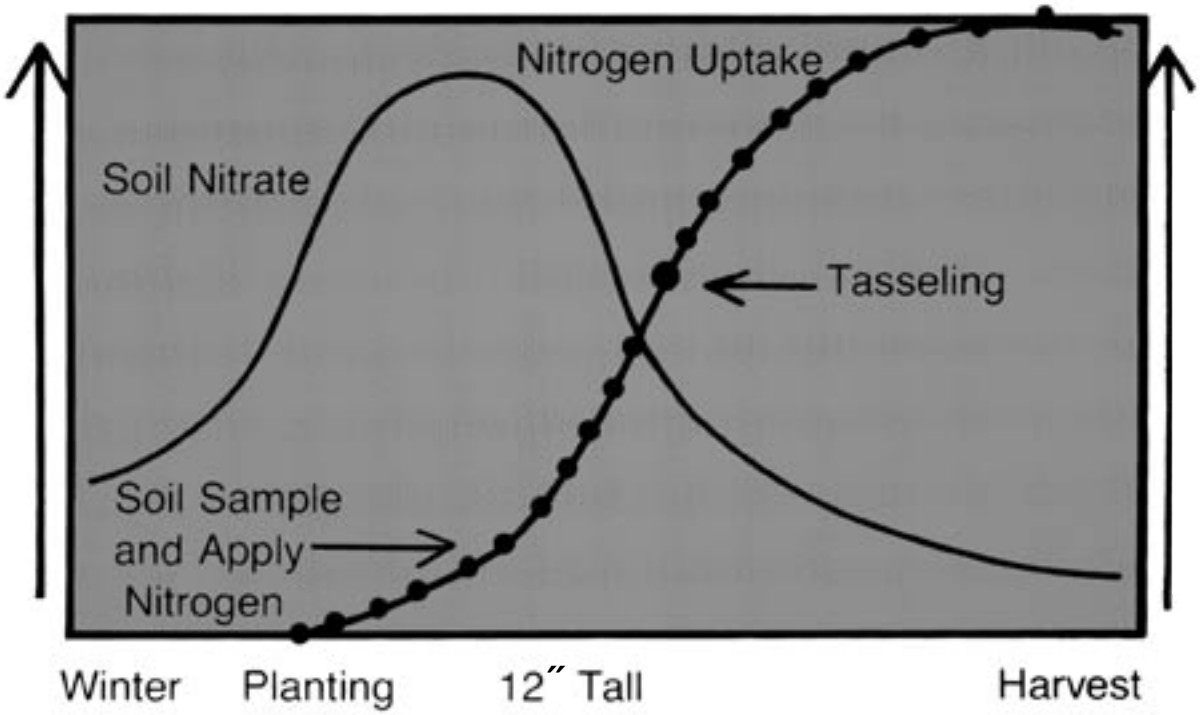

Figure 1. Relationship of soil nitrate accumulation to plant nitrogen uptake.

Another limitation of the pre-sidedress NO_3-N soil test is that it does not account for any NH_4-N that might also be present in the root zone. Although usually existing in much smaller quantities than NNO_3-N, some NH_4-N is taken up also by plants.

The biological decomposition of organic nitrogen is temperature- and moisture-dependent. Thus, during that portion of the year when soil temperatures are cooler (such as late fall, winter, and early spring), soil microbes are relatively inactive and subsequently soil nitrate levels remain low. As soil temperatures rise in the spring, microbial activity increases, thereby increasing soil nitrate levels.

During early spring, corn grows relatively little and the subsequent demand for nutrients is low. The young corn plant accumulates relatively little dry matter and takes up only small amounts of nitrogen, P_2O_5, and K_2O during its first 25 to 30 days of growth. After approximately the first month, rapid increases in growth and dry matter accumulation result in dramatic increases in plant demand for nutrients (Figure 1).

The result of the increased microbial activity and low plant uptake early in the growing season is a temporary buildup of NO_3-N in the soil. Since nutrient uptake by plants increases dramatically soon after sidedressing time (when the plants are about 12 inches tall), this is the time when the soil's NO_3-N should be at its highest. This relationship of soil NO_3-N to plant growth is illustrated also in Figure 1. Thus, this would be the most appropriate time to test for soil NO_3-N. For the most accurate and consistent soil test result, it is critical that the pre-sidedress NO_3-N soil test be used only during this rigidly specified and narrow time slot; that is, sample the soil 12 inches deep when the corn is 12 inches tall.

Nitrogen Recommendations Based on the Pre-Sidedress NO_3-N Soil Test

The goal of a good nitrogen management program is to have maximum nitrate in the soil when vegetative growth is rapid, yet to end the season with a minimum of residual nitrate in the soil. The object is to achieve maximum nitrogen efficiency and minimize the chance of groundwater contamination.

To achieve this goal, it is critical that NO_3-N levels in the top 12 inches of soil be tested in mid-June when the corn plants are about 12 inches tall, as stated previously. If the pre-sidedress NO_3-N soil test results are 25 parts per million (equivalent to 100 pounds of nitrogen per acre) or more, research indicates that the probability for needing additional nitrogen fertilizer is low. If the soil test levels are less than 25 parts per million NO_3-N, there is a higher probability of a need for additional nitrogen from fertilizer or manure. In most cases, the 100 pounds of nitrogen per acre measured by the pre-sidedress NO_3-N soil test at sidedress time will not be adequate to produce the highest yields. In addition to this NO_3-N though, some NH_4-N will also be present, which can be utilized by plants. In addition, microbial activity will normally continue to release nitrogen from soil organic matter throughout the summer, as long as soil moisture and other conditions are favorable. There also will be NO_3-N and NH_4-N available to the corn plant at depths below 12 inches because corn will normally root to 3 feet or more in Maryland. Thus, the total amount of nitrogen available from the soil during the growing season is usually greater than that indicated by the 12-inch soil test at sidedress time.

Research indicates that the pre-sidedress NO_3-N soil test is most useful for identifying those soils that need additional nitrogen and separating them from those soils that do not. At this time the test does not appear to be sensitive enough to use as an indicator for proportionately adjusting nitrogen rates in those soils that contain less than 25 parts per million of NO_3-N and are thus considered to be nitrogen-deficient.

To use the pre-sidedress NO_3-N soil test properly, keep in mind that the test's usefulness is currently calibrated for just one crop—corn. Furthermore, do not use this soil test to predict how much nitrogen to apply. The total amount of nitrogen needed in nitrogen-deficient soil and the recommended method of application will continue to depend on such factors as yield goal, manure additions, and previous cropping history.

Developing the Nitrogen Recommendation

Before a nitrogen recommendation can be established—even with a reliable nitrogen sufficiency soil test— take into account several other important factors by doing the following:

- Calculate the total nitrogen requirement of the corn crop to be grown. In most cases, this will depend on establishing a realistic yield goal.
- Determine the amount of nitrogen expected from other sources, such as a previous legume crop, the kind of leguminous crop residue in the field, the percentage of legumes in the stand, and the kind and amount of manure or sewage sludge applied.
- Identify the soil that already has adequate available soil nitrogen and separate it from soil that needs additional nitrogen.

Once the crop's total nitrogen requirement is known, and if the pre-sidedress NO_3-N soil test indicates a need for additional nitrogen, any remaining nitrogen requirement can be recommended from commercial fertilizers, manure, or crop residues, whichever is appropriate.

After many years of evaluating nitrogen rates on nonirrigated no-tillage and conventional tillage (plow tillage) corn, experts have learned that the traditional recommendation of 1.2 pounds of nitrogen per bushel of yield is too high. A revised recommendation of 1 pound of nitrogen per bushel more closely satisfies plant needs for the majority of anticipated yield levels with less risk of nitrogen enrichment of the environment. It is also much easier to calculate than previous procedures. For instance, whatever the selected yield goal is in bushels per acre, that value also equals the pounds of nitrogen per acre recommended. For example, using the revised method, for a 100-bushel-per-acre yield goal, 100 pounds of nitrogen per acre is recommended. For a 125- or 150-bushel-per-acre yield goal, the recommendation is 125 or 150 pounds of nitrogen per acre, respectively.

All nitrogen recommendations suggested by University of Maryland Cooperative

Extension assume that growers follow best management practices when applying nitrogen. For example, nitrogen must be applied in a timely manner (a small amount of starter, but most nitrogen sidedressed to coincide with the time of the plant's greatest need for nitrogen) using application techniques that minimize losses caused by leaching, ammonia volatilization, and denitrification. For more specific information on nitrogen management for corn, refer to Fact Sheet 514, "No-Till Corn Production: Achieving Maximum Nutrient Efficiency."

To develop a nitrogen recommendation for field corn, first establish a realistic yield goal for the field. It is important to take into consideration soil type, past overall fertilization practices, variety selection, weather, and management. The yield capability of all soil is not equal.

The best strategy, if records are available, is to simply average the yields from each field over the previous 3 to 5 years. Then, depending on expected conditions for the coming growing season, adjust this average value by a factor of plus or minus 5 to 10 percent. If yields from a field have been increasing in recent years, increase the yield goal by 5 to 10 percent. The important point is to be realistic in establishing a yield goal.

Higher corn yields are more likely under properly managed no-tillage than plow tillage. No-till corn recommendations can be as high as 180 to 200 bushels per acre on good land. However, the maximum realistic yield goal for nonirrigated plow tillage corn on highly productive land should not normally exceed 160 to 170 bushels per acre. It is possible that these goals will be exceeded if all growing conditions are favorable.

Once the total nitrogen rate has been calculated, in the absence of the pre-sidedress NO_3-N soil test or if the pre-sidedress NO_3-N soil test indicates a need for additional nitrogen, subtract from the total any other nitrogen that might be supplied from manure, legume residues, or some other similar source, as suggested in Table 1.

At this stage, the pre-sidedress NO_3-N soil test can be helpful in determining whether additional nitrogen is needed. The pre-sidedress NO_3-N soil test can even be used in those cases where some nitrogen fertilizer has already been applied, so long as the nitrogen was broadcast and the amount of nitrogen applied did not exceed 50 pounds per acre. Nitrogen banded with P_2O_5 as a starter fertilizer should not interfere with the reliability of the NO_3-N soil test so long as soil sample cores were not taken from the fertilizer band itself.

Nitrogen Efficiency

When developing a nitrogen recommendation for corn, it is important that maximum yields not be the only main determinant. Nitrogen efficiency is also important and should be a prime consideration. Research shows that nitrogen efficiency declines rapidly as yield goals increase. For instance,

Table 1. Nitrogen credit allowances for leguminous crop residues. Use in absence of NO_3-N soil test or if NO_3-N soil test is less than 25 ppm

Crop	Nitrogen (lb/A)
Alfalfa (75% stand)	50 to 100[a]
Ladino clover	60
Winter annuals—crimson clover, hairy vetch, Austrian winter peas	50 to 100[b]
Red clover	40
Birdsfoot trefoil	40
Lespedeza	20
Soybeans (grain harvest residue)	15

[a] Depends on stand density. For example, 75% stand = 100 lb N/A; 50% stand = 75 lb N/A; 25% stand = 50 lb N/A.
[b] Depends on stand density and date of kill.

after 17 years of evaluating nitrogen rates on nonirrigated no-tillage and conventional tillage corn, it has been found that as maximum yields are approached, the last few bushels of yield require much more nitrogen fertilizer than the first few bushels.

As growers strive to obtain increasingly higher yields, production costs increase dramatically for inputs, such as nitrogen fertilizers. This is a major reason yield goals should be established at realistic levels. Yield goals that are unreasonably high waste nitrogen resources, misuse grower's dollars, and may contribute to ground and surface water pollution.

The nitrogen response data referred to earlier are based on 17 years of research at two Maryland locations. Under the conditions of this research, maximum yields averaged over the duration of the tests were 166 and 159 bushels per acre for no-tillage and plow tillage corn, respectively (Table 2).

Because the amount of nitrogen required per bushel increases rapidly as the point of maximum yield is approached, maximum yields are not the most efficient yields. Maximum economic yield is defined as the yield where the cost of the nitrogen fertilizer applied is equal to the value of the grain produced. This is typically only slightly lower than maximum yield, but it usually requires significantly less nitrogen to produce and is thus more profitable.

Based on trends demonstrated by these long-term data, and assuming the cost of nitrogen to be $0.25 per pound and the value of corn to be $2.50 per bushel, the maximum economic yields would be 165 and 158 bushels per acre for no-tillage and plow tillage corn, respectively (Table 2).

At this cost to price ratio ($0.25/$2.50), the differences between maximum yields and maximum economic yields would be just 1 bushel per acre for both tillage systems. Yet, the difference between the amount of nitrogen required to achieve maximum yields and that required to achieve maximum economic yields would be a more significant and costly 20 pounds of nitrogen per acre.

Both tillage systems require an additional 20 pounds of nitrogen per acre to produce the last bushel of corn. At $0.25 per pound of nitrogen, the last bushel would cost $5 for nitrogen alone, not to mention the uncertainty associated with trying to grow that last bushel. Obviously, in this case, if corn were worth only $2.50 per bushel, maximum yields would not be economically feasible since the nitrogen cost of production alone is twice the value of the additional yield.

Management becomes even more critical should the cost of nitrogen increase in relation to the price received for corn. To illustrate with a more extreme case, consider a cost of nitrogen at $0.35 per pound and the price of corn at $2 per bushel. Data in Table 2 show that with this much higher cost-to-price ratio ($0.35/$2), maximum economic yield would drop just 2 bushels to 163 and 156 bushels per acre for no-tillage and plow tillage corn, respectively. But the nitrogen required to produce maximum economic yield for both tillage systems would be 35 pounds per acre less than that required for maximum yield. In this case, when nitrogen rates exceed 187 or 165 pounds per acre for no-tillage or plow tillage corn, respectively, the cost of producing each additional increment of grain would exceed the value of the crop produced.

Table 2. Average maximum yields, maximum economic yields, and associated N rates for two tillage systems. **University of Maryland Cooperative Extension, LESREC Poplar Hill Facility and Wye REC, 1973–1989**

	No-tillage		Plow tillage	
	Bu/A	N-lb/A	Bu/A	N-lb/A
Maximum yield	166	222	159	200
Maximum economic yield[a]	165	202	158	180
Maximum economic yield[b]	163	187	156	165

[a] N cost at $0.25/lb and corn valued at $2.50/Bu.
[b] N cost at $0.35/lb and corn valued at $2/Bu.

From the examples in Table 2, it is evident that the higher the nitrogen rate, the less efficient nitrogen becomes and the more expensive it becomes to produce each additional bushel of corn. Ideally, the most efficient yield goal would be one that is high enough to permit maximum returns above production costs, yet not so high that the cost of producing each additional bushel of grain exceeds the value of that extra bushel. You must be the best judge of what your maximum economic yield goal should be. Once decided, the pre-sidedress NO_3-N soil test can potentially result in significant cost savings for nitrogen fertilizers, especially where manure or legume crop residues are available.

An Overview of Developing Nitrogen Recommendations

To develop the most efficient nitrogen recommendations for corn, follow these suggestions:

1. Obtain a representative soil sample from the field sometime during the previous fall, winter, or spring and have routine tests performed to determine any need for lime, P_2O_5, and K_2O. If suspected deficiencies of secondary and micronutrients are a concern, run appropriate special soil tests at this time. Develop suitable lime and fertilizer recommendations based on a realistic yield goal.
2. Keep any preplant broadcast nitrogen fertilizer to less than 50 pounds per acre if you're using the pre-sidedress NO_3-N soil test. If more than 50 pounds of nitrogen per acre has been broadcast, do not use the pre-sidedress NO_3-N soil test. However, starter nitrogen banded with P_2O_5 should not affect the reliability of the pre-sidedress NO_3-N soil test as long as soil samples are not taken from the fertilizer band itself.
3. Conduct the pre-sidedress NO_3-N soil test at the proper time. Sample soil in early to mid-June when the corn plants are 12 inches tall, typically just prior to the traditional nitrogen sidedressing stage.
4. Take a representative, well-mixed soil sample for the pre-sidedress NO_3-N soil test. Take soil samples from the top 0 to 12 inches. For the most precise text, take at least twice as many soil cores per acre as you would take for a routine soil test. A good rule of thumb for time and depth of sampling is to *sample the soil 12 inches deep when the corn is 12 inches tall.*
5. Air-dry the pre-sidedress NO_3-N soil sample immediately to stop microbial formation of additional nitrates. Analyze for NO_3-N as soon as the soil is air-dried. Carry out the soil analysis in exactly the prescribed manner to determine if the soil is likely to respond positively to additional nitrogen. For a list of soil testing labs, check with your county Extension agent or go to the web at http://www.agnr.umd.edu/soiltesting.
6. Determine if additional nitrogen is needed. If the pre-sidedress NO_3-N soil test indicates there are 25 parts per million of NO_3-N or more, the probability that corn will respond to additional nitrogen is very low, and no additional nitrogen should be recommended. If the pre-sidedress NO_3-N soil test indicates a high probability that corn will respond to additional nitrogen fertilizer (less than 25 parts per million of NO_3-N), calculate the total amount of nitrogen that should be applied at sidedress time.
7. Use the values in Table 1 to estimate the amount of nitrogen that will be supplied by the old crop residue if a leguminous crop has preceded the present corn crop. Also, calculate any nitrogen credits for manure and fertilizer nitrogen applied preplant.
8. Subtract any nitrogen credits from the total nitrogen recommendation if the pre-sidedress NO_3-N soil test was not used or if the pre-sidedress NO_3-N soil test was used and the results were less than 25 parts per million of NO_3-N. Apply any remaining nitrogen requirement when the corn plants are 12 to 18 inches tall.
9. Establish a reasonable, realistic yield goal for the crop to be grown based on soil

capability, past cropping history, and crop management. Use yield records from past years as a guide. Keep in mind that, ideally, the most efficient yield goal should be high enough to permit maximum returns above production costs, yet low enough that the cost of producing each additional bushel does not exceed the value of that extra bushel. If yields have been increasing in recent years, add 5 to 10 percent onto the past yield records.

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