SOIL NITROGEN AND CARBON MANAGEMENT PROJECT

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Introduction

An important component for predicting nitrogen (N) application needs (regardless of productivity level) is to estimate the soil capacity to supply plant-available N each year corn is grown. Differences in N supply between fields have been difficult to predict, and are often underestimated when N applications are made to production fields. In a general way differences are incorporated into N recommendation systems (for example crop rotation effects). However, for improving prediction of corn N needs, and especially avoidance of over application and increased environmental consequences, knowing if and how much response may occur in a field is highly desirable. This would be particularly useful to producers if known ahead of preplant N applications. This is important in situations where little to no N fertilization is required, and where rates based solely on yield may direct more N application than the system needs.

Tests that measure soil nitrate as a means to estimate available N have been available for some time, such as the presidedress or late spring soil nitrate test. But producers desire alternative methods, including those designed for use before preplant N application. An example of such a test would be one that estimates mineralization of organic-N fractions. It is also important to conduct studies in high-yield environments (where corn uses large amounts of N) so concerns about limiting corn yield potential or negatively impacting soil can be documented or allayed.

Nitrogen management and cropping system history (tillage and crop rotation) have direct impacts on soil organic N and carbon (C) pools, and the tie between soil organic N and C. Soil organic C levels have important implications for organic N retention/release and carbon dioxide (CO_2) fluxes. Specific organic-N pools in soil can be an important source of plant-available N. Nitrogen availability in the soil environment also plays a significant role in determining soil C status, as it is an essential nutrient for microbial metabolism. Nitrogen availability, through influence on yield, will also affect the quantity and quality of plant residue available as a source of soil C.

Soil C storage is a long-term process. However, short-term changes in soil C status due to N and soil management can be estimated by monitoring soil C change and CO_2 flux. Long-term changes in soil C are indicators of soil potential for storing C and the impact of management on that potential. However, immediate relationships and short-term changes in soil C can be developed through changes in CO_2 emission by monitoring the impact of different N rates on CO_2 flux during the growing season. The maintenance of organic matter can help prevent soil degradation. Soil, as an open system, can play an important role in regulating greenhouse emissions to the atmosphere. Since changes in agricultural practices, like N use, can influence the soil organic C storage in, and greenhouse gas fluxes from soils, the net benefit due to changing agricultural practices needs to be considered.

Nitrogen use rate is an important consideration for soil C retention and potential nitrate movement to water systems. If farmer use practices are not consistent with recommended N and

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C management practices, then work as proposed in this project could help farmers predict appropriate field-specific N rates and C management practices. With demonstrations being conducted locally and availability of tools for individual site assessment, then producer confidence should improve that productivity can be maintained if a production practice is changed.

Basis for the Illinois N Soil Test

Scientific study of organic soil N forms has often utilized a chemical fractionation procedure based on liberation of N compounds by heating soil with strong acid for 12 to 24 hours. This process is called acid hydrolysis. The N forms are separated by various analysis procedures into the following fractions: acid insoluble-N, ammonia-N, amino acid-N, amino sugar-N, and hydrolyzable unknown-N. Recent research by Mulvaney and Khan (2001) at the University of Illinois documented a problem in the conventional procedure used for determining the amino acid and amino sugar fractions. In particular, the amino-sugar fraction has been underestimated in past fractionation work. This may have caused a misinterpretation of the effects of cropping, tillage, rotation, and N management on the amino sugar level in soils. Especially pertinent to predicting crop responsiveness to applied N, the hydrolyzable amino sugar-N fraction has not previously been shown to be sensitive to these differences. Hence, the amino sugar fraction has not been well correlated to crop N responsiveness or predictive of no response. Amino sugars in soils are generally assumed to be of microbial origin. While the amino sugar-N fraction is a labile source of soil N, it should be more stable than inorganic forms.

The University of Illinois researchers developed a diffusion procedure for analysis of soil hydrolysates that improved accuracy and specificity in determination of the amino sugar and other organic N fractions (Mulvaney and Khan, 2001). Using soil samples (collected mid-March to mid-April, 0-12 inch depth before planting) and corn yield response data from eighteen previous field research sites in Illinois, they found that the newly developed diffusion analysis procedure resulted in the amino sugar-N fraction being predictive if a site would respond to applied N (Mulvaney et al., 2001) – correctly categorized all tested sites as either responsive or non-responsive and most importantly those that previously could not be by other tests. They also found the amino sugar-N fraction was related to the relative magnitude of corn yield increase to applied N at responsive sites. Since the acid hydrolysis and fractionation procedure requires at least 12 hours of complicated laboratory work, the researchers developed a simple soil test procedure designed for use in routine laboratory analysis – the Illinois N Soil Test (Khan et al., 2001). The Illinois N Soil Test measures N liberated from soil organic-N compounds (assumed to be amino sugar-N) and exchangeable ammonium-N during direct soil diffusion for five hours at 48-50ºC with 2 *M* sodium hydroxide. The test does not include nitrate-N. Development work at the University of Illinois (Khan et al., 2001) indicated correct classification of 25 Illinois soils (0-12 inch depth) as corn-N responsive if the Illinois N Soil Test was <225 mg kg^{-1} and non-responsive if the test was >235 mg kg^{-1}. Test results are expected to be higher with 0-6 inch depth samples.

Objectives

The objectives of this project are twofold. One is to demonstrate corn N fertilization needs and the short- and long-term N–C relationships across diverse soils, productivity, and crop management systems. The second is to demonstrate the potential of a newly proposed soil N test

(Illinois N Soil Test) as a predictor of soil N supply and corn response to applied N, and for adjustment of corn N fertilization.

Field Demonstration Description

The strategy for this project was to conduct on-farm field demonstrations that encompass a range of soil characteristics, tillage systems, yield potentials, and N use and N source histories. Multiple rates of N were applied shortly after corn planting in replicated treatments. Application areas reflected standard field protocols and producer equipment. Normal producer crop management practices were used for the geographic area the site represents (such as tillage, adapted hybrids, and pest control). Producers applied no N to the demonstration site. Soil pH and other soil nutrients were maintained by application of lime and fertilizers as needed.

Multiple sampling and analyses were conducted to measure site characteristics and N responsiveness: routine soil tests, soil N tests, plant N status, corn grain yield, corn and soybean plant dry matter, and soybean grain yield. Additional soil samples from various depths in the fall, spring, and sidedress were collected to determine the potential viability and sampling protocol of the new Illinois N Soil Test. Soil was sampled by depth increments before N application to measure soil organic and inorganic C, to measure particulate organic matter, and to provide baseline soil C and estimated bulk density. Carbon dioxide flux was monitored at selected sites and selected N rates during the growing season, after harvest, and in the following soybean crop.

Field Activity

This project began in the spring of 2001. The field sites were chosen based on criteria of corn after soybean, no manure or primary fertilizer N applied in the fall or spring of the current crop year, and a conservation tillage or no-tillage system. Cooperators were asked not to apply N or manure to the area designated for the demonstration site. All other field activities were completed as normal by the cooperator.

Fourteen sites were located for the project in 2001, eleven new sites in 2002, and thirteen new sites in 2003 (Figure 1). All sites were used for corn N response and soil N testing. Seven of the fourteen sites from 2001 were identified for multi-year soil sampling and analysis for C and N (Figure 1). These same seven sites were monitored in 2002 and 2003 for soil C and N, soybean and corn residue C, crop yield, and response to applied N.

Six rates of N (0 to 200 lb N/acre in 40 lb increments) were applied shortly after planting (from planting to V2 growth stage) as surface applied ammonium nitrate. The N rates were replicated four times. No other N was applied except for incidental N in starter or with phosphate fertilizer, which occurred at three sites.

Sites were soil sampled for routine soil tests, soil N tests, and soil C and N. Sampling for soil N testing included fall, spring preplant, in-season, and post-harvest. Soil was collected at 0-6 inch and 0-12 inch depths. Corn response to N was monitored through leaf greenness using a Minolta® SPAD 502 chlorophyll meter at the R1 (silking) growth stage and grain yield. In order to monitor change in soil C and N throughout the project life, initial soil samples were collected at 0-2, 2-4, 4-6, 6-12, and 12-24 inch depths from seven sites in 2001. Bulk density and pH were determined at each depth and samples were analyzed for total N and C. Particulate organic matter (POM) was also determined. After harvest, plant residue was collected, weighed, and analyzed for total N and C. At three sites emission of CO_2 was monitored throughout the year with a Li-Cor 6400 CO_2 analyzer at the 0, 80, 160, and 200 lb N/acre rates.

Results

Corn Response to Applied N

Overall productivity was high in the three years, with an average maximum yield of 187 bu/acre. One site in southwest Iowa had low yield due to late season moisture stress. The grain yield produced with no applied N was quite large (average of 151 bu/acre). These results document that with the right conditions, Iowa soils have the capacity to supply large quantities of plant-available N. At all sites corn was rotated after soybean, which moderates N response.

Site responsiveness to N was calculated as the economic yield increase from applied N compared to the yield with zero N (no-N control), and expressed on a percent of the zero N rate yield. An economic optimum N rate estimate was calculated from fitted response curves to applied N at each site (an economic break-even rate at a corn to N price ratio of 10:1; example is $2.50/bu corn and $0.25/lb N).

Corn grain yield and economic optimum N rate varied considerably between sites (Figure 2). Seven sites (16% of all sites) were non-responding (economic rate of zero lb N/acre), twenty sites had an economic optimum N rate greater than 100 lb N/acre, and three sites had a rate greater than 150 lb N/acre. Thirty-seven percent of sites had an economic optimum N rate in the 100-160 lb N/acre range, with 26% between 100-120 lb N/acre. Generally the need for applied fertilizer N was not high. This can change substantially between years. For example, sites in 2003 were generally more responsive to N (greater yield increase from applied N and higher optimum N need), and the three sites with economic optimum N above 150 lb N/acre were in 2003. For comparative purposes using a moderate N application of 125 lb N/acre, for those three high N need sites the calculated yield would be 13.5, 4.9, and 8.1 bu/acre lower than if the individual site optimum rate had been applied. At other sites where the optimal rate was above 125 lb N/acre, the calculated yield loss at an N rate of 125 lb N/acre will be minimal (less than 1-2 bu/acre).

For the four sites with N rates applied in both 2001 and 2003, one site was essentially non-responsive both years and the economic optimum N rate difference between years at the other three sites averaged 46 lb N/acre higher in 2003 (ranged from 32 to 63 lb N/acre higher). This indicates that it can be difficult to predict N need in a given year from prior crop N response information, and that soil N supply and corn response to applied N is influenced by many factors, including season.

The average economic optimum rate for all sites across the three years (excluding the non-responding sites) was 108 lb N/acre, or 104 lb N/acre including all sites. The economic optimum rate is less than the rate to produce maximal yield increase from applied N; however the average yield difference between maximum and economic N rates (20 lb N/acre higher at maximum yield) at the sites in the project was only one bu/acre. The economic optimum N rate did not increase with increasing productivity, even when yields were greater than 200 bu/acre (Figure 2).

However, the largest yield increases to applied N occurred when maximum yields were above 200 bu/acre. Conversely, the magnitude of N fertilizer response tended to be lowest, and most of non-responsive sites occurred, when zero N rate yields were high. This again indicates the soil N supply influence on productivity and N response.

The corn crop greenness (leaf chlorophyll) can also be used as an indicator of soil N supply and corn responsiveness to applied N. Figure 3 shows the Minolta SPAD meter readings taken on the ear leaf at the R1 growth stage (silking). The SPAD meter measures leaf greenness, with readings being related to leaf chlorophyll and N concentration. Therefore, this meter provides a non-destructive method to assess the N status of corn during the growing season, and an alternative to leaf or plant sampling and laboratory determination of N concentration. Taking readings at silking is an important growth stage timing to determine N stress impacts. Leaf greenness can indicate N stress (loss of green color), but not excess N (greenness does not increase with excess available N). Many variables can affect leaf greenness (examples are hybrid, moisture stress, and growth stage), and this can be noticed in differences between sites at maximum N. Within a site, SPAD values are a good indicator of the N status and differences between N rates. Converting values to a relative basis (reading divided by reading at non-limiting N) allows N status comparison between sites.

Most sites with greatest response to applied N had low SPAD readings with zero N. Readings less than 50 typically indicate significant N stress. Sites with high leaf greenness values with zero N, and little change in values compared to the maximum N rate, also showed small yield response to applied N. These high zero N rate SPAD values are another indicator of high soil N supply to corn.

In some instances the low or no yield response to applied N related to recent history of N or manure input, but not in all cases. To help producers better understand the potential soil supply of plant-available N, corn responsiveness to applied N, and N input needs, then plant sensing like leaf greenness may provide valuable information that can improve economics of corn production. Most important will be identification of non-responsive sites. Also, as producers adjust N inputs it will be important to monitor the soil N supply and adjust N fertilization as the supply capability adjusts.

<u>Preliminary Evaluation of the Illinois N Soil Test</u>

Figures 4 and 5 give the relationship between the Illinois N Soil Test value and corn yield response to N fertilizer at the 2001-2003 sites. Figure 4 has results for spring preplant soil samples collected from the 0-12 inch depth, and Figure 5 has results for spring preplant soil samples collected from the 0-6 inch depth. Based on a 235 mg kg^{-1} critical level for 0-12 inch samples (Khan et al., 2001), the test did not differentiate between sites responsive to applied N or non-responsive. Looking at the distribution of soil test values versus percent yield increase in Figures 4 and 5 one can easily see the lack of predictive relationship between the Illinois N Soil Test and corn yield response to applied N.

There would be great utility for a soil N test to have recommended sampling in the fall before planting corn. Figure 6 shows there was a good relationship between the Illinois N Soil Test values for soil samples collected in the fall and spring. This indicates the potential that soil sampling could be done either in the fall or spring.

One possible reason for the lack of predictive ability of the Illinois N Soil Test on soils at the project sites is the general relationship between test values and total soil N (Figure 7). The same general relationship would hold for soil organic matter because of the close tie between total soil N and organic C. Across the sites in this project there was no correlation between soil organic matter and corn response to applied N (Figure 8), economic N rate (data not shown), or relative corn yield (data not shown). In other words, total soil N, soil organic-C, nor soil organic matter was predictive of N response or N application need. It is possible that the Illinois N Soil Test is reflecting general soil N and not being specific to the amino sugar-N fraction or a plant-available N pool.

Preliminary results from the Illinois N Soil Test evaluation in this project indicate there may be different pools of soil organic-N measured by the hydrolyzable amino sugar-N procedure and the Illinois N Soil Test. It is possible that the specific amino sugar-N fraction measured by acid hydrolysis will be a better predictor of N responsiveness than the Illinois N Soil Test, but that needs to be confirmed for these sites. If that is the case, then the underlying basis for the Illinois N Soil Test (acid hydrolyzed soil amino sugar-N) could be correct (can predict site N responsiveness), but the procedure developed for routine soil analysis (the Illinois N Soil Test) is not. At this point in time caution should be exercised with use of the Illinois N Soil Test for interpreting the need for N application in corn production on Iowa soils.

Example Results for Soil C, Soil N, and CO_2 Emission: Boone-S Site

Figure 9 illustrates there were no significant differences in CO_2 emission rate between N rates throughout the 2002 growing season. Peak CO_2 emission rates occurred approximately 50 days after soybean planting. In 2003, no significant differences were found in CO_2 emission rates until approximately 78 days after planting corn. Significant differences in CO_2 emission rates were noted throughout the rest of the growing season in 2003 between all N rates. Two peaks in CO_2 emission rates occurred around 78 and 95 days after planting.

Figure 10 shows no significant difference between N rates in cumulative CO_2 flux for years 2002 and 2003. The highest cumulative CO_2 emission in 2002 was at the prior-year 200 lb N/acre rate. The highest cumulative CO_2 emission in 2003 was observed at 0 lb N/acre.

Table 1 shows the results of the average soil bulk density, total C, total N, organic matter and the C:N ratio for each depth. These soil samples were taken in 2001 prior to any N application. Analysis for each depth was averaged among all replicate samples collected. Bulk densities were relatively the same in the top 0-2, 2-4 and 4-6 inch depths. At the 6-12 inch depth, a noticeable increase in soil bulk density was measured compared to bulk densities above and below this depth. In the 12-24 inch depth, soil bulk density was similar to the bulk density of the 0-2, 2-4 and 4-6 inch depths. No significant differences in total C were found in the top three depths. A significant difference in total C was measured between the 6-12 inch depth and the 12-24 inch depths. A significant difference in total C was also evident between the 12-24 inch depth and other depths. Total N analysis indicates no significant difference between 0-2, 2-4 and 4-6 inch depths. Significant difference in total N was noted between the 6-12 inch depth and the

12-24 inch depth and other depths. Average soil organic matter showed no significant differences in the 0-2, 2-4 and 4-6 inch depths. There was a significant difference in soil organic matter between 6-12 inch and all other depths. The same occurred for the 12-24 inch depth.

Table 2 shows the results of corn residue analysis from 2001. No significant differences were found for dry matter yield between N rates. Total C analysis indicated no significant differences in total C between N rates. Results of the residue total N analysis indicate no significant difference between 0, 80, and 160 lb N/acre rates. No significant difference in total N content was found between 80, 160, and 200 lb N/acre rates. However, there was a significant difference between 0 and 200 lb N/acre.

Table 3 shows the result of the soybean residue analysis from 2002. No significant differences were found for dry matter yield, average total C, and average total N among all N rates. Average C:N ratio was relatively similar for all N rates.

In conclusion, the applied N fertilizer rates had no short-term effect on cumulative CO_2 emission. As crop growth progressed, different N rates resulted in a significant effect on CO_2 emission rate in one year, 2003. The residual effect of different N rates applied to corn had no significant effect on total C or N input from soybean residue.

Project Partners

Iowa Crop Producers
Iowa State University Extension
Iowa State University Extension Crop Field Specialists
Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation
Iowa Natural Resources Conservation Service
Agribusiness Association of Iowa
Kirkwood Community College
Iowa Central Community College

References

Khan, S.A., R.L. Mulvaney, and R.G. Hoeft. 2001. A simple test for detecting sites that are nonresponsive to nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1751-1760.

Mulvaney, R.L., and S.A. Khan. 2001. Diffusion methods to determine different forms of nitrogen in soil hydrolysates. Soil Sci. Soc. Am. J. 65:1284-1292.

Mulvaney, R.L., S.A. Khan, R.G. Hoeft, and H.M. Brown. 2001. A soil organic nitrogen fraction that reduces the need for nitrogen fertilization. Soil Sci. Soc. Am. J. 65:1164-1172.

Table 1. Initial total C and N at each sampling depth in 2001, Boone-S site.

Depth	Bulk Density	Total C	Total N	OM	C:N Ratio
in.	g/cm^3	- - - - - - - - - - - - lb/acre	- - - - - - - - - -		
0-2	1.4	14628 a	1090 a	27362 a	13 : 1
2-4	1.5	15079 a	1111 a	28194 a	14 : 1
4-6	1.4	14445 a	1038 a	27020 a	14 : 1
6-12	2.1	20213 b	1459 b	37847 b	14 : 1
12-24	1.4	11378 c	744 c	21424 c	15 : 1

*Calculations of TC, TN and OM are based on equal increments (2 in.) for all depths.

*Means with the same letters are not significantly different at Pr ≤ 0.05.

Table 2. Corn residue C and N input to soil, fall 2001 Boone-S site.

N rate	Dry Matter	Total C	Total N	C:N Ratio
- - - - - - - - - - - - - - - - -	lb/acre - - - - - - - - - - - - - - - - - -			
0	6385 a	2573 a	37.4 a	69 : 1
80	6911 a	2710 a	50.5 ab	54 : 1
160	6255 a	2473 a	48.2 ab	51 : 1
200	7341 a	2919 a	63.4 b	46 : 1

*Means with the same letters are not significantly different at Pr ≤ 0.05.

Table 3. Soybean residue C and N input to soil, fall 2002 Boone-S site.

N rate	Dry Matter	Total C	Total N	C:N Ratio
- - - - - - - - - - - - - - - - -	lb/acre - - - - - - - - - - - - - - - - - -			
0	6267 a	2697 a	68.7 a	39 : 1
80	6025 a	2608 a	68.6 a	38 : 1
160	6590 a	2822 a	81.9 a	34 : 1
200	7385 a	3179 a	91.0 a	35 : 1

*Means with the same letters are not significantly different at Pr ≤ 0.05.

Figure 1. Demonstration sites in 2001-2003. Stars indicate sites with multi-year C measurements.

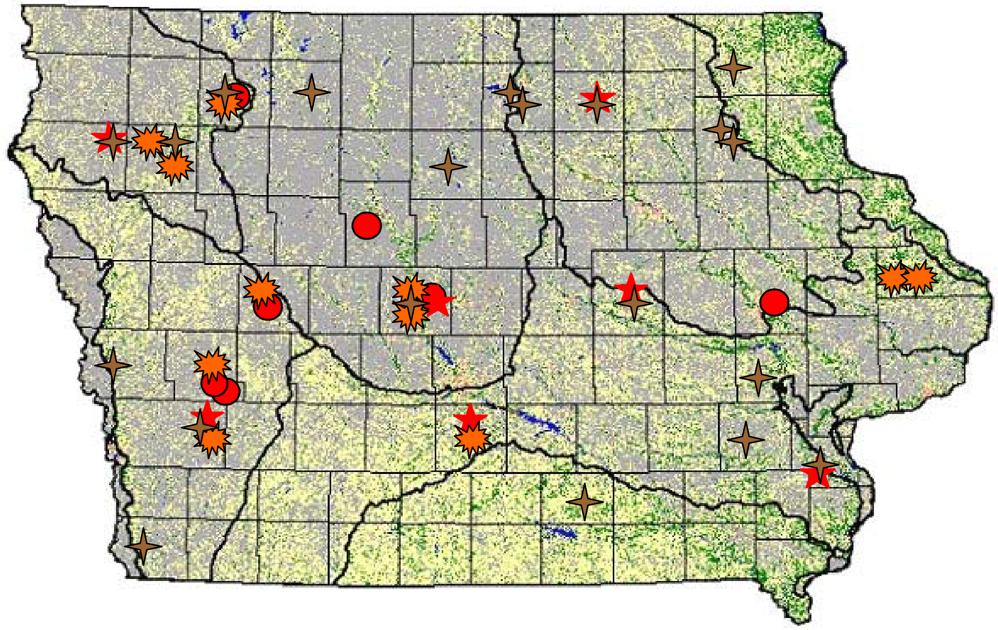

Figure 2. Economic optimum N rate at each site ranked by maximum yield. The horizontal line indicates the economic optimum N rate determined from the average N rate response, 2001-2003.

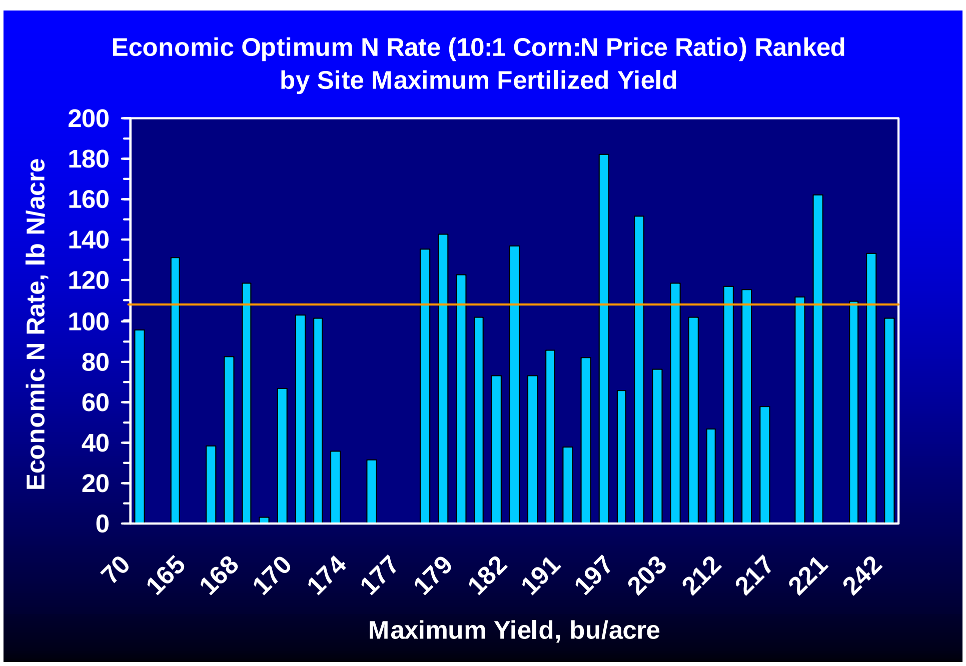

Figure 3. Ear leaf greenness measured with a Minolta 502 SPAD meter for the zero and highest N rate, ranked by maximum yield, 2001-2003.

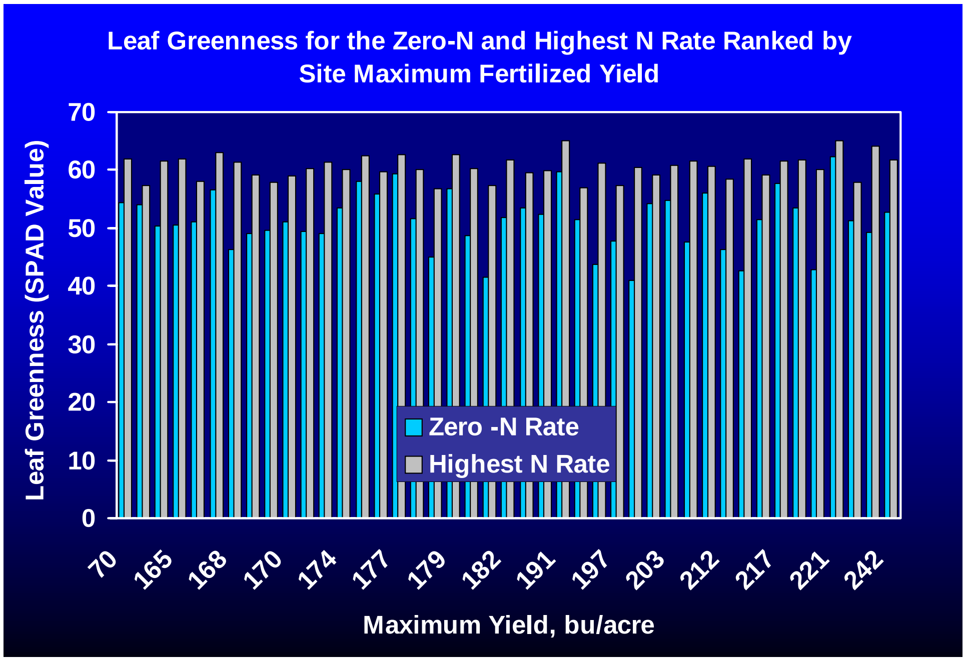

Figure 4. Relationship between the Illinois N Soil Test (0-12 inch soil sample depth) and corn yield response to applied N for 2001-2003. The N fertilizer response calculated as 100 x (optimal yield – control yield)/control yield.

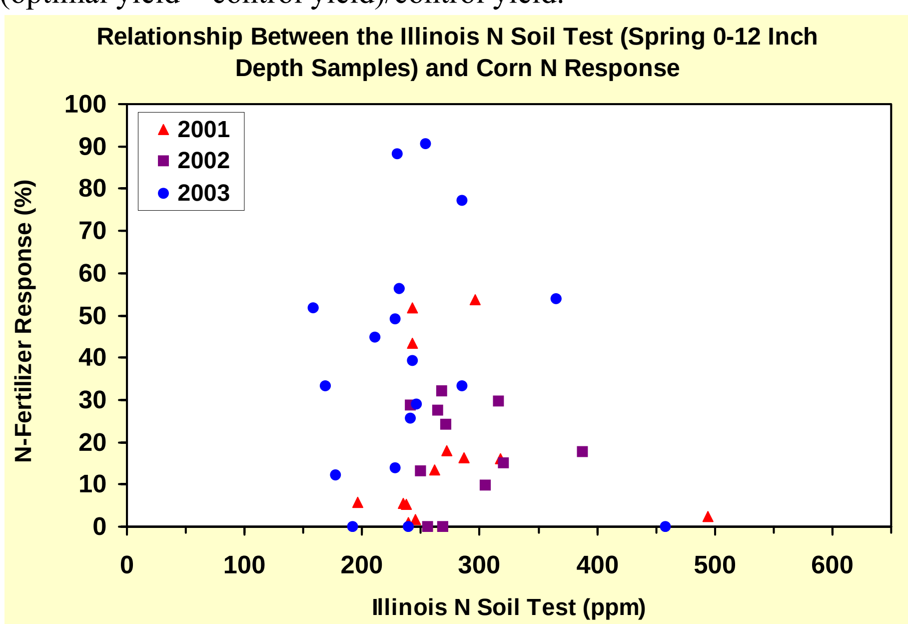

Figure 5. Relationship between the Illinois N Soil Test (0-6 inch soil sample depth) and corn yield response to applied N for 2001-2003. The N fertilizer response calculated as 100 x (optimal yield – control yield)/control yield.

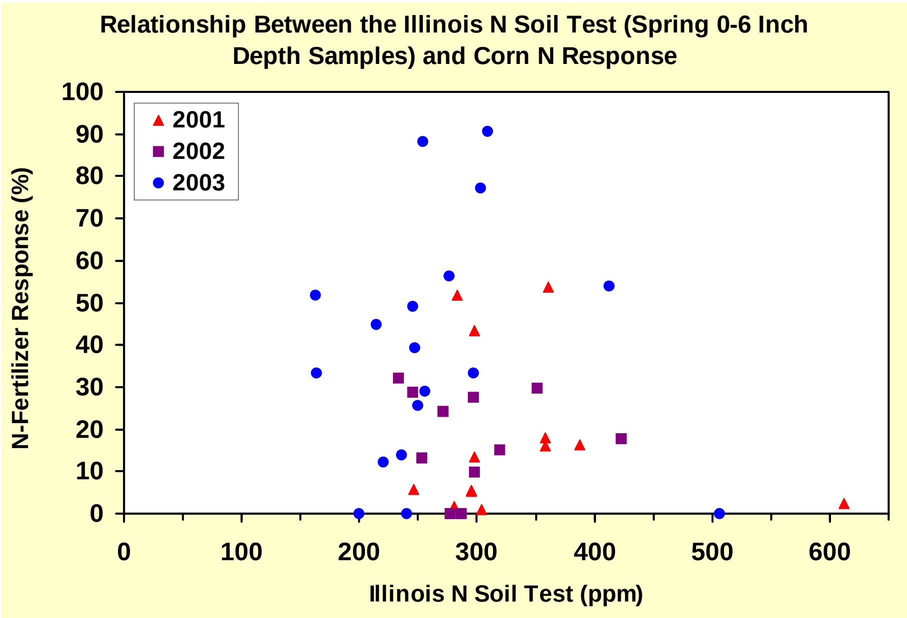

Figure 6. Relationship between the Illinois N Soil Test for 0-6 and 0-12 inch samples collected in the fall and spring (preplant), 2001-2003.

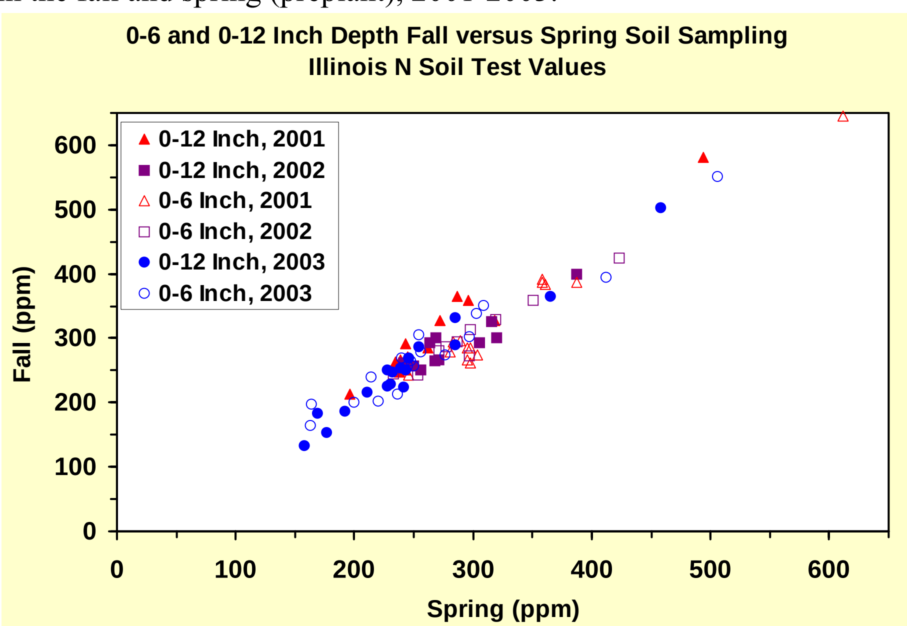

Figure 7. Relationship between the Illinois N Soil Test (spring 0-12 inch soil sample depth) and total soil N, 2001-2003.

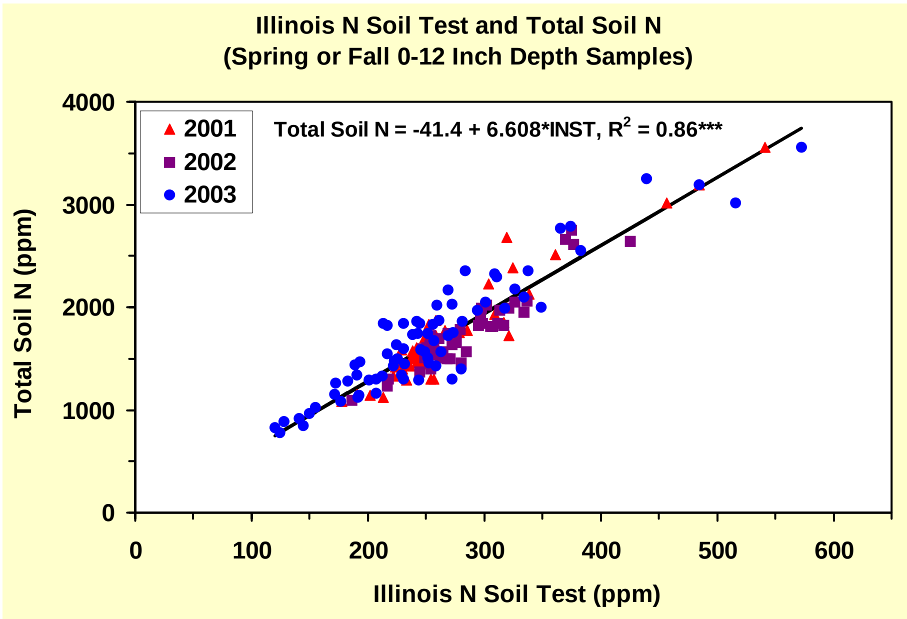

Figure 8. Relationship between soil organic matter (0-12 inch soil sample depth) and corn yield response to applied N, 2001-2003.

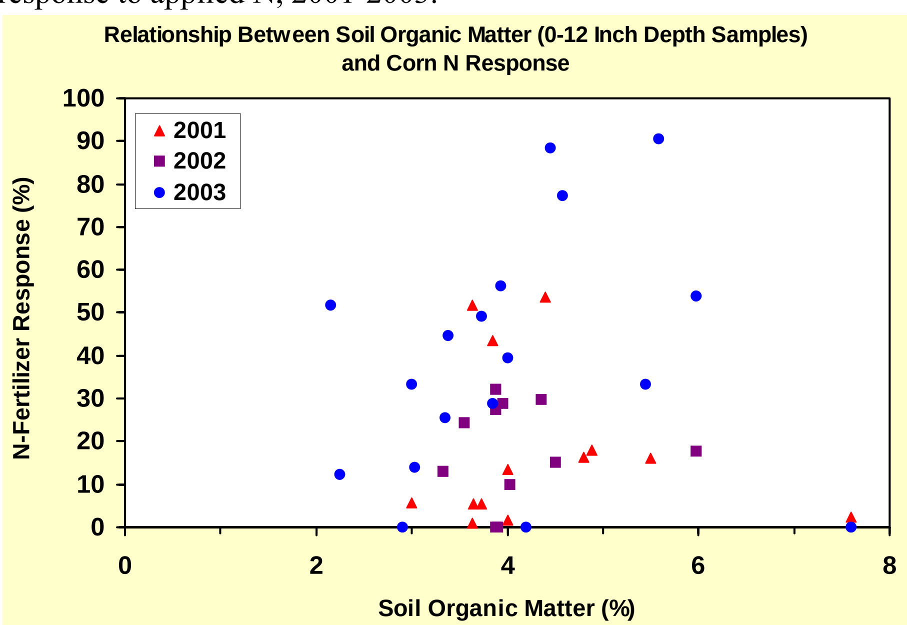

Figure 9. Average CO_2 emission rates from the soil surface in a corn-soybean rotation with different N rates applied to corn; 2002 soybean and 2003 corn, Boone-S site.

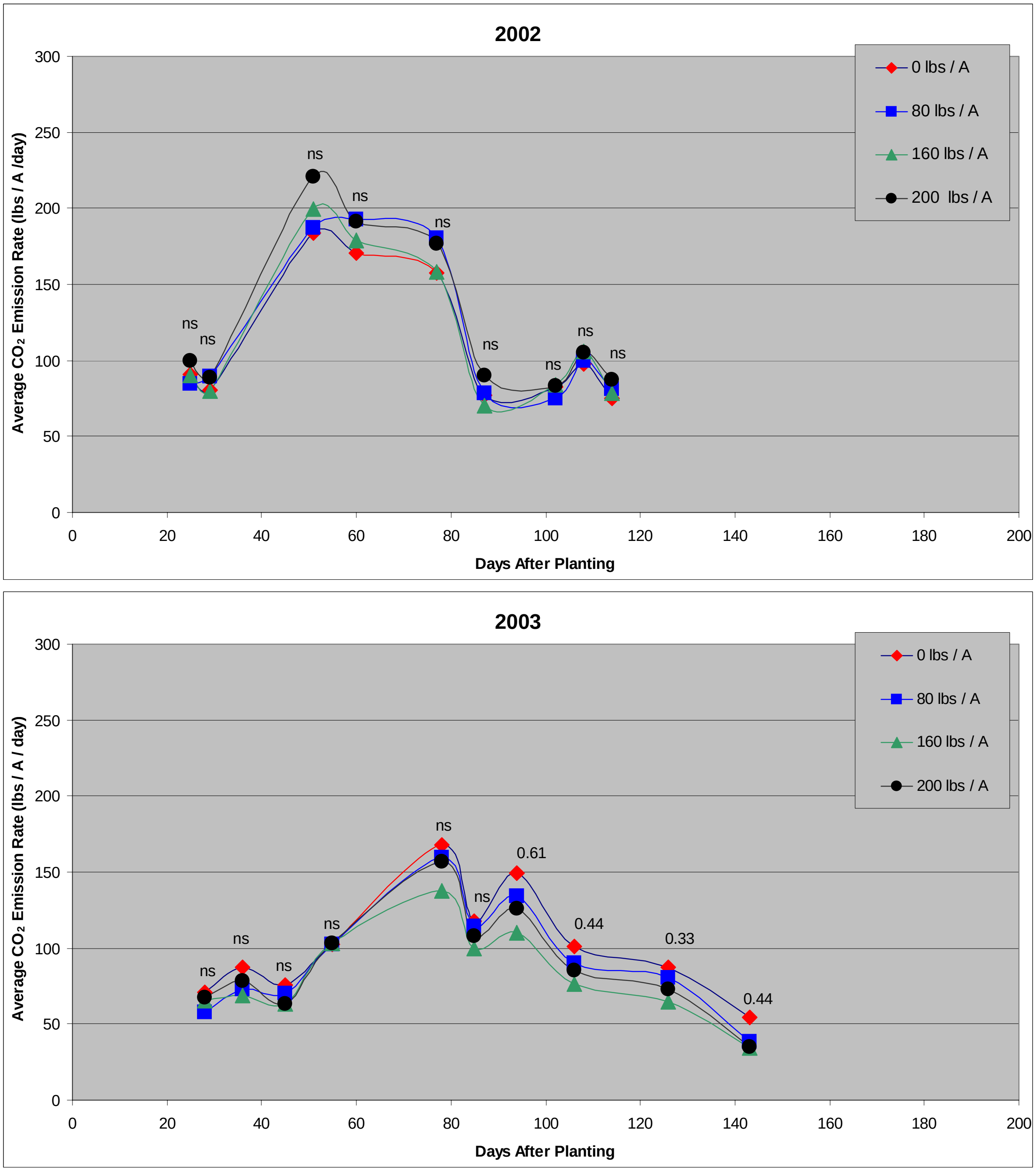

Figure 10. Cumulative CO_2 emission rates in a corn-soybean rotation with different N rates applied to corn; 2002 soybean and 2003 corn, Boone-S site.