NITROGEN MINERALIZATION ESTIMATES FOR N RATE SUGGESTIONS

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Introduction

To improve the accuracy of N rate recommendations for corn, reliable estimates of soil N supplying capability are needed. The important influence of soil N supplying capability on estimating corn N needs is illustrated by a recent compilation of data on corn yield response to N fertilization from over 300 experiments in Illinois, Iowa, Minnesota, and Wisconsin showing that 50 to 70% of the observed corn yield was produced with N supplied by the soil alone (Sawyer et al., 2006). The soil available N supply originates from two main sources; inorganic N stored in the soil profile and N released by mineralization of organic N sources. For many soils, a substantial portion of the soil contribution to the available N supply is provided through soil organic N mineralization during the growing season. Although this release of plant available inorganic N occurs through decomposition of soil organic matter, total organic matter content alone is usually not a good predictor of soil N mineralization. This is because only a small fraction of the total soil organic N (usually 2-5%) is mineralized in a single growing season. Therefore, most methods for predicting N mineralization have focused on quantifying the readily mineralizable fraction of soil organic N.

Although numerous chemical and biological tests for assessing the amounts of available N supplied through soil N mineralization have been developed and evaluated over several decades, none of these procedures has proven satisfactory. This lack of success is largely due to the complexity of the N cycle in soils and the need to integrate numerous physical, chemical, biological, and site specific factors in arriving at the estimate of soil N supplying capability. These experiences should be valuable guidance for future research designed to predict soil N supplying capability in advance of production. For example, in his review of progress in predicting the N supplying power of soils, Whitmore (1999) stated "Unfortunately, it is hard to avoid the conclusion that if such a test was possible it would have been found by now". Because reliable estimates of soil N supplying capability are critical for improving N rate recommendations in crop production the search for techniques to provide these estimates is continuing.

Current Status of Methods for Assessing Soil N Supplying Capability

The goal of methods for assessing soil N supplying capability is to estimate the amounts of plant available N that will be provided by the soil, preferably in advance of the growing season, or during the growing season, such that any required additional N can be applied to meet crop needs. To accomplish this goal, the amounts of plant available N in the soil at the beginning of the growing season must be accounted for and the amounts of N that will be released by mineralization of organic N compounds in the soil during the growing season must be estimated. Estimates of N mineralization must account for the simultaneous and competing reactions of mineralization and immobilization, such that the final estimate reflects net N mineralization. Soil N supplying capability includes the initial soil inorganic N content plus net N mineralization amounts minus losses of available N that occur before crop use.

Preplant or Residual Soil Nitrate Measurements

Sampling and analysis of soils for residual or carryover nitrate is a long-standing practice in low rainfall areas of the Midwest and in the Great Plains region (Dahnke and Vasey, 1973). In addition, several states in humid regions have shown benefits from preplant soil nitrate testing (Bundy and Malone, 1988; Schmitt and Randall, 1994). Although residual nitrate tests are not appropriate for every year in every production situation, particularly in humid regions. these tests are substantially underutilized as methods for assessing the soil N supply.

Soil-Based Estimates of N Mineralization

In-season soil nitrate testing using the presidedress (Magdoff 1984) or late spring (Blackmer et al., 1989) soil nitrate test provides a field method of estimating the amounts of N that will be provided through mineralization. In general, experience with this test indicates that it is effective in identifying situations where mineralization provides adequate N to meet crop needs, and it is less reliable in identifying the amounts of supplemental N needed where mineralization is not adequate to supply the entire crop N requirement (Bundy et al., 1999). The presidedress test is likely to underestimate potential N mineralization when soil temperatures during the period between corn planting and soil sampling are below long-term averages. For example, a Wisconsin study showed that N recommendations based on the presidedress test often exceeded crop N needs when average May and June air temperatures were more that 1° F below the long-term average temperature for this period (Andraski and Bundy, 2002).

Laboratory Tests for N Mineralization

In general, these methods for estimating N availability can be classified into two groups; chemical procedures and biological methods. Usually, biological methods are thought to have the greatest potential for estimating N mineralization because they use the same microbial agents that are responsible for releasing available N under field conditions (Bundy and Meisinger, 1994; Jarvis et al., 1996). Work conducted in Iowa during the 1950's provides an early example of using a laboratory aerobic incubation (biological) method to adjust corn N recommendations for soil N mineralization (Hanway and Dumenil, 1955).

During 1995 to 1998, a North Central Regional Research Committee (NC-218) conducted a study to characterize soil N availability and crop response in the region. This work included performing several chemical and biological N tests for N availability on soils from 67 sites in Illinois, Kansas, Michigan, Minnesota, Missouri, Nebraska, and Wisconsin. A replicated N rate response experiment with corn was conducted at each site so that the economic optimum N rate (EONR) could be determined, and the results of the N availability tests could be related to corn response to N. Results from this work (Table 1) show that of the 16 tests performed only the 14-day aerobic incubation method was related to crop N response as reflected by the site EONR. This finding lends support to the idea that biological methods of assessing N mineralization may have the greatest potential. However, the low predictive value for the significant relationship ($r = -0.41$) indicates that additional information will likely be needed for reliable estimates of soil N availability. The regression model for the relationship between the aerobic incubation test results and EONR was improved from $r^2 = 0.21$ to $r^2 = 0.42$ by including the results of preplant soil nitrate measurements (0-2 ft) in a multiple regression model.

Table 1. Relationship between economic optimum N rate (EONR) and several chemical and biological tests for soil N availability in 67 corn N response experiments conducted in the North Central region during 1995-1998. †

Test	Relationship (r)
Chemical tests:	
Phosphate-borate buffer distillation (pH 11.2), 4 min.	0.02
Phosphate-borate buffer distillation (pH 11.2), 8 min.	0.07
Distillation with 2*M* KCl + MgO, 4 min.	-0.13
Distillation with 2*M* KCl + MgO, 8 min.	-0.01
Incubation with hot 2*M* KCl, 20 hr.	0.08
Sodium borate buffer distillation (pH 11.5), 4 min.	-0.08
Sodium borate buffer distillation (pH 11.5), 8 min.	<0.01
Sodium tetraphenylboron extraction, 5 min.	-0.10
Sodium tetraphenylboron extraction, 7 days.	-0.16
Biological tests:	
Long-term (300-day) aerobic incubation (N_o)	-0.11
Aerobic incubation (14-day, 30°C), soil:sand mix	-0.41**
Anaerobic incubation (14-day, 30°C) field moist	-0.12
Anaerobic incubation (14-day, 30°C) air dried	-0.03
Preplant soil nitrate (0-3 ft)	-0.13
Presidedress soil nitrate (0-1 ft)	-0.26
Presidedress soil nitrate (0-2 ft)	-0.27

† NC-218 Regional Committee, unpublished data.
** Significant at the 0.01 probability level.

Results from the regional study summarized above indicate that N mineralization data from an aerobic incubation test can provide useful information for predicting crop N needs. However, even when this information is combined with soil nitrate test information, less than half of the variation in EONR is explained by the test results. The data from the regional study represents a wide range of soils, climates and managements, and it seems likely that N availability assessments focused on a more limited range of soil and environmental conditions could have greater success in predicting crop N needs.

This idea is supported by data obtained in a Wisconsin study where N mineralization was assessed using an aerobic soil incubation method on a single soil with a wide range of N availability due to crop rotation treatments (van Schaik, 1998; van Schaik and Bundy, 1998). In this work, soil samples from the Lancaster crop rotation experiment representing ten phases in crop rotations ranging from continuous corn to first-year corn following alfalfa were subjected to aerobic incubation at 25°C for various times up to 16 weeks. Soils were collected from control plots that did not receive N fertilization in each rotation phase. Results showed that the amounts of N mineralized were usually well related to corn yield without added N in the various rotation phases (Table 2). Soil samples were collected in 1996 and N mineralization data from these samples were related to corn yields without added N in 1996, 1997, and the average unfertilized yields from 1987 to 1996.

Table 2. Relationship between N mineralized during aerobic incubation and corn yield in ten unfertilized crop rotation phases, Lancaster, WI. 1996, 1997, and 1987-1996. †

Incubation weeks	Year 1996	1997	1987-1996
		r^2	
2	0.75	0.14	0.33
4	0.82	0.49	0.69
6	0.86	0.56	0.62
8	0.88	0.54	0.72
10	0.92	0.72	0.72
12	0.88	0.74	0.23
14	0.92	0.72	0.60
16	0.70	0.54	0.50

† van Schaik, 1998.

As expected, the strongest relationships were obtained when the N mineralization data from 1996 soil samples was related to 1996 yields; however good relationships were obtained with yield results collected in the following growing season (1997) and with average yields from the previous ten years (1987-1996). These results suggest that once N mineralization data is determined for a specific soil and location, these results may be useful in predicting N mineralization amounts for several years.

Crop-Based Estimates of N Mineralization

Measurement of plant color to assess the N status of crops and the need for N fertilization provides a plant based approach to estimate soil N supplying capability including soil N mineralization. In this area of work, chlorophyll (SPAD) meters were used to measure crop color and these determinations were related to crop N status. More recently, vehicle–mounted crop color or other sensors and aerial images are used to assess the crop N status and, in some cases, apply the required amounts of supplemental N.

Chlorophyll Meter (CM) Measurements

Previous work with CM (Schepers et al., 1992; Varvel et al., 1997) established the relationships between meter readings and crop N status and showed that adequately fertilized reference strips were useful in confirming crop need for N fertilization. Recently, Scharf et al. (2006) evaluated CM use for predicting N need and yield response for corn in the North Central region. This study included 66 experiments conducted in seven states over a 4-yr period and employed the previously described data base compiled by the NC-218 regional research committee (see Laboratory Tests for N Mineralization section above). Results from this study showed significant relationships between CM readings and EONR or yield response to N at a wide range of growth stages (V5 to R5). The predictive value of these relationships was higher for relative than for direct CM readings and was lower at the V5 to V9 growth stages compared to later stages of development. This finding suggests that the best accuracy may be achieved at corn growth stages where conventional ground N application equipment could not be used. Use of soil nitrate measurements or N availability indices in combination with CM measurements did not improve the predictive value of the tests. Coefficients of determination for the CM reading vs. EONR relationships ranged from r^2 = 0.53 to

0.76 and should be capable of improving N rate recommendations compared to those developed with current practices.

Vehicle-Mounted Crop Sensors
These sensors can be used to quickly measure crop color and N status over large areas. These measurements are particularly valuable where substantial in-field variability in crop N status exists, since required N applications can be made at variable rates to meet crop needs. Several approaches for using in-field crop sensing have been developed (Raun et al., 2002; 2005; Scharf and Lory, 2002). Development of these technologies will likely continue in the future resulting in variable rate N applications that will match crop needs more closely than can be achieved with current practices.

Potential for Future Improvements in Assessing Soil N Supplying Capability

Several of the approaches for estimating soil N supplying capability and accounting for soil N mineralization discussed in this paper have potential for improving N rate recommendations but are currently greatly underutilized. These include soil nitrate testing, mineralization estimates based on aerobic soil incubation, and crop sensing techniques. In addition, N guidelines based on crop response functions generated on major soil groups within states result in recommendations that consider the average soil N supplying capability in the N response database. Used individually, these approaches could achieve some improvement in the accuracy of N recommendations; however, the greatest benefits are likely to come from integrating information from these procedures to yield comprehensive information about soil N availability. History tells us that one-dimensional tests or procedures that are not directly connected to crop N response are not likely to achieve the desired improvements in accuracy of N application guidelines. Most efforts in modeling soil N processes to improve N management have suffered from excessive complexity and data requirements. Perhaps an applied modeling approach that attempts to integrate some of the factors contributing to soil N supplying capability would be feasible. Such an attempt could be patterned after the semi-quantitative models used to predict P losses in runoff with P indices.

Any of the likely approaches with potential for improving N recommendations will require a higher level of management and probably greater cost than the current processes used to make decisions about N application rates. Higher future N fertilizer costs and/or limitations on N use to achieve environmental objectives could provide the incentive to adopt the necessary management improvements.

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