SOIL NITROGEN AND CARBON MANAGEMENT PROJECT

Final Report
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Introduction

An important component for predicting nitrogen (N) fertilization needs 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 corn N fertilization need 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 C management practices, then work as conducted 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 (Amino Sugar N 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, known as 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, and grain yield. Additional soil samples from various depths in the fall, spring, and in-season 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 provide baseline total soil organic C (TC), particulate organic matter (POM), mineral fraction C (MFC), total soil N (TN), and estimated soil bulk density. Carbon dioxide flux was monitored at selected sites and selected N rates during the growing season, after harvest, and in the following crops.

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. Cooperators supplied field site and cropping history information (Table 1).

Fourteen sites were located for the project in 2001, eleven new sites in 2002, and thirteen new sites in 2003 (Table 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, crop yield, and response to applied N.

Sites were soil sampled for routine soil tests, soil N tests, TN, and soil organic matter (Table 2). Sampling for soil N test evaluation included fall, spring preplant, in-season, and post-harvest. Soil was collected at 0-6 inch and 0-12 inch depths.

Six rates of fertilizer 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 (see footnote in Table 3 for amount) in starter or with phosphate fertilizer which occurred at five sites (Boone-N, Boone-S, Carroll, 2001; Shelby-E, 2001; Johnson, 2003).

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, initial soil samples were collected at 0-2, 2-4, 4-6, 6-12, and 12-24 inch depths from seven sites in 2001. These same depth samples were collected again in the spring of 2002 and fall of 2003. Bulk density and pH were determined at each depth and samples were analyzed for TC, POM, MFC, and TN. At three sites emission of CO_2 was monitored throughout the growing season with a Li-Cor 6400 CO_2 analyzer at 0, 80, 160, and 200 lb N/acre fertilization 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 (Table 3) 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 (Table 3). 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). Eight sites (19% 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 was minimal (less than 1-2 bu/acre).

At 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. Using the approach of Nafziger et al. (2004) to calculate the economic response to N using each site response data, the N rate at the average maximum net economic return to N was 113 lb N/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 at or 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 and Table 4 show 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 applied N rate. Within a site, chlorophyll meter readings are a good indicator of the N status and differences between N rates. Converting readings to a relative or normalized basis (RCM value – reading divided by reading at non-limiting N) allows N status comparison between sites.

Most sites with greatest response to applied N had low chlorophyll meter 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 chlorophyll meter readings are another indicator of high soil N supply to corn.

The relationship between chlorophyll meter readings and differential from economic optimum N was poor for both deficit N (N rate below zero differential from optimum N) and excess N (N rate above zero differential from optimum N). This is understandable because of variation in chlorophyll meter readings that occurred due to different hybrids, growing seasons, and stress conditions across these sites. The relationship between chlorophyll meter readings and differential from economic optimum N was improved when the readings were normalized (RCM value) to the highest N rate at each site (Figure 4.). Regression analyses indicated a significant quadratic plateau equation for RCM values versus differential from optimum N. The RCM value where the regression crossed the optimum N rate (zero differential from optimum N) was at 0.97. This, along with the join point in the quadratic plateau regression at 59 lb N/acre, indicates the corn ear leaf at the R1 stage cannot express much loss of chlorophyll (little N stress) or productivity will be reduced.

Several observations can be made from the relationship between RCM value and N rate differential from optimum N (Figure 4). One, RCM values do not indicate excess N rate. Two, RCM values do indicate N stress and N stress severity. Three, chlorophyll meter readings, when normalized to a well N-fertilized reference (non-N deficient), reduces variability in the relationship with yield and applied N, however variability still exits. Four, there is only small separation in RCM values from slightly N deficient corn to corn with adequate and excess N. This may limit the potential to discern and address small N rate needs, which could limit ability to adjust the last economic increments of needed N. Five, despite the significant regression fit, the scatter in data when N rate is deficit may limit potential to discern small N rate changes. However, considering the wide range is hybrids, soils, and climatic seasons, the strength in the relationship between RCM value and differential N is quite good.

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.

Evaluation of the Illinois N Soil Test

Figures 5, 6, and 7 give the relationship between the Illinois N Soil Test value and corn yield response to N fertilizer at the 2001-2003 sites. Figure 5 has results for spring preplant soil samples collected from the 0-12 inch depth, and Figure 6 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 relative yield in Figure 7 one can easily see the lack of calibration 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 8 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 TN (Figure 9). The same general relationship would hold for soil organic matter because of the close tie between TN and organic

C. Across the sites in this project there was no correlation between soil organic matter and corn response to applied N (Figure 10) or economic N rate (data not shown). In other words, TN, 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.

Results of the Illinois N Soil Test calibration from 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 with further testing. 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 time the Illinois N Soil Test is not recommended for interpreting the need for N application or N rate adjustment in corn production on Iowa soils.

Nitrogen Fertilization Effects on Soil Organic Matter

An objective of this project is to evaluate the effect of N fertilization on soil organic matter. One of the indicators to make this evaluation is determination of CO_2 emission from the soil during multiple growing seasons with several N fertilizer rates.

Changes in CO_2 emission from the soil during the growing season as a result of different N rates applied to corn and in the following year soybean crop without N application were measured at three selected sites beginning in 2002; Boone-S, Floyd, and Warren, with the addition of the Tama site in 2003 due to management problems at the Warren site. The CO_2 emission from soil, reported as a daily CO_2 rate and cumulative amount of CO_2-C, are summarized in Figures 11 though 16 (A for daily CO2 emission and B for cumulative CO_2-C emission) for the four sites in 2002 and 2003 crop years.

The field monitoring of CO_2 emission rate with four different N rate treatments revealed that high N rate applications had no significant effect on CO_2 emission rate regardless of the crop or time of the year. However, the greatest C loss as CO_2 was during the middle of the growing season (June through August). Generally, N application greater than 80 lb N/acre resulted in a reduction in the total amount (cumulative) of C lost as CO_2 compared to the zero-N control treatment, especially during the corn year. This reduction in C loss due to high N application may be attributed to the depressing effect of high N rates on soil microbial activity and the slow down of organic matter decomposition by soil microbes. A concurrent lab study (data not shown) indicated that high N rates resulted in a slowing of microbial activity and consequently less CO_2 release. On the other hand, although N fertilizer was not applied to the soybean crop in 2002, it appears N fertilizer applied to the prior-year corn had a residual effect on C loss from the soil as CO_2. Our results show that the prior-year high N rates (applied to the previous corn crop), compared to low N rates, tended to have slightly higher CO_2 emission rates during the soybean growing season. One explanation is that high prior-year N application may provide needed N for microbial activity during the soybean crop year, thus increasing soil organic matter decomposition and CO_2 emission. These results show that a balance in N fertilization is critical for sustaining soil organic matter, increasing residue C input, and maximizing soil C sequestration.

Nitrogen Fertilization Effect on Soil C Changes

The other indicators that were evaluated to assess N fertilization effects on soil C dynamics included soil TC, POM, MFC, and TN. Prior to applying fertilizer N at the initiation of the study, soil samples were taken at the six selected sites in the spring of 2001 for the following depths: 0-2, 2-4, 4-6, 6-12, and 12-24 inch. Similarly, in spring 2002 and fall 2003 soil samples were taken for the same depths and analyzed for the same parameters. Results presented in Tables 5 and 6 are for the top 6-inch only (sum of the 0-2, 2-4, and 4-6 inch depths). Soil C and N at these depths is most affected by soil management practices. The initial values for these parameters showed wide differences between sites for all soil C components and TN. These differences are more likely influenced by soil type, management history, and cultural practices.

The effect of N fertilization rate on soil C components and TN after the first corn growing season would be reflected in soil samples collected in the spring 2002 (Table 5). The results show that N fertilization had no significant effect on soil TC, POM, MFC, or TN content at the 6-inch soil depth at any of the six locations. This lack of significant effect of N fertilization rate on soil C components and TN is expected given the short time period (one year and one N application). Although the differences are not large, there were some TC losses in the top 6-inch depth (average of 1-2 ton/acre) for several sites, especially with the zero-N control treatment.

After 3 years (two N applications, two corn crops, and one soybean crop), changes in all soil C components and soil TN was still not significant between N rates at all sites, fall 2003 sampling (Table 6). The changes in soil C components reflect the effects of site-specific management and soil conditions on soil organic matter. The results of this study demonstrated that N fertilization rate, in the short term, had no real impact on soil C and N. However, changes in these parameters can be used as an indicator of potential long-term impact of N fertilization programs on soil C, soil N, and soil productivity.

References

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Education Component and Outreach Activity

Outreach activities occurred at project sites, field days, and conferences. Field signs indicating the project name, program, and cooperating organizations were located at many sites.

Information gained from the project was delivered to farmers, agbusiness, CCA's, and agency personnel at over sixty-six project meetings, conferences, and extension education programs. Material was also disseminated in newsletters and web materials. An important educational multiplier was use of project information in extension and other education programs related to N and C management.

Expected Benefits

Benefits for producers include a better understanding of corn N requirements and soil N-C dynamics. These benefits improve producer understanding of corn N needs and setting appropriate N rates, especially when low or no N application is needed. Data from this project is being used in statewide and regional evaluations of corn N requirements and investigation of methods to formulate N recommendations for corn. This will assist producers in maximizing economic corn production and minimizing environmental N impacts. Unfortunately the new Illinois N Soil Test could not be calibrated and was not found useful for adjusting N application rates on Iowa soils and crop production conditions. This information has been shared with soil test labs in Iowa and surrounding states.

Nitrogen application and soil management have a significant impact on soil organic matter, and specifically soil C. The loss of C from the soil as CO_2 can impact the environment, soil tilth, soil C pools, and the degradation of soil organic matter. The outcome of this project furthered this understanding in regard to the interrelationship of N fertilization on short-term C loss and in the long-term maintenance of soil organic C. This will assist producers with decisions regarding N and C management.

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

Table 1. Site characteristics, management, and prior crop yield history, 2001-2003 project sites.

County-Site	Soil	Tillage[†]	Yield History[‡] Corn	Yield History[‡] Soybean	N History[§]	Manure History
			- - - bu/acre - - -		lb N/acre	
2001						
Boone-N	Canisteo	Conservation Tillage	153	45	140	None
Boone-S	Clarion	Conservation Tillage	153	45	140	None
Carroll	Marshall	Conservation Tillage	138	41	132	Finishing Swine - last 1996
Clay	Nicollet	Conservation Tillage	152	52	130	None
Floyd	Clyde	Conservation Tillage	165	54	140	None
Linn	Kenyon	Conservation Tillage	160	57	150	Solid Beef - last 1999
Louisa	Mahaska, Otley	Conservation Tillage	159	52	135	None
Plymouth	Galva	Conservation Tillage	156	49	130	None
Pottawattamie	Marshall	No-Tillage	165	54	150	None
Shelby-E	Marshall	Conservation Tillage	148	45	150	None
Shelby-W	Zook	Conservation Tillage	170	68	150	None
Tama	Tama, Garwin	Conservation Tillage	149	52	170	Dairy Pit - 1997, 1998, 1999, 2000
Warren	Nevin	No-Tillage	150	50	150	None
Webster	Webster	Conservation Tillage	169	54	175	None
2002						
Boone-P	Zenor, Spillville	Conservation Tillage	172	49	75	Finishing Swine - 1997, 1998, 2000, 2001
Boone-SN	Webster, Clarion	Conservation Tillage	162	34	125	None
Carroll	Marshall, Exira	No-Tillage	145	40	120	Finishing Swine - last 2000
Cherokee-O	Galva	Fall Strip Tillage	171	58	160	None
Cherokee-S	Galva	Conservation Tillage	150	51	100	Finishing Swine - 1996, 1998, 2000
Clay	Marcus	Conservation Tillage	163	52	115	None
Jackson-E	Downs	No-Tillage	152	53	100	None
Jackson-W	Downs	No-Tillage	159	53	100	Beef Feedlot - prior to 1990
Pottawattamie	Marshall	No-Tillage	173	58	133	None
Shelby	Marshall	Conservation Tillage	147	50	140	None
Warren	Macksburg	No-Tillage	-	-	-	None
2003						
Boone-S	Clarion	Conservation Tillage	163	44	155	None
Cerro Gordo-K	Webster	Conservation Tillage	157	46	150	None
Cherokee	Galva	Fall Strip Tillage	176	62	160	None
Clay	Marcus	Conservation Tillage	158	44	140	Finishing Swine - Spring 2000
Fayette-D	Kenyon	Conservation Tillage	175	52	140	None
Fayette-I	Fayette	Conservation Tillage	130	47	120	None
Floyd	Clyde	No-Tillage	165	54	140	None
Fremont	Kennebec	No-Tillage	155	50	150	Composted Swine - 1998
Harrison	Monona	No-Tillage	150	46	150	None
Johnson	Dinsdale	Conservation Tillage	165	54	175	None
Louisa	Mahaska, Otley	No-Tillage	155	47	135	None
Monroe	Haig	Conservation Tillage	164	51	200	None
Palo Alto	Webster	Conservation Tillage	155	40	120	None
Pottawattamie	Marshall	No-Tillage	165	54	150	None
Tama	Tama, Garwin	No-Tillage	149	52	170	Dairy Pit - 1997, 1998, 1999, 2000
Washington	Otley	Conservation Tillage	180	57	175	Finishing Swine -Fall 2000
Winneshiek	Downs	Conservation Tillage	170	50	110	None
Wright	Kossuth	Conservation Tillage	-	-	-	-

[†] Tillage system for the current crop year.

[‡] Yield history is average of last two to five crop years. In each project year corn followed soybean.

[§] Nitrogen application history for the last two to three corn crops.

Table 2. Routine soil tests and soil N test data, 2001-2003 project sites.

Sites	STP†	STK†	pH†	O.M.†	LSNT‡	Illinois N Soil Test§
	- - - - ppm - - - -			%	- - - - - ppm - - - - -	
2001						
Boone-N	28	90	8.1	6.59	7	336
Boone-S	19	110	6.0	4.44	5	309
Carroll	44	272	6.5	4.00	6	290
Clay	43	174	7.0	5.51	13	345
Floyd	32	115	6.3	9.20	12	510
Linn	149	324	7.5	4.06	30	275
Louisa	43	292	6.3	3.96	4	273
Plymouth	63	354	7.1	5.11	5	344
Pottawattamie	29	246	7.5	4.18	9	272
Shelby-E	18	279	5.8	3.96	9	285
Shelby-W	162	420	7.1	4.14	8	278
Tama	49	190	7.9	3.68	6	220
Warren	25	209	6.5	3.88	3	276
Webster	29	140	6.1	5.44	10	330
2002						
Boone-P	183	308	6.3	4.05	12	297
Boone-SN	23	136	6.1	3.95	8	253
Carroll	110	379	6.2	4.45	10	319
Cherokee-O	22	166	6.4	4.75	11	314
Cherokee-S	46	208	5.9	4.88	12	336
Clay	27	196	6.5	6.28	11	448
Jackson-E	22	141	6.8	4.05	13	291
Jackson-W	202	383	7.4	4.78	17	289
Pottawattamie	33	239	7.2	4.05	22	276
Shelby	21	232	6.0	3.50	11	257
Warren	26	188	6.5	4.00	9	273
2003						
Boone-S	19	110	6.0	4.00	10	243
Cerro Gordo-K	19	150	7.4	6.03	20	285
Cherokee	34	160	5.5	4.73	10	285
Clay	36	167	6.1	6.43	7	365
Fayette-D	29	142	6.8	2.50	8	158
Fayette-I	12	95	5.6	2.95	--	177
Floyd	32	115	6.3	9.22	13	458
Fremont	42	397	5.7	3.10	10	192
Harrison	38	214	5.8	3.03	10	228
Johnson	39	139	6.6	4.30	17	239
Louisa	43	292	6.3	3.98	5	246
Monroe	35	148	6.9	3.95	10	211
Palo Alto	35	165	7.2	6.23	8	254
Pottawattamie	29	246	7.5	4.20	10	228
Tama	49	190	7.9	3.70	7	169
Washington	28	218	6.3	4.03	11	232
Winneshiek	15	117	6.0	3.70	9	241
Wright	17	151	6.8	5.20	9	230

† Routine soil tests from 0-6 inch samples collected in the fall or spring prior to planting. Soil test P (STP) determined by Mehlich-3 P and soil test K (STK) determined by ammonium acetate.

‡ Late spring soil nitrate test (LSNT) from 0-12 inch depth soil samples collected when corn was 6- to 12 inches tall from the no-N check (control) plots.

§ Illinois N Soil Test from 0-12 inch depth soil samples collected in the spring prior to planting.

Table 3. Corn grain yield response to applied N, 2001-2003 project sites.

Site	No-N Check Yield[†]	Economic Response[‡] N Rate	Economic Response[‡] Yield	Maximal Response[§] N Rate	Maximal Response[§] Yield	Yield Increase[¶]
	bu/acre	lb N/acre	bu/acre	lb N/acre	bu/acre	%
2001						
Boone-N	149	36	172	39	173	16.2
Boone-S	148	103	167	163	170	15.5
Carroll	160	0	160	0	160	0.0
Clay	118	137	181	157	182	54.6
Floyd	158	0	158	0	158	0.0
Linn	200	47	211	65	212	5.8
Louisa	126	73	181	79	181	43.7
Plymouth	150	143	174	200	178	19.0
Pottawattamie	167	31	176	39	176	5.7
Shelby-E	166	0	168	200	177	6.6
Shelby-W	182	38	185	162	191	5.0
Tama	150	0	150	0	150	0.0
Warren	137	102	208	111	209	52.2
Webster	140	82	165	105	166	18.7
2002						
Boone-P	221	0	221	0	221	0.0
Boone-SN	138	122	177	148	179	29.9
Carroll	171	86	188	120	190	10.9
Cherokee-O	174	76	200	91	201	15.6
Cherokee-S	137	102	178	118	179	30.3
Clay	160	73	189	86	189	18.0
Jackson-E	174	58	216	62	216	24.4
Jackson-W	217	0	217	0	217	0.0
Pottawattamie	53	96	67	152	70	32.9
Shelby	168	82	190	110	191	14.0
Warren	181	133	239	153	240	32.8
2003						
Boone-S	126	135	176	160	177	40.3
Cerro Gordo-K	177	110	235	122	236	33.7
Cherokee	112	152	198	167	199	77.9
Clay	140	116	215	126	216	54.3
Fayette-D	143	112	216	122	217	52.2
Fayette-I	178	119	200	180	203	14.0
Floyd	136	0	136	0	136	0.0
Fremont	174	0	174	0	174	0.0
Harrison	148	67	169	83	170	14.5
Johnson	176	0	176	0	176	0.0
Louisa	164	117	211	136	212	29.5
Monroe	116	119	167	137	168	45.5
Palo Alto	114	162	216	177	217	91.3
Pottawattamie	93	131	139	159	141	50.6
Tama	128	101	171	116	172	33.8
Washington	154	101	241	108	242	56.6
Winneshiek	157	66	197	72	197	25.8
Wright	104	182	195	200	196	89.3

[†] Yield with no applied N.

[‡] Economic N rate and yield at economic rate calculated at a break-even 10:1 corn:nitrogen price ratio (example $2.00/bu corn and $0.20/lb N).

[§] Nitrogen rate and yield at maximum response to applied N from the fitted response equation.

[¶] The percent yield increase from applied N at the maximal response above the no-N check.

Note: Carroll 2001 site had 12 lb N/acre applied at corn planting with starter; Boone-N and Boone-S sites had 12 lb N/acre as DAP; Shelby-E 2001 site had 13 lb N/acre applied as DAP; and Johnson 2003 site had 23 lb N/acre as DAP and starter.

Table 4. Corn ear leaf greenness response to applied N (R1 silking growth stage measured with a Minolta SPAD chlorophyll meter), 2001-2003 project sites.

Site	No-N Check†	Economic N Rate‡	Maximum§
	- - - - - - - - SPAD Reading - - - - - - - -		
2001			
Boone-N	49.1	56.0	61.3
Boone-S	51.0	59.0	59.0
Carroll	50.5	50.5	61.9
Clay	51.9	61.1	61.7
Floyd	49.0	49.0	59.2
Linn	56.0	57.7	60.6
Louisa	41.5	56.2	57.4
Plymouth	45.0	56.6	56.8
Pottawattamie	58.1	60.2	62.4
Shelby-E	59.3	59.3	62.7
Shelby-W	59.8	61.6	65.1
Tama	51.0	55.3	58.0
Warren	47.5	60.5	61.5
Webster	56.5	61.8	63.1
2002			
Boone-P	62.3	62.3	65.1
Boone-SN	56.8	61.3	62.6
Carroll	52.4	57.8	59.9
Cherokee-O	54.2	58.5	59.2
Cherokee-S	48.6	56.7	60.3
Clay	53.5	58.7	59.5
Jackson-E	51.4	57.9	59.2
Jackson-W	57.7	57.7	61.5
Pottawattamie	54.4	61.6	62.0
Shelby	51.5	54.8	57.0
Warren	49.3	63.4	64.1
2003			
Boone-S	51.7	59.0	60.0
Cerro Gordo-K	51.2	57.5	57.9
Cherokee	41.0	60.4	60.5
Clay	42.6	60.0	61.9
Fayette-D	53.4	61.6	61.7
Fayette-I	54.8	59.4	60.8
Floyd	54.1	54.1	57.3
Fremont	53.4	53.4	60.1
Harrison	49.6	56.7	57.8
Johnson	55.8	55.8	59.7
Louisa	46.3	56.0	58.4
Monroe	46.3	62.4	61.4
Palo Alto	42.8	57.5	60.1
Pottawattamie	50.4	54.0	61.5
Tama	49.4	54.8	60.2
Washington	52.7	60.0	61.8
Winneshiek	47.8	53.7	57.3
Wright	43.8	59.4	61.1

† SPAD reading with zero N applied.

‡ Interpolated SPAD reading at the economic N rate calculated at a break-even 10:1 corn:nitrogen price ratio (example \$2.00/bu corn and \$0.20/lb N).

§ At highest N rate.

Table 5. Soil C components and TN measured at the 0-6 in depth prior to fertilizer N application at the initiation of the study and in the spring of 2002 at six site locations.

Year	Soil Analysis†	N Rate	Site					
			Boone	Floyd	Louisa	Plymouth	Pottawattamie	Tama
		lb/acre	- - - - - - - - - - - - - - - - ton/acre -					
Spring	TC	Initial	23.4	38.5	21.0	24.8	21.6	18.2
2001	POM		2.9	7.2	2.1	3.8	3.1	2.4
	MFC		20.4	31.3	18.9	21.0	18.6	15.6
	TN		1.4	3.1	1.8	2.1	2.1	1.5
Spring	TC	0	20.2a	37.9a	20.1a	25.0a	22.3a	17.6a
2002		80	23.7a	38.6a	19.8a	25.4a	22.6a	17.7a
		160	24.3a	41.1a	19.5a	25.3a	22.4a	18.6a
		200	22.7a	39.9a	20.4a	24.8a	21.8a	18.6a
	POM	0	1.7a	10.2a	2.8a	3.3a	2.4a	2.5a
		80	2.2a	7.5a	2.9a	3.2a	2.1a	2.2a
		160	1.9a	10.9a	2.9a	2.9a	1.8a	2.0a
		200	2.5a	8.0a	2.9a	2.8a	2.0a	2.0a
	MFC	0	18.5a	27.7a	17.3a	21.7a	19.9a	15.1a
		80	21.5a	31.1a	16.9a	22.2a	20.5a	15.5a
		160	22.4a	30.2a	16.6a	22.4a	20.6a	16.6a
		200	20.2a	31.9a	17.5a	22.0a	19.8a	16.6a
	TN	0	1.0a	3.0a	1.6a	2.1a	1.7a	1.5a
		80	1.3a	3.1a	1.4a	2.1a	1.7a	1.4a
		160	1.3a	3.1a	1.5a	2.1a	1.7a	1.5a
		200	1.4a	2.9a	1.5a	2.1a	1.7a	1.5a

† TC, total organic soil C; POM, particulate organic matter; MFC, mineral fraction C; TN, total soil N.

‡ Values in column of same site for each soil analysis followed by the same letter are not significantly different at $P \leq 0.05$.

Table 6. Soil C components and TN measured at the 0-6 inch depth prior to fertilizer N application at the study initiation and in the fall of 2003 at six site locations.

Year	Soil Analysis†	N Rate	Site					
			Boone	Floyd	Louisa	Plymouth	Pottawattamie	Tama
		lb/acre	- - - - - - - - - - - - - - - - ton/acre -					
Spring	TC	Initial	23.4	38.5	21.0	24.8	21.6	18.2
2001	POM		2.9	7.2	2.1	3.8	3.1	2.4
	MFC		20.4	31.3	18.9	21.0	18.6	15.6
	TN		1.4	3.1	1.8	2.1	2.1	1.5
Fall	TC	0	19.4a	39.9a	19.5a	23.1a	20.9a	17.8a
2003		80	24.1a	38.6a	19.4a	22.8a	22.1a	11.8a
		160	24.0a	41.0a	18.0a	21.2a	22.6a	17.8a
		200	22.0a	38.2a	18.4a	22.5a	22.0a	17.2a
	POM	0	2.1a	2.9a	1.8a	2.9a	2.3a	2.1a
		80	2.1a	3.0a	1.3a	3.0a	2.2a	3.7a
		160	2.5a	3.0a	1.2a	2.5a	2.1a	2.6a
		200	3.2a	2.5a	1.2a	2.4a	2.0a	5.0a
	MFC	0	17.3a	37.0a	17.7a	20.2a	18.6a	15.7a
		80	22.0a	35.6a	18.1a	19.8a	19.9a	8.1a
		160	21.5a	38.0a	16.8a	18.7a	20.5a	15.2a
		200	18.8a	35.7a	17.2a	20.1a	20.0a	12.2a
	TN	0	1.4a	3.2a	1.6a	1.8a	1.9a	1.4a
		80	1.4a	3.3a	1.6a	1.9a	1.7a	1.2a
		160	1.3a	3.3a	1.4a	1.7a	1.7a	1.4a
		200	1.4a	3.3a	1.3a	1.8a	1.8a	1.3a

† TC, total soil organic C; POM, particulate organic matter; MFC, mineral fraction C; TN, total soil N.

‡ Values in column of same site for each soil analysis followed by the same letter are not significantly different at $P \leq 0.05$.

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

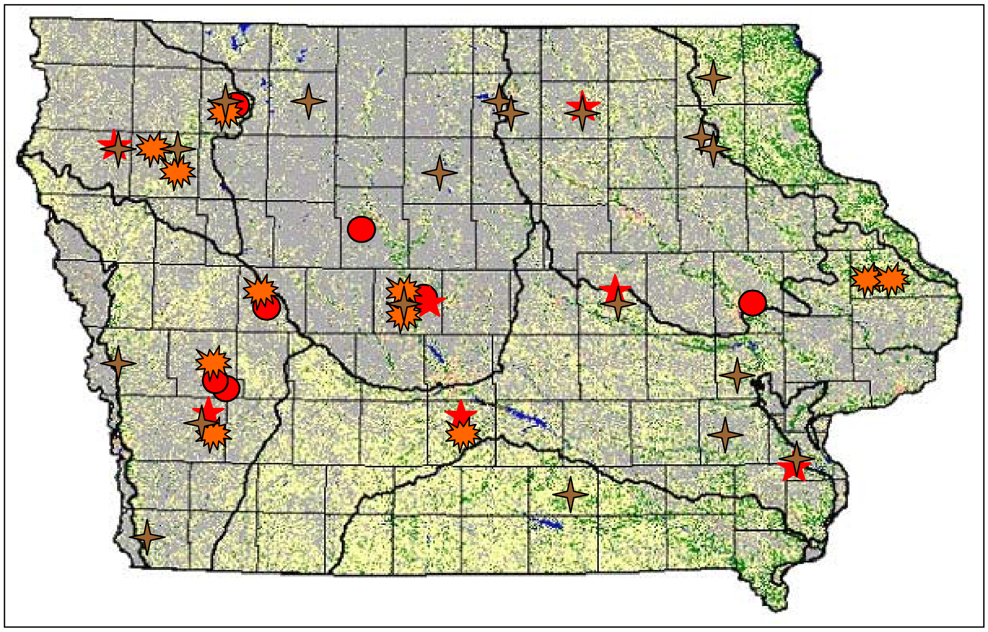

Figure 2. Economic optimum N rate at each site ranked by maximum yield, 2001-2003.

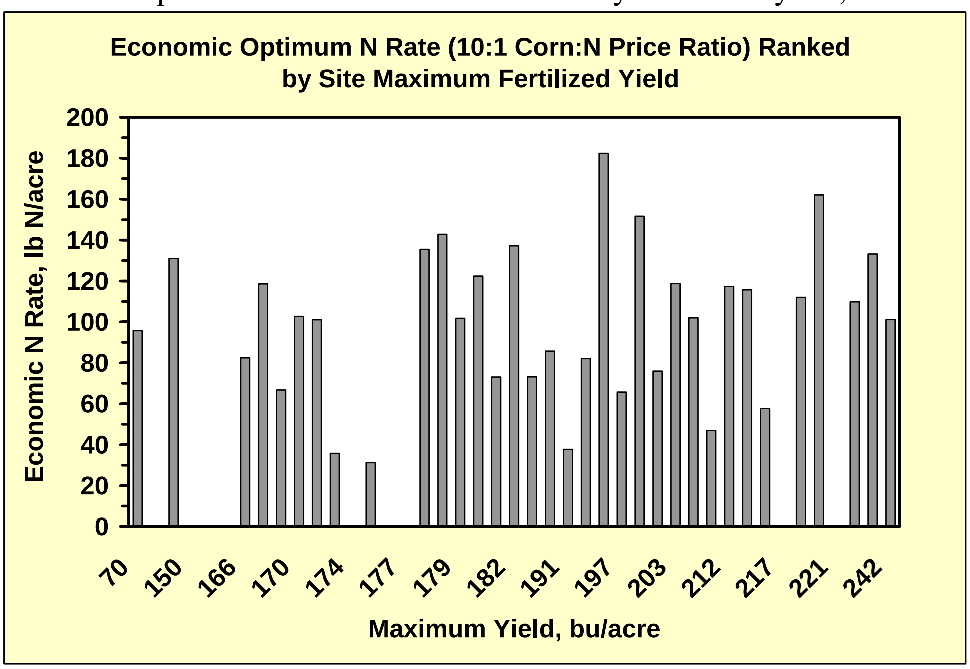

Figure 3. Ear leaf greenness measured with a Minolta 502 SPAD meter for the zero and highest N rate, ranked by maximum yield, 2001-2003.

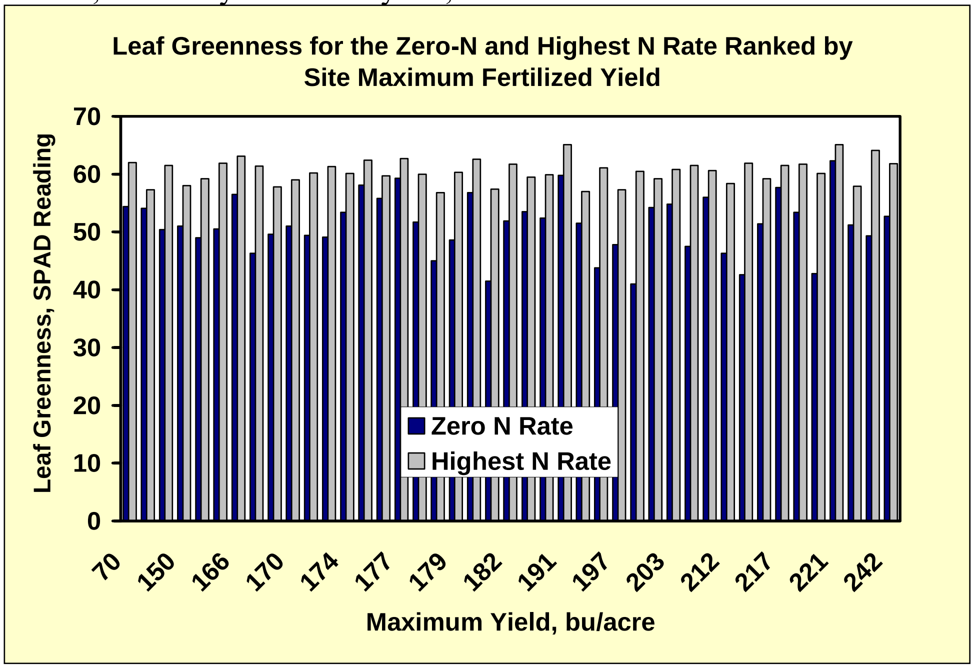

Figure 4. Relative chlorophyll meter values as related to N rate differential (ND) from optimum N, corn following soybean (n = 306).

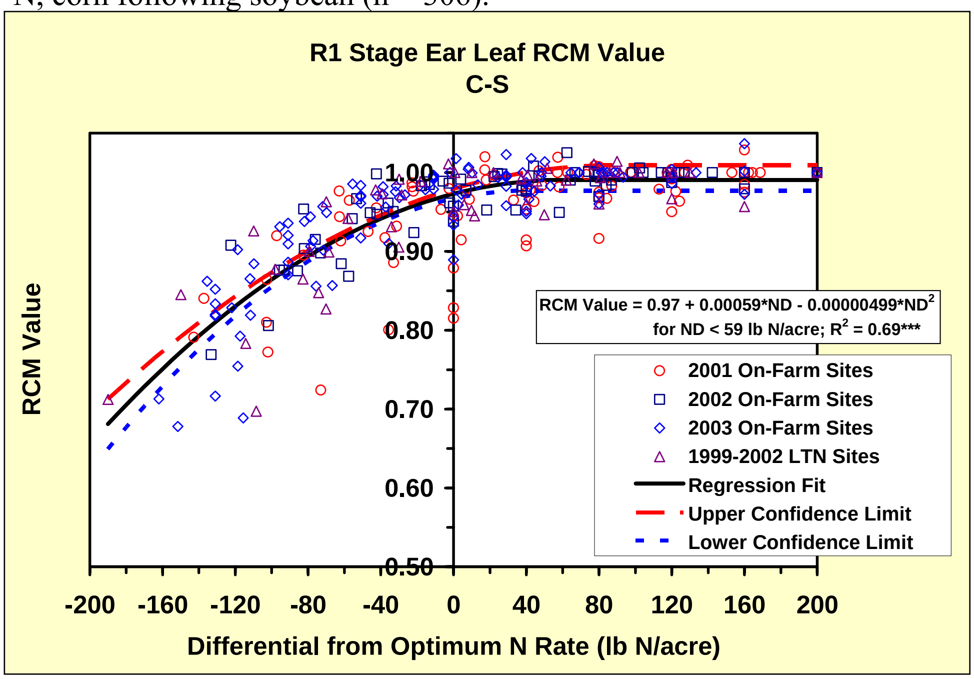

Figure 5. Relationship between the Illinois N Soil Test (0-12 inch soil sample depth) and corn yield response to applied N, 2001-2003. The N fertilizer response calculated as 100 x (optimal yield – control yield)/control yield.

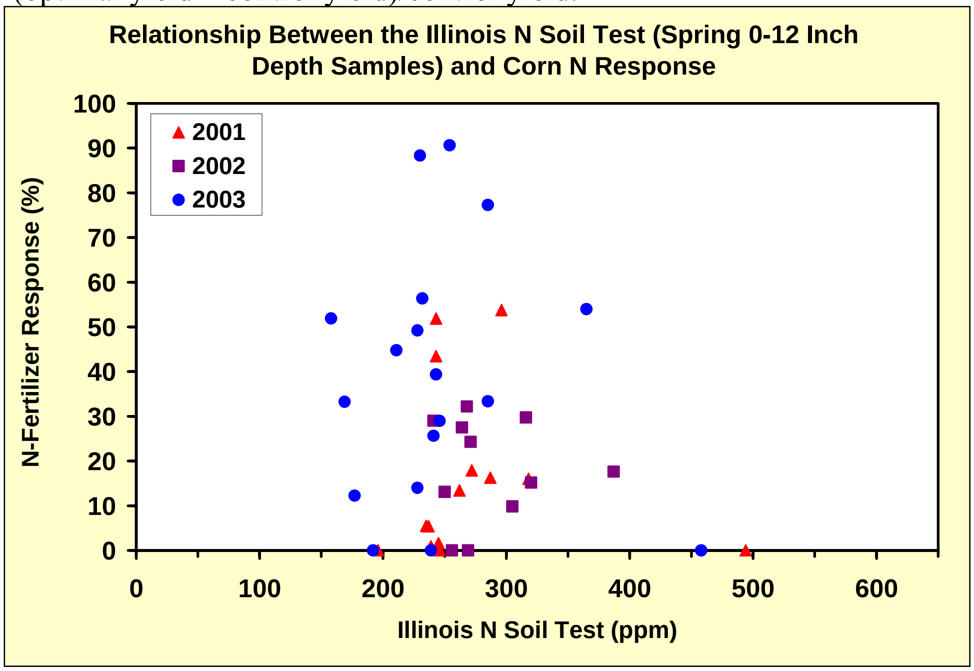

Figure 6. Relationship between the Illinois N Soil Test (0-6 inch soil sample depth) and corn yield response to applied N, 2001-2003. The N fertilizer response calculated as 100 x (optimal yield – control yield)/control yield.

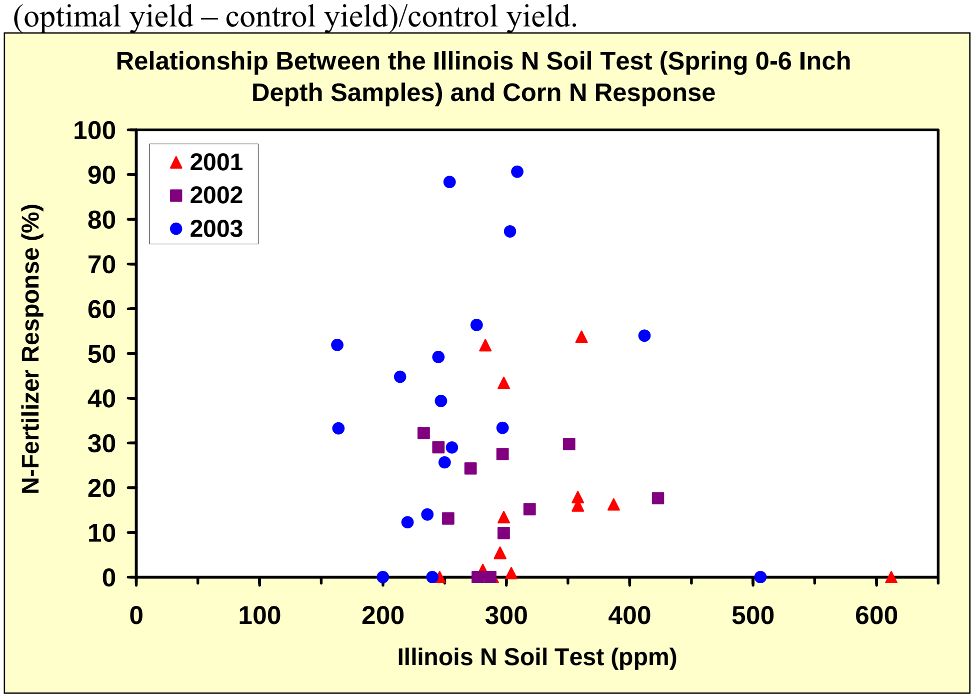

Figure 7. Relationship between the Illinois N Soil Test (0-12 inch sample depth) and relative corn yield, 2001-2003.

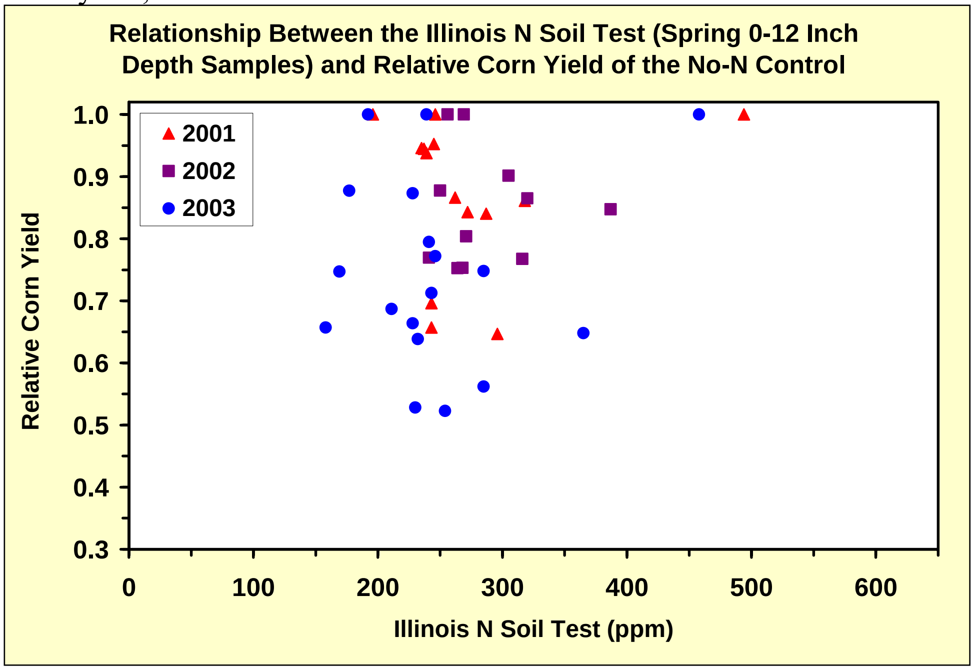

Figure 8. Relationship between the Illinois N Soil Test for 0-6 and 0-12 inch samples collected in the fall and spring (preplant), 2001-2003.

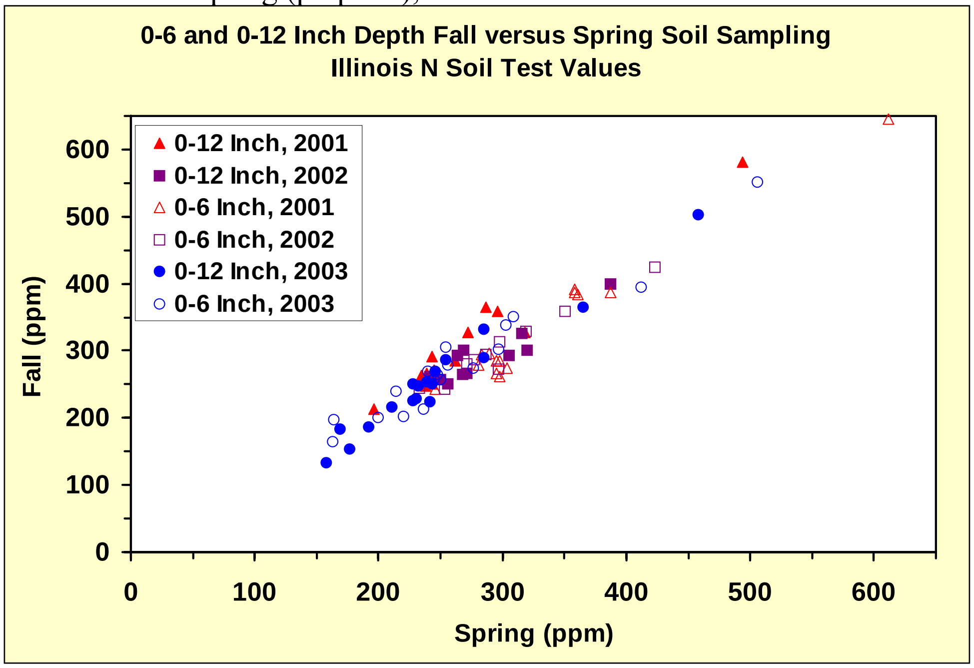

Figure 9. Relationship between the Illinois N Soil Test (spring 0-12 inch soil sample depth) and TN, 2001-2003.

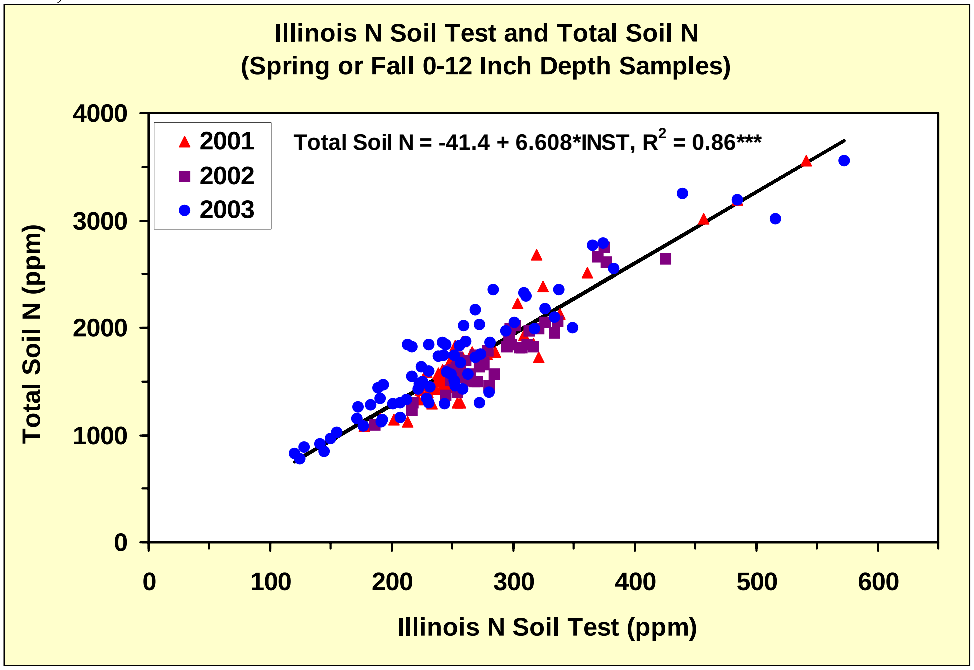

Figure 10. Relationship between soil organic matter (0-12 inch soil sample depth) and corn yield response to applied N, 2001-2003.

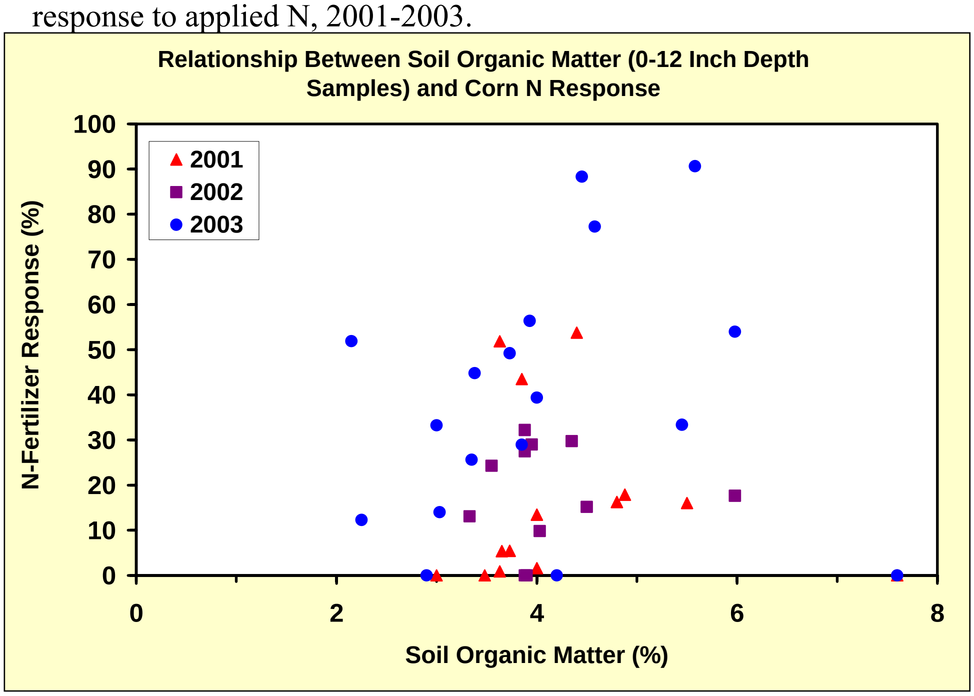

Figure 11. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the soybean crop year with different N rates applied to the prior-year corn at the Boone-S site, 2002.

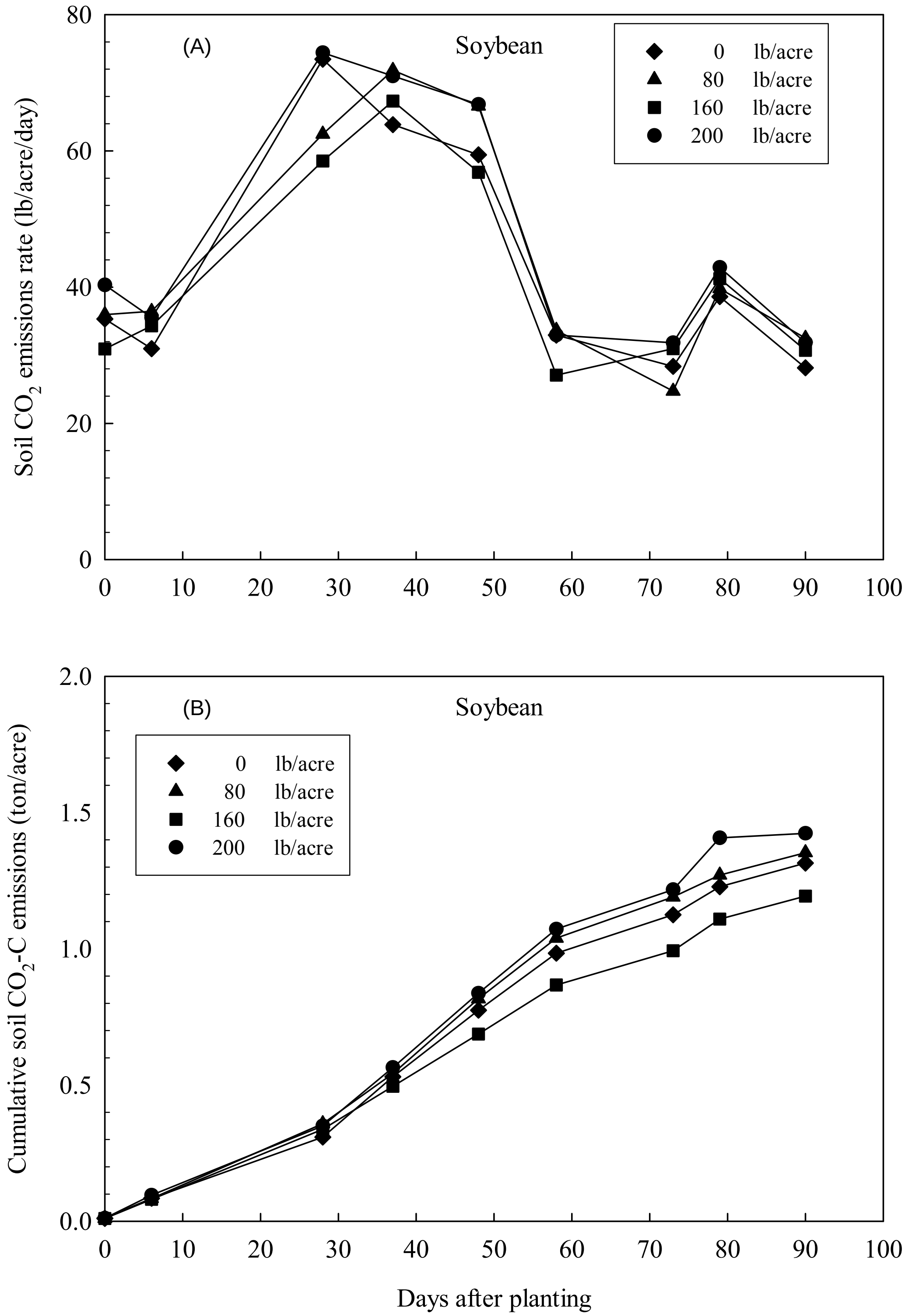

Figure 12. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the soybean crop year with different N rates applied to the prior-year corn at the Floyd site, 2002.

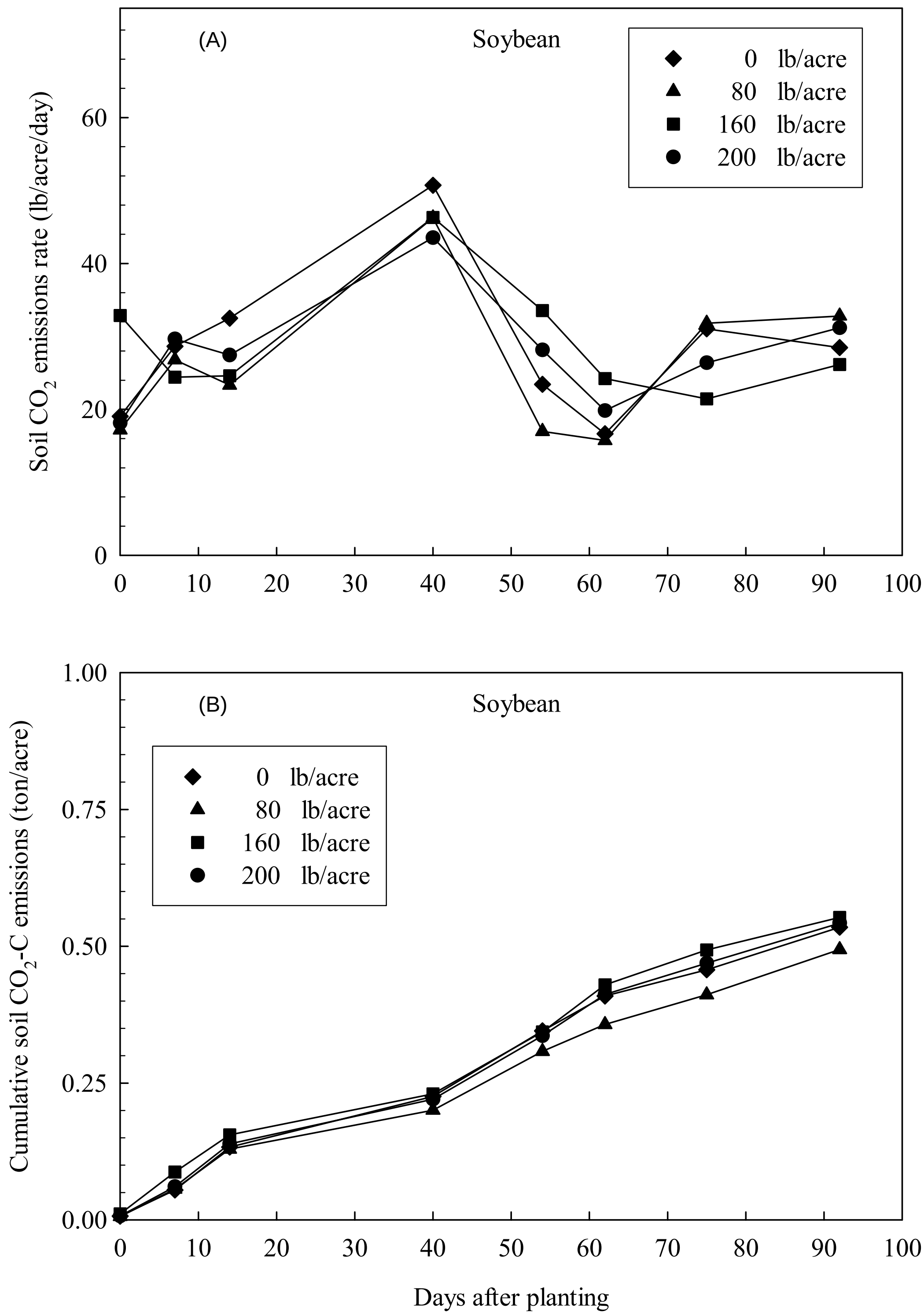

Figure 13. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the soybean crop year with different N rates applied to the prior-year corn at the Warren site, 2002.

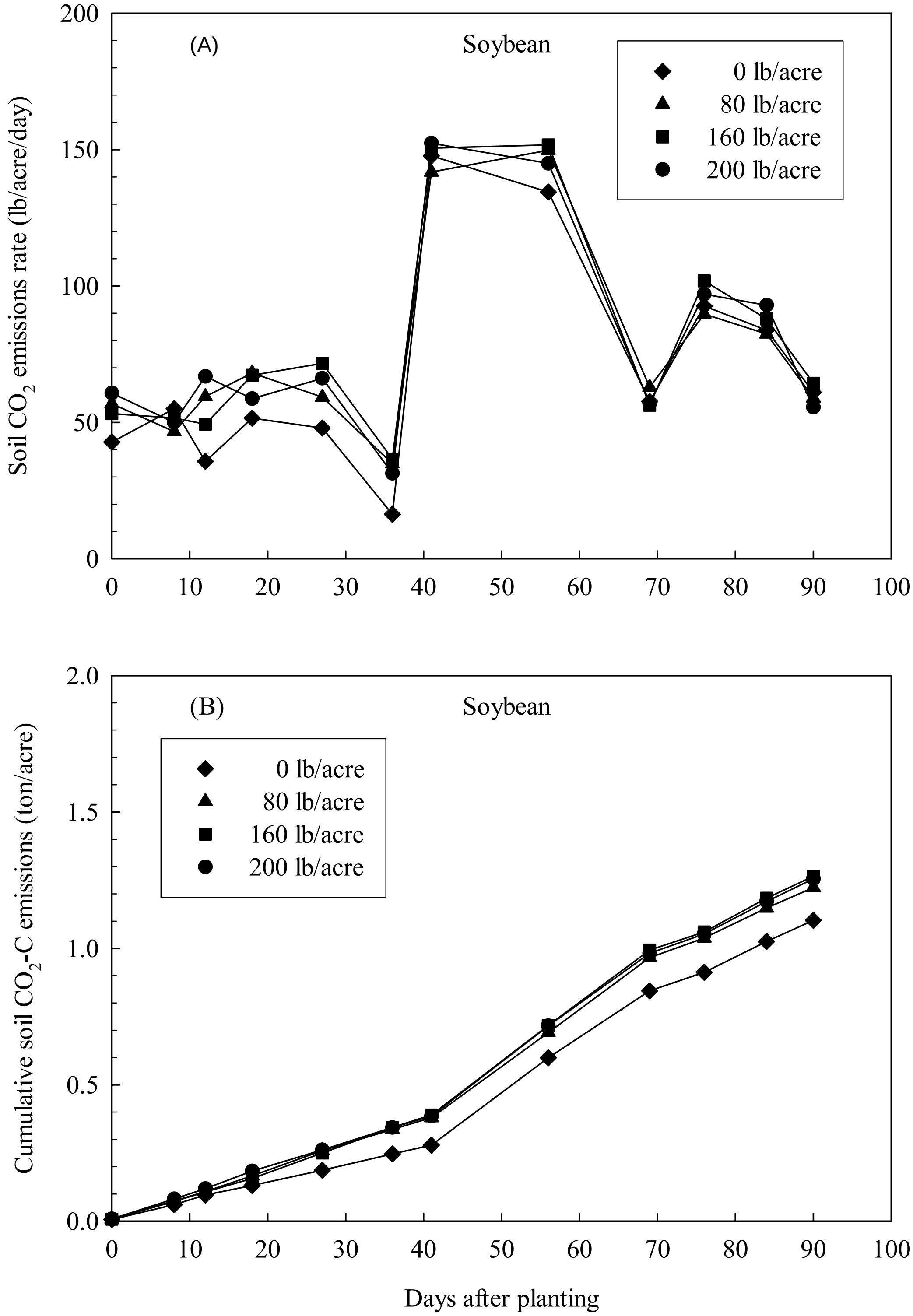

Figure 14. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the corn crop year with different N rates (second year for N rate application) at the Boone-S site, 2003.

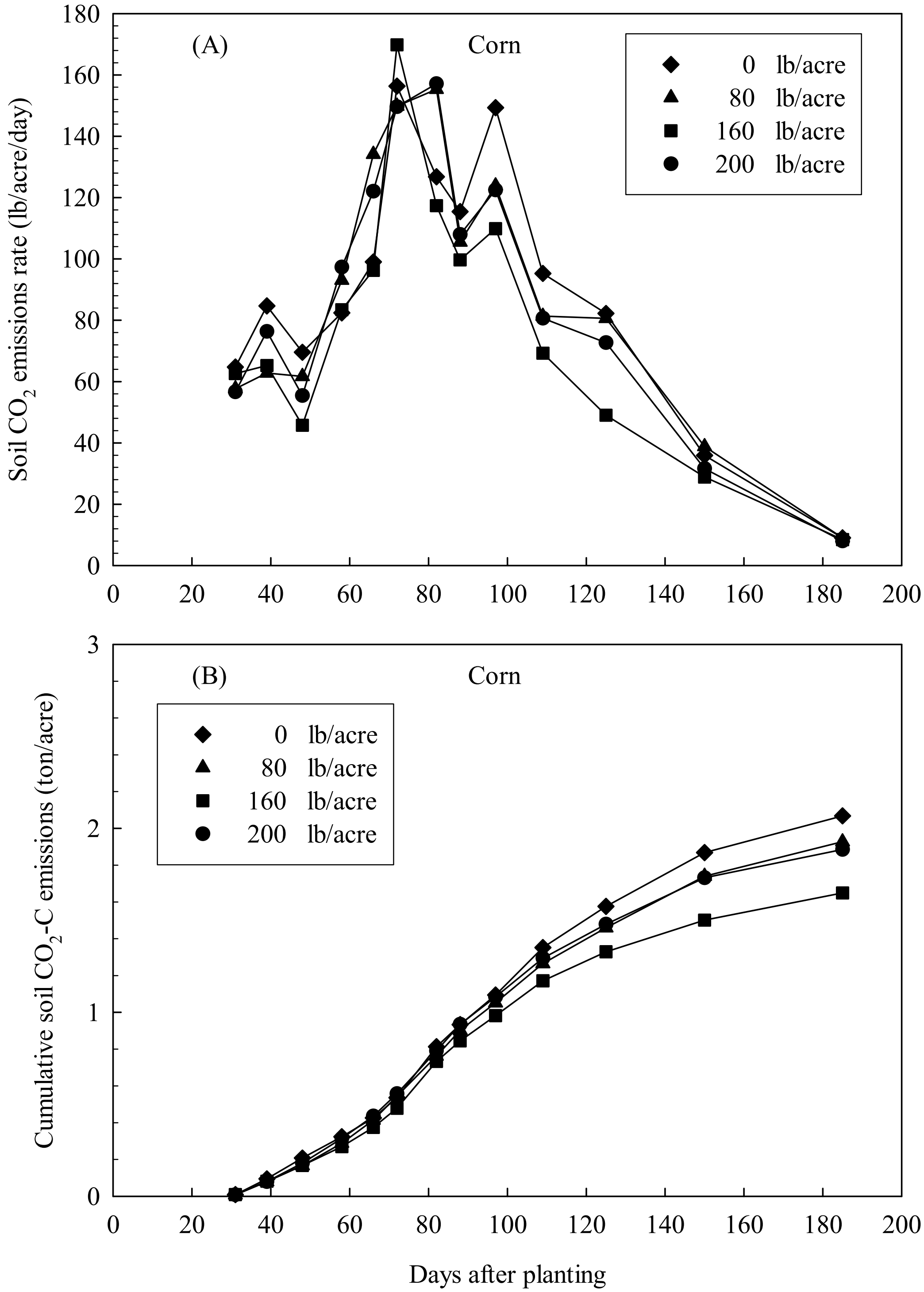

Figure 15. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the corn crop year with different N rates (second year for N rate application) at the Floyd site, 2003.

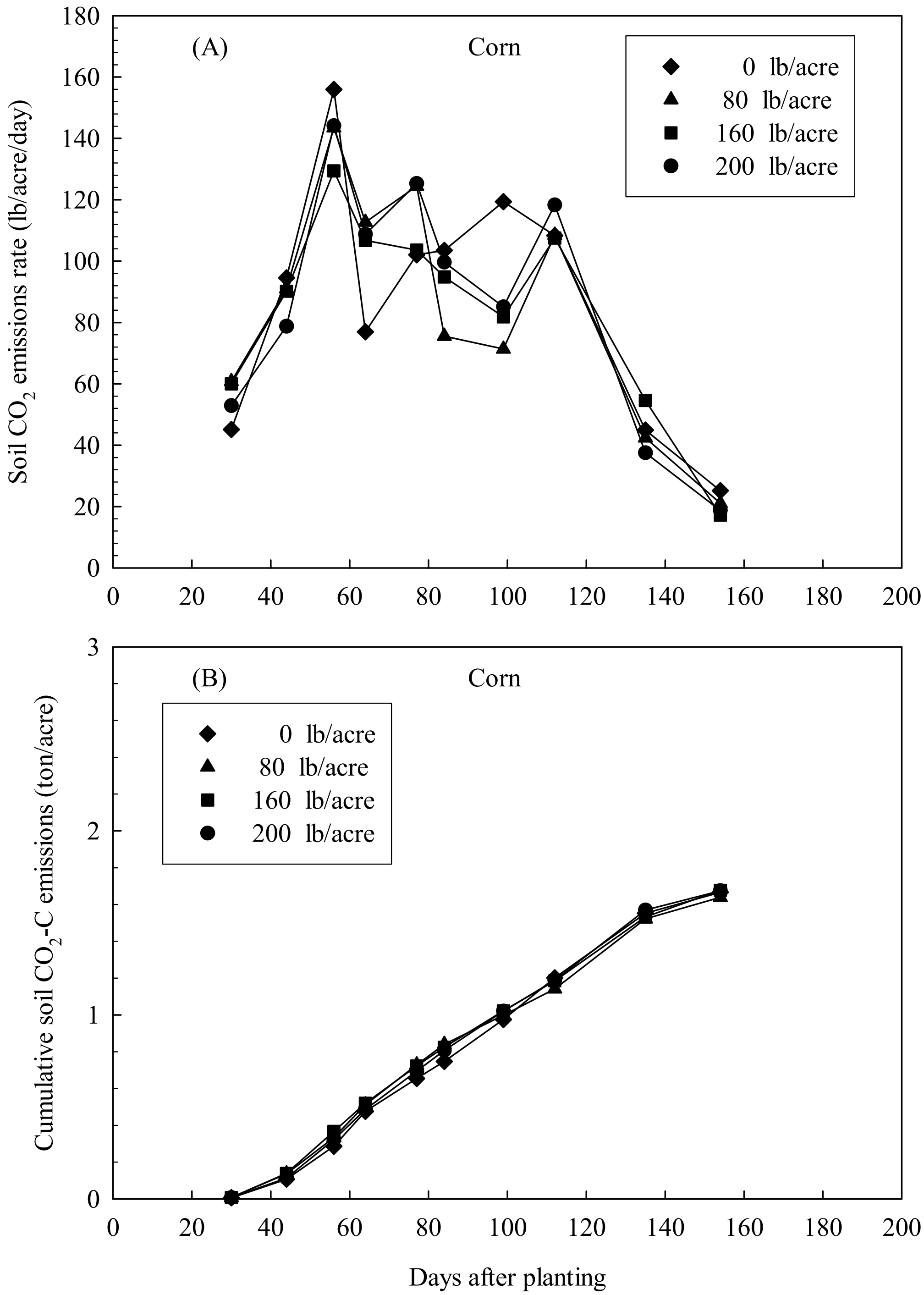

Figure 16. Field measurement of daily CO_2 emission from soil (A) and cumulative CO_2-C emission (B) in the corn crop year with different N rates (second year for N rate application) at the Tama site, 2003.