Section E

How to determine the optimum rate of nitrogen fertilizer

A general strategy for developing a nutrient management program is the **4Rs system:** the **R**ight rate, the **R**ight source, the **R**ight placement, and the **R**ight timing. These 4Rs are interrelated and have to be adjusted based on some choices, but the major first step is the right rate. The University of Nebraska–Lincoln (UNL) has developed its nitrogen recommendation procedure over the last 50 years based on research and the experience of the soils faculty. More detail on the procedures and other nutrients can be found in the references at the end of this chapter. An Extension Circular (EC) that details the calculations, and two tools help do the calculations. All UNL nitrogen recommendations are given when soil test values are entered at the online *soiltest.unl.edu/soiltestlab/pages/index.jsp.* For nitrogen application to corn, the Excel spreadsheet is a way to formulate a recommendation.

Since corn under irrigation is by far the major user of nitrogen this chapter will focus on developing a nitrogen recommendation for corn. *Table E-1* gives a simplified table of general nitrogen needs to grow a bushel of our major crops. On the soil test website a recommendation for any common crop can be found. In addition, there are NebGuides for individual crops available at: *ianrpubs.unl.edu/epublic/pages*.

Table E-1. Nitrogen required per unit of production.

Crop	Estimated Nitrogen Required
Corn	1.2 lb nitrogen/bushel
Wheat	2.0 lb nitrogen/bushel
Grain sorghum	1.0 lb nitrogen/bushel
Sugar beet	20 lb nitrogen/ton
Grass pastures	40 lb nitrogen/ton
Brome grass hay	35 lb nitrogen/ton

UNL's approach to nitrogen recommendations, as outlined in this manual, uses a realistic expected yield and considers credits for various sources of nitrogen. After expected yield is estimated, the next step is to calculate the total amount of nitrogen needed for production. Fertilizer needs are then determined by reducing the total nitrogen needs according to existing soil nitrate levels, expected mineralization from soil organic matter, and other nitrogen credits. In the next section the various credits are explained in detail. In addition to the agronomic credits, we adjust the recommendations for economics and for timing.

Most agronomists agree that the above approach is correct in principle. Minor differences may occur due to specific details of how much to credit soil nitrate, organic matter release, and previous crops. Managers may not have experience calculating these credits, may not be familiar with the research which supports their use, or may consider the risk of reducing fertilizer amounts to be too great. As described in Section B, the result is often a greater-than-necessary nitrogen fertilizer application, which increases costs and negatively impacts water quality.

Because of unknown weather throughout the growing season and all the transformations discussed in Section D, the optimum N fertilizer rate for any field in any year cannot be determined with absolute certainty. However, enough is known or can be estimated to arrive at a rate that is reasonable. An N rate lower than optimum will increase the risk of lower yields. Selecting an N rate above optimum will cost more, may offer no additional yield, and may be lost to the groundwater. UNL has developed a procedure to help determine the N application rate that will meet crop needs and minimize the risk of N losses. When nitrogen losses are known to occur after application, the rate needs to be adjusted, and the management plan refined, so future nitrogen loss is minimized.

Realistic crop yield expectations

Selecting an optimum rate of nitrogen fertilizer for corn is based upon the expected yield for a given field. The total nitrogen required by corn is related to yield. The UNL recommendation system requires a realistic estimate of expected yield. To set a realistic expected yield for a given field, use the average of the five most recent crop yields, plus 5%. An unusually bad year can be omitted.

Example: Calculation of realistic corn yield for an irrigated corn field

Irrigated corn

5 years of yields (bu/acre)

208, 221, 215, 170 (hail), 205

Average all years= 203 bu/acre

Average with 170 bu/acre omitted = 212 bu/acre

Expected yield (EY) in this case is 212 x 1.05 = **223 bu/acre**

Caution: Do not over-estimate crop yields for nitrogen use decisions. Increasing the average yields by 5% will provide enough increase in the nitrogen recommendation to account for the increasing yield potential provided by advancing technology. If yield is unsatisfactory, several factors can contribute to grain yield so just increasing the yield goal is unlikely to increase yields. Examine the complete cropping system to determine what the limiting factor is and address this directly.

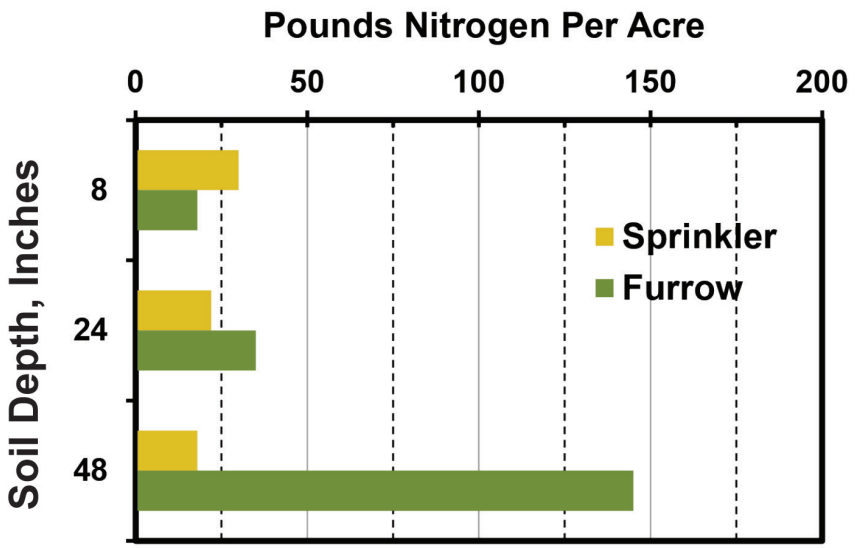

Figure E-1. **Summary of two sets of soil samples: 1) taken from a soil that was sprinkler irrigated; and 2) taken from a soil that was irrigated by a furrow irrigation system.**

Soil sampling: Proper sampling for soil testing is a critical step in making a realistic estimate of available soil nitrates. Because nitrate is very soluble and moves with the water in the soil profile, 1-foot deep samples have very little value except when doing the pre-sidedress nitrate test. For the preplant nitrogen rate determination deep samples are necessary.

Sampling depth: The 0- to 8-in depth increment is important since it is used for general fertility (organic matter, pH, phosphorus, potassium, zinc) as well as N, while deeper increments should be analyzed for nitrate-nitrogen only. In order to assess soil nitrate availability, the ideal sampling depth should be as deep as the effective rooting depth for the crop. However, recommended soil sampling programs must also be practical. Samples taken to a depth of 3 ft or greater are generally acceptable for corn, wheat, and sugar beet. However, the estimate of available soil residual N will be more accurate by using a greater sampling depth. Samples collected to a depth of 4 ft are more time consuming and labor-intensive, but provide a better estimate of residual N than 2- or 3-ft samples.

Deeper soil samples are desirable because it is possible for residual N to have a greater concentration in the lower part of the root zone than in the top foot. For example, *Figure E-1* shows the amount of N distributed in a 4-ft profile collected from sprinkler and furrow irrigated fields. Collection of cores in depth increments can identify unusual situations and allow the field manager to develop a management plan to address the N distribution issues. High levels of N in the 2- to 4-ft depth presents problems for the manager. Nitrogen is needed early in the growing season but drainage could decrease N available to the growing crop. Without taking samples at various depths, this situation would not be discovered and the field manager may have incorrectly adjusted the N application rate upward. With the preseason samples in hand, the manager can resample the field and adjust with a sidedress and/or fertigation nitrogen application.

Figure E-1 also depicts a sample profile from a center pivot irrigated field where most of the nitrogen has been removed by the previous crop. Even if substantial precipitation is recorded early in the growing season, little additional nitrogen would be leached out of the root zone. In this case, taking samples from deeper depths appears to add little information to the manager. However, if the samples had not been collected, the field manager may have applied too little nitrogen.

Number of cores to be collected: Because of natural variability, a better estimate of a field's fertility can be obtained by taking more individual soil cores per sample and more samples per field. UNL has two publications on soil sampling, one for traditional soil sampling and one for precision agriculture. For the traditional approach areas need to be no larger than 40 acres. Divide fields according to patterns of cropping history, topography, soil type, or any reason where differences are expected. From each area, collect a minimum of 10 cores (0 to 8 in depth) for general fertility status, compositing the cores into one sample for each area. At least four deep soil samples (2 ft minimum, 3 ft acceptable, and 4 ft preferred for corn) should be collected and composited into one sample from each area as well. Additional cores collected to represent the deeper portion of the crop root zone give a better estimate of nitrates. ***Multiple soil cores will improve the estimate of nitrates in the soil, but check with your NRD for specific requirements.***

Using the soil nitrate-nitrogen values from the soil test

The amount of N in the soil is related to a combination of several management practices and climatic conditions. Each of the following can contribute to a greater or lesser amount of residual nitrate:

- Past amount of commercial N fertilizer applied,
- Application of biosolids (manure, sludge, compost, etc.),
- Previous crop: some crops remove more soil nitrogen than others,
- Precipitation: more residual nitrogen is present with dry fall and spring conditions; less residual nitrogen is present with wet fall and wet spring conditions,
- Irrigation water management, and
- Soil organic matter

How much nitrogen is credited from the soil test is an important question that will affect the final nitrogen recommendation. Normally, agricultural soil testing laboratories report soil nitrate-nitrogen in parts per million (ppm) and pounds N per acre (lb/acre). The challenge is how to use the soil nitrate numbers taken from a soil sample from only part of the root zone and accurately adjust the recommended nitrogen fertilizer rate. UNL nitrogen fertilizer recommendations use the weighted-average nitrate-nitrogen concentration in ppm in the sampled horizons. Therefore, regardless of the number of depths sampled, 1.0 ppm value is entered into the equation. The example on the next page presents the procedure using example calculations made to determine the weighted-average N concentration from samples collected from three depth increments.

Example: Weighted average soil nitrate-nitrogen concentration based on sample analysis results from three sampling depth increments.

Depth Increment (in)	Core Sample Length (in)	x	Nitrate-Nitrogen (ppm)	=	Length x ppm
0-8	8		11		88
8-24	16		7		112
24-48	24		5		120
				Total	320

$$\text{Average ppm nitrate-nitrogen} = \frac{\text{Total}}{\text{inch of depth}} = \frac{320}{48} = 6.7 \text{ average ppm nitrate-nitrogen}$$

Calculation of the weighted-average soil nitrate-nitrogen concentration has been incorporated into an algorithm where the ppm is multiplied by 8 to get the residual soil nitrate credit. *Table E-2* shows values of residual soil nitrogen for a range of soil nitrate-nitrogen contents. Questions may arise: *Where does the 8 come from*? and *Is all the soil nitrate available to the crop?* One way to answer these questions is to consider how much 10 ppm nitrate-nitrogen would be in pounds of nitrogen if it were the weighted-average concentration in the top 48 inches. The calculations would go like this: there are about 3.6 million pounds of soil in an acre-foot (1 acre of surface area, 1 ft deep), 4 ft would weigh 14.4 million pounds (4 x 3.6 = 14.4 million pounds and this is an estimate). If we multiply 10 ppm nitrate-nitrogen by 14.4, we get 144 lb of nitrogen in the top 4 ft of soil. However, our equation uses 8, so we are not accounting for all the nitrogen that is really contained in the top 4 feet. If we divide 80 by 144 we find we are only accounting for 55% of the nitrogen that may be contained in the soil. The use of only 55% of the nitrogen that may be available covers some uncertainty about whether the nitrogen will remain at a specific soil depth or will it be leached out of the root zone during the growing season. In addition, use of 55% of the potential nitrogen available helps to account for the inability of roots to remove all the nitrogen, especially deeper in the profile.

Table E-2. Nitrogen fertilizer rate reduction for residual soil nitrate.

Residual Soil Nitrate-Nitrogen* (ppm)	Reduction in Nitrogen Fertilizer Needed by Crop** (lb/acre of nitrogen)
3	24
9	72
15	120
21	168
27	216

**Average ppm in at least the top two feet. Deeper samples are better.*
***Not the total nitrate N, but the N credited.*

Determining nitrogen fertilizer needs for corn

UNL developed an **algorithm or a set of steps that are followed in order to solve a problem,** which is used to estimate corn nitrogen fertilizer needs. The original research was conducted in the early 1980s from 81 nitrogen rate experiments on Nebraska soils over a range of organic matters, soil textures, and residual nitrate levels. The algorithm was developed from statistical analysis of the data and is a mathematical model. The output is an N recommendation and the algorithm should be viewed as a whole, not according to the individual parts. However, the terms and coefficients do make practical sense. Additional N experiments done across Nebraska in the early 2000s with 34 sites with much greater yield levels (+260 bu) were added to the data set. The algorithm has been verified with the new set of data and by on-farm testing. The algorithm is:

Nitrogen fertilizer needed (lb/acre) =

[35 + (1.2 x EY)] - (8 x average soil nitrate ppm) - (0.14 x EY x OM) - (other credits)

- EY is Expected Yield (1.05 x 5-year average or from above, 1.05 x 212 = 223)).
- OM is the percent Organic Matter determined from a surface soil sample analysis. (Do not use greater than 3% OM or less than 1% OM)
- Other credits are nitrogen from legumes, manure, other organic wastes and irrigation water (See Section F).

If no other credits were involved, the recommended application rate would be 187 lb N/ac. In the next chapter, procedures for including other sources of N are presented using a series of examples. A video clip developed to show how to use the spreadsheet can be accessed at: *water.unl.edu/waternmgt*

Example: Calculate the amount of N fertilizer needed.

Calculate the nitrogen fertilizer needed for corn using an expected yield of 223 bu/acre, a soil organic matter of 2%, and soil nitrate content of 6.7 ppm. Using the equation above for nitrogen fertilizer needed, we substitute the numbers and do the calculations:

N needed (lb/acre) = 35 + (1.2 x 223) - (8 x 6.7) - (0.14 x 223 x 2) - (other credits)

N needed (lb/acre) = 35 + 268 - 54 - 62 - (other credits)

N needed (lb/acre) = 187 - (other credits)

More Extension Publications (available at ianrpubs.unl.edu)

EC117, Fertilizer suggestions for corn

EC154, Soil sampling for precision agriculture

EC155, Nutrient management for agronomic crops in Nebraska

EC168, N rate calculator for corn

G1740, Guidelines for soil sampling