Demonstration of In-Season Nitrogen Management Strategies For Corn Production

Final Report

June 30, 2007

John Sawyer, Associate Professor, Soil Fertility Extension Specialist
John Lundvall, Extension Program Specialist
Jennifer Hawkins, Formerly Graduate Research Assistant
Department of Agronomy, Iowa State University

Introduction

Water quality impairment related to nitrogen (N) continues to be an important issue in Iowa. Proposed Environmental Protection Agency surface water quality criteria for N could dictate strict guidance for N inputs to corn, which occupies large acreage and is important for economic vitality of Iowa farmers. This focus could even designate N use practices that require very high levels of management and risk, with unknown economic consequences. Therefore it is important to demonstrate emerging N management strategies that have potential to improve N use and economic return to corn production.

Rate of N application is an important management factor in corn production related to increase in nitrate reaching surface and groundwater. Rate is also important in regard to economics of corn production. Application exceeding crop need increases the pool of nitrate remaining in soil after crop harvest – nitrate with the potential to move out of the soil profile. Excessive N application to corn also reduces a corn producer's profits. While applying only the needed fertilizer N rate in a given year will not stop nitrate from leaving cornfields, nor necessarily achieve proposed water quality criteria, it can result in reduced residual soil nitrate and help lessen corn production's impact on water quality. Therefore, it is possible that being able to assess corn N fertilization need differentially each season could improve corn N use efficiency and reduce nitrate susceptible to loss compared to application of an average agronomic rate each year.

Monitoring the corn plant to determine N status and seasonal N availability has advantages in that the plant integrates N supply over a wide period of time, and hence can reflect the soil N supply as affected by weather, soil processing, and fertilization. It can also reflect spatial variation. The longer the corn plant has grown, the larger the fraction of total N accumulated (corn accumulates approximately 50-65% of total N by silking – the R1 growth stage). The total crop N need (and season-long soil N supply) is better reflected in the crop late in the season (during grain fill). This is a limitation with corn plant monitoring (plant sensing) to determine N status as the best time to closely determine crop N need is after it is too late to apply and have N be accessible for plant uptake. The corn N uptake pattern also implies that small plants sensed early in the season will only indicate large N shortage and cannot differentiate total season N need, especially if available soil N plus preplant N is large. A compromise is to monitor the crop during mid-to-late vegetative growth stages, but after considerable N has been taken up. This might allow time for N to be effective if application is needed, and limit potential yield loss because of delayed application or crop N stress; however, if severe N stress develops unrecoverable yield loss may occur. The potential for irreversible yield loss can be reduced by applying preplant or early-sidedress N, monitoring for development of plant N deficiency, and making post-sensing (late-sidedress) applications timed before significant N stress occurs. Nitrogen can be applied with high clearance equipment and research has shown that N applied as late as the R1 growth stage can still add to the pool of N being accumulated during seed fill and improve yield if N supply is short.

Limitations to in-season monitoring and N application are dry surface soils where applied fertilizer is not accessible for uptake by active roots, or wet periods that limit field access. Also, to date sensors for assessing corn plant N status can only determine plant N stress (lack of adequate N). This means that to adjust seasonal N rates using this approach the corn crop must be showing N stress before an application need can be predicted. Having effective systems that allow N rate prediction and application later (later than traditional sidedress timing) into the growing season does provide a wider window for N application in corn.

Several emerging technologies now allow post-sensing N application and rate adjustment to be practiced. One, high clearance equipment can move through tall corn, some even at full growth height. Two, high clearance equipment has been developed that can inject urea-ammonium nitrate (UAN) fertilizer solutions into the soil (Hagie Manufacturing Co. NTB® applicator; Miller Applications Technologies Co. NITRO® toolbar applicator). Three, a plant chlorophyll sensor (Minolta SPAD 502 chlorophyll meter) is available and well-researched in regard to the relationship with optimal N rate and plant N status. Other handheld, machine-mounted, and remote aerial sensors are being commercially developed, with research for determination of efficacy and N-rate prediction underway. Therefore, it is feasible for producers to begin investigating in-season N management systems based on plant monitoring. However, field-scale demonstration is needed to document and resolve several issues: integration into corn production systems, corn productivity, feasible strategy for post-sensing N management, and economics compared to preplant and early-sidedress N.

Objectives

Objectives of this project include: one, demonstrate use of corn plant N deficiency/sufficiency monitoring (sensing) to determine need and rate of post-sensing N (hereafter referred to as post-N) application and effect on corn yield; two, demonstrate the impact of set preplant or early-sidedress N rates (hereafter referred to as pre-N) on corn plant N sufficiency and N stress development, frequency and rate of needed post-N application, total fertilizer N application, and corn yield; and three, compare corn yield response and economic return of “pre-N” vs. “pre-N plus post-sensing N” application strategies.

Field Demonstration Description

Demonstrations used cooperating producer fields, with fertilizer applications in replicated strips across field lengths. At each site cooperators were asked to not make broadcast applications of manure or N fertilizer to the site area, other than replicated N treatment strips. All other field activities were completed as normal by the cooperator, including grain harvest of treatment strips. Each treatment strip was replicated three times to compare demonstration effects.

A summary of the application strategies is given in Table 1. Set pre-N rates were either fall or spring applied preplant or early-sidedress fertilizer application: 1) no-N control; 2) non-N limiting reference rate at 240 lb N/acre (corn after soybean) or 270 lb N/acre (corn after corn); 3) reduced N rate at 60 lb N/acre (corn after soybean) or 90 lb N/acre (corn after corn); 4) agronomic N rate at 120 lb N/acre (corn after soybean) or 180 lb N/acre (corn after corn). Pre-N was applied at three sites in late fall, at seven sites spring preplant, and at 27 sites preemergence or early sidedress. Twelve sites had pre-N applied as anhydrous ammonia and 25 sites as UAN solution. Post-sensing N applications varied and were determined from corn plant N stress sensing when corn was between V10 (uppermost leaf with a visible leaf collar was the tenth leaf on the majority of plants at a site) and VT (tassel emergence) growth stages: 5) reduced pre-N rate (see number three for rate) plus post-N applied before the R1 corn growth stage (applied if needed and rate determined from corn plant sensing); and 6) agronomic pre-N rate (see number four for rate) plus post-N applied before the R1 corn growth stage (applied if needed and rate determined from corn plant sensing). Post-N applications were applied to one of two strips of reduced and agronomic pre-N rates in each replication. Post-sensing fertilizer N source was UAN solution surface-dribbled or coulter-injected with high-clearance equipment.

The agronomic N rate, set at 120 lb N/acre (corn after soybean) or 180 lb N/acre (corn after corn), is based on the approximate midpoint of current Iowa State University published recommended N rate ranges for each rotation. Recent economic analysis of 200+ site-years of corn yield response data from across Iowa also indicates an economic optimum N rate near 120 lb N/acre for corn following soybean and 180 lb N/acre for corn after corn. This demonstration project allows for the following comparisons: 1) field response to applied N and relative magnitude of response with each strategy; 2) rates of N application; 3) pre-N application and post-sensing application of additional N; 4) frequency and rate of needed post-N with each strategy; 5) timing of N deficiency development between pre-N rates; 6) ability of the monitoring system to determine needed post-N rate; and 7) economics of using pre-N rates vs. pre-N rates plus post-sensing N application adjustment strategies.

Two pre-N rates were used to demonstrate two overall strategies of in-season plant N stress monitoring and potential for post-N application by producers. One strategy is to apply an agronomic N rate and then monitor to see if a problem develops in regard to N sufficiency. This is a management strategy where post-N applications might be infrequent across years. It allows producers to confidently use agronomic N rates while having a backup system available in case N deficiency problems develop during early vegetative growth (examples include high N loss or a year of greater than expected fertilizer N need). This approach does not allow for adjusting rates if less than an average agronomic rate would suffice in a particular year. The second strategy is to apply a reduced rate of pre-N, expecting that post-N application will be required most years. This approach could allow for a closer match between corn N need and total fertilizer N application each year. Having some pre-N applied can help limit severity of N stress development and therefore irreversible yield potential loss.

Corn plants were sensed throughout each strip before post-N application to monitor N deficiency development and to determine post-N application rates. A Minolta SPAD 502 chlorophyll meter was used to monitor N deficiency development. The SPAD chlorophyll meter is handheld, allows for determination of corn N deficiency in defined field areas, and provides instant feedback. The SPAD chlorophyll meter has been intensely researched, with well documented relationships to plant N and development of N deficiency in corn (ISU Extension Publication PM 2026). Work conducted in the Iowa Department of Agriculture, Division of Soil Conservation Integrated Farm/Livestock Management (IFLM) demonstration program project “Determining Corn Nitrogen Fertilization Requirements and Soil Carbon Status in Diverse Soil Nitrogen Supply Environments” has shown a positive relationship between relative (normalized) SPAD readings (RSPAD) and the N rate difference (lb N/acre) between an applied rate and the economic optimum N rate (ND). This relationship is described by the quadratic-plateau equation: $RSPAD = 0.97 + 0.00059ND - 0.00000499ND^2$ (plateau at 0.99 RSPAD at a ND of 59 lb N/acre; with the RSPAD at 0.97 when the average N rate is at the economic optimum rate, ND=0). This equation was used to determine the post-N application rate in each designated "pre-N plus post-sensing N" treatment strip. The non-N limiting reference N rate was included in the demonstration because research with the SPAD chlorophyll meter and with remote imagery has shown that readings should be adjusted (normalized) to an adequately N-fertilized reference area to reduce effects other than from N deficiency (drought, hybrid greenness differences, and diseases).

Each strip was sensed after all N applications were completed (R3, milky kernel reproductive growth stage) to monitor plant response to applied N. Corn was harvested by cooperators using combines equipped with a yield monitor and GPS positioning equipment or by weigh wagon, with grain yields adjusted to 15.5% moisture.

A total of 37 demonstration sites were established with 28 cooperators in 21 Iowa counties from 2004 to 2006 (Figure 1). Thirty demonstration sites featured corn after soybean (corn-soybean) and seven demonstration sites featured corn after corn (corn-corn). Demonstration sites varied in soil type, tillage system, yield history, recent N application rate history, and manure application history. Refer to individual crop year reports (2004 through 2006) for details pertaining to individual site characteristics (recent yield and N application history, planting dates, N applications, and grain yields).

2004-2006 Results

Corn Plant N Stress Measurement and Post-Sensing N Application Rates

Corn plant N status (leaf greenness) was monitored at all demonstration sites using a SPAD chlorophyll meter (Figure 2). Initial chlorophyll meter data collection used to determine post-sensing N application was targeted to begin at approximately the V10 corn growth stage, but the timing ranged from V10 to VT stages for different sites. Chlorophyll meter (SPAD) readings were taken on twenty randomly selected plants surrounding multiple pre-flagged points throughout the center of each treatment strip. Initial SPAD readings were taken on the uppermost developed leaf with a collar fully visible and follow-up (after post-sensing N application) SPAD readings (targeted for R3 growth stage) were taken on the ear shoot leaf. Within each treatment strip, the average SPAD reading was calculated. Relative chlorophyll meter (RSPAD) values, normalized relative to chlorophyll meter readings taken on corn plants within the same pre-flagged field areas in 240 lb N/acre (corn-soybean sites) or 270 lb N/acre (corn-corn sites) non-N limiting reference strips, were calculated for each treatment. As expected, leaf greenness readings increased with higher pre-N rates at N responsive sites. The SPAD readings and leaf chlorophyll (leaf greenness) do not indicate excess N, but will show deficiency or N stress. Therefore, readings do not increase once maximum greenness is reached, even with more N.

Post-sensing N application rates (60+ and 120+ treatments at corn-soybean sites, 90+ and 180+ treatments at corn-corn sites) were calculated for each site by entering RSPAD data into the aforementioned quadratic-plateau equation that describes the relationship between RSPAD readings and the N rate differential (lb N/acre) from the economic optimum N rate. The RSPAD value ranges and corresponding post-sensing N application rates are summarized in Table 2. For example, if a site's 60 lb pre-N treatment strips had an average RSPAD reading of 0.96 (suggesting that corn fertilized with 60 lb pre-N was estimated to be 96% as green as corn fertilized with the 240 lb pre-N reference rate) the "prescribed" post-N application rate for "60+"

treatment strips was 30 lb N/acre. Across the 30 corn-soybean sites, initial RSPAD averages for the respective N treatments were as follows: 0.82 (0), 0.93 (60), 0.93 (60+), 0.97 (120), 0.98 (120+), and 1.00 (240 reference). Across the seven corn-corn sites, initial RSPAD averages for the respective N treatments were as follows: 0.85 (0), 0.97 (90), 0.98 (90+), 0.99 (180), 0.99 (180+), and 1.00 (270 reference).

At some demonstration sites high-clearance toolbars equipped with coulter-injectors were used to apply post-N (UAN) treatments (Figure 3). At other demonstration sites post-N was surface-applied using high-clearance booms equipped with drop nozzles to direct UAN solution below the leaf canopy and onto the soil surface.

Corn yellowing from N deficiency stress with zero or reduced pre-N application rates was quite apparent at some sites. Figure 4 illustrates an example of extreme deficiency in the zero-N strips. The RSPAD values in those strips would be quite low.

Corn response to post-N applications was monitored at demonstration sites by taking follow-up SPAD chlorophyll meter readings from the ear leaf of randomly selected plants at the same pre-flagged strip points throughout each treatment strip used to collect the initial SPAD readings. Follow-up chlorophyll meter data collection was targeted for the R3 growth stage. Generally, post-N applications did not result in significant increases in corn leaf greenness, however, reductions in corn leaf greenness between initial and follow-up chlorophyll meter data were less where post-N was applied (data not shown). Better retention of leaf greenness (indicating more-sufficient N levels) during the critical pollination and early reproductive growth stages may explain corn grain yield response to post-N application.

Growing Season Precipitation

Growing season (March 15 to October 15) precipitation totals and precipitation totals recorded two weeks before and two weeks after post-N applications were summarized for individual demonstration sites in the individual crop year reports. Precipitation records were used from nearby National Weather Service (NWS) weather stations. Weather stations were generally within five to 10 miles of demonstration sites. Precipitation to maintain moist soil and active roots during the critical period two weeks before and after UAN application, and to move applied N into the rooting zone, should increase corn response to post-N application. Across the 28 corn-soybean sites receiving post-N applications, precipitation during the two weeks before UAN application averaged 1.28 inches, with a range of no precipitation to 3.48 inches. Precipitation during the two weeks after UAN application averaged 2.49 inches, with a range of 0.71 to 5.50 inches. Across the four corn-corn sites receiving post-N applications, precipitation during the two weeks before UAN application averaged 0.35 inches, with a range of 0.05 to 0.75 inches. Precipitation during the two weeks after UAN application averaged 1.87 inches, with a range of 0.74 to 4.07 inches.

The 2005 Marshall site represents an example of post-sensing N application and timely critical period precipitation combining to result in very good response to post-N. There was a yield increase of 32 bu/acre for the 60+ treatment (with 85 lb N/acre post-N application) vs. the 60 lb N/acre pre-N rate only. Precipitation of 0.58 and 2.87 inches were recorded at the nearby NWS weather station two weeks before and after the V13 stage post-N application, respectively. The 2006 Jasper site represents an example of post-sensing N application and lack of critical period precipitation combining to result in no response to post-N. There was no significant ($P \leq 0.10$) yield response to post-N application at that site, and only 0.82 and 0.64 inch of precipitation were recorded at the nearby NWS weather station two weeks before and after the VT stage post-N application, respectively.

Corn Grain Yield Response to N Fertilizer Rate and Timing: Corn Following Soybean Sites

Corn grain yield level and response to N fertilizer rate and timing varied between the 30 sites. Corn yield increase with pre-N application was statistically significant at all demonstration sites. This means that all sites were responsive to N. Zero-N application (control) treatment strips yielded from 62 to 207 bu/acre across sites, with an average yield of 141 bu/acre (Table 3). Reduced pre-N application (60 lb N/acre) treatment strips yielded from 109 to 233 bu/acre across sites, with an average yield of 177 bu/acre. Corn yield response to the first 60 lb N/acre was statistically significant ($P \leq 0.10$). Agronomic pre-N application (120 lb N/acre) treatment strips yielded from 110 to 256 bu/acre across sites, with an average yield of 192 bu/acre. Corn yield response to increasing pre-N from 60 to 120 lb N/acre was statistically significant ($P \leq 0.10$), with an average yield increase of 15 bu/acre. At 22 sites, the yield with 60 lb N/acre was statistically lower than yield with 120 lb N/acre, and at eight sites was the same. At five of these eight sites, the yield with 60 lb N/acre was the same as with the 240 lb N/acre rate, and therefore 60 lb N/acre was a sufficient rate. At three of these eight sites, the yield with the 60 lb N/acre rate was less than with the 240 lb N/acre rate, and therefore was not a sufficient rate. This means that at 25 of the 30 sites 60 lb N/acre applied as pre-N was not a sufficient rate. Non-N limiting reference pre-N application (240 lb N/acre) treatment strips yielded from 120 to 262 bu/acre across sites, with an average yield of 197 bu/acre. The average corn yield response to increasing pre-N from 120 to 240 lb N/acre was not statistically significant ($P \leq 0.10$). At individual sites, six had yield that was statistically lower with the 120 lb N/acre rate compared to the 240 lb N/acre rate, but was the same at 24 sites.

The 60+ treatment (55 lb N/acre average post-N rate) yielded from 116 to 232 bu/acre across sites, with an average yield of 185 bu/acre (Table 3). Post-N was applied to 60+ treatment strips at 28 of 30 demonstration sites, as prescribed by plant N stress sensing with the SPAD chlorophyll meter. Corn yield response to post-N (vs. pre-N application of 60 lb N/acre with no post-N) was statistically significant ($P \leq 0.10$), with an 8 bu/acre yield increase. The 60+ treatment yielded statistically less than the 120 lb N/acre pre rate (average 7 bu/acre less).

The need to apply post-N in addition to the pre-N 60 lb/acre rate was correctly identified by plant N stress sensing at 13 of 30 sites (including two sites where N stress sensing correctly predicted there would be no corn yield response beyond 60 lb N/acre). Yield increase from post-N application was statistically significant at 11 of 28 sites (17 sites with no yield increase from post-N application), and this strategy (60+ treatment) returned yield as high as the 120 lb N/acre pre rate at 13 of 28 sites. This means full yield recovery from the N stress was achieved at 11 sites, but was not achieved at 17 sites. One site had an unexplained yield decrease with post-N application. There were no sites where N stress sensing indicated no need for additional N, and there was a yield increase to higher pre-N rates. These results mean that there were no instances when N stress sensing missed the need for additional N with the pre-N application of 60 lb N/acre, but there was a 61% occurrence where there was no response to post-N when a higher total N application was needed. This means corn did not respond well to the post-N applications. Five sites had N stress sensing that indicated additional N need, but the 60 lb N/acre pre-N rate was actually an adequate rate. This means the sensing indicated an N deficiency at five of 28 sites when the N supply was adequate (18% occurrence or misidentification of N deficiency). Sites with minimal increase in yield with post-N rates applied in addition to the 60 lb N/acre pre-N rate confirmed that rainfall deficits near the time of post-N application may have limited corn plant uptake of post sensing applied N. Also, yield response to the post-N may have been limited due to irreversible loss of yield potential as a result of early-season plant N stress.

The 120+ treatment strips (11 lb N/acre average post-N rate) yielded from 116 to 235 bu/acre, with an average yield of 193 bu/acre (Table 3). Post-N was applied to 120+ treatment strips at nine of 30 demonstration sites, as prescribed by plant N stress sensing. Average corn yield response to post-N (vs. pre-N application of 120 lb N/acre with no post-N) was not statistically significant ($P \leq 0.10$). Of the nine sites with post-N application, one site had a yield increase (120+ vs. 120 pre-N), six sites had no yield increase, and two sites had an unexplained yield decrease with post-N application. At 18 sites N stress sensing indicated no N deficiency, and those sites did not have a yield response to N greater than 120 lb N/acre. This means a correct identification of adequate N with the 120 lb N/acre pre-N application rate. At three sites N stress sensing indicated no N deficiency, but those sites had a yield increase with the 240 lb N/acre pre-N application. This means a miss in identification of N deficiency. At six sites N stress sensing indicated an N deficiency, and post-N was applied. However, there was no need for that N as the yield with the 120 lb N/acre pre-N rate was the same as the 240 lb N/acre pre-N rate. This means a misidentification of N deficiency that did not exist. Plant N stress sensing correctly predicted corn yield increase to post-N application in 120+ treatment strips at only one site, that is corn yield increase to post-N (vs. pre-N application of 120 lb N/acre with no post-N) was statistically significant ($P \leq 0.10$).

Nitrogen application rate treatment comparisons, N rate differences, and resulting average corn grain yield differences are summarized for all corn-soybean sites in Table 4. Among N treatments, increasing pre-N from 60 to 120 lb N/acre resulted in the largest yield increase (14.9 bu/acre). Adding an average post-N application of 55 lb N/acre to the pre-N 60 lb/acre rate (total N application of 115 lb N/acre) resulted in a yield increase of 8.0 bu/acre (compared to 60 lb N/acre pre-N rate). Adding an average post-N application of 11 lb N/acre to the pre-N 120 lb/acre rate (total N application of 131 lb N/acre) resulted in a yield increase of only 0.9 bu/acre (compared to 120 lb N/acre pre-N rate).

A cost/benefit economic analysis of treatment comparisons that includes the total applied N and corn grain yield differences is summarized in Table 5. The economic analysis incorporates expected N cost ($/lb N), corn price ($/bu), an $8.00/acre estimated charge for post-N applications, and a $3.75/acre estimated charge for N stress sensing with a SPAD chlorophyll meter. The post-N application charge ($8.00/acre) is based on conversations with industry representatives. The post-N application charge is only applied to sites where the post-N was applied. The plant sensing cost ($3.75/acre) represents the average per-acre crop scouting charge reported in the 2007 Iowa Farm Custom Rate Survey (ISU Extension Publication FM 1698, March 2007). A producer's expected net return (gain or loss) associated with the various N application strategies is calculated by subtracting the N, sensing, and post-N application costs from income (corn yield difference times expected corn price). Focusing on the 60+ vs. 120 pre-N comparison, the average total-N application rate in 60+ treatment strips was 115 lb N/acre, resulting in a total N application rate difference of only five lb N/acre (115 vs. 120 lb N/acre). Average corn yield for the 120 lb pre-N treatment was 6.9 bu/acre greater than 60+ treatment yield. Reduced yield potential plus total sensing/post-N application costs of $11.75/acre contribute to the $33.62/acre net return advantage for the 120 lb pre-N application vs. 60 lb pre-N + 55 lb post-N application. Additional net return calculations using low- and high-N costs and corn prices at price ratios of 0.05, 0.10, and 0.20 ($/lb N:$/bu) are presented in Table 6. While the net gains/losses for the comparisons may change somewhat at different price ratios, the greatest net return is for application of 120 lb N/acre as a one-time pre-N (preplant or sidedress) application.

The in-season management (that is reduced pre-N or agronomic pre-N rate followed by N stress sensing and post-N application as indicated by the plant monitoring) had lower net returns. The lowest net return comparison was for application of 240 lb N/acre, especially with higher N prices. If in-season N stress sensing were to be practiced, doing so following an agronomic rate strategy of 120 lb N/acre returned more net income that using the reduced rate strategy of 60 lb N/acre (60+). Despite some sites needing no more than 60 lb N/acre, overall it was more economical to use the 120 lb N/acre pre-N rate than starting with the reduced 60 lb N/acre rate.

Corn Grain Yield Response to N Fertilizer Rate and Timing: Corn Following Corn Sites

Corn yield level and response to N fertilizer rate and timing varied between the seven sites. Corn yield increase with pre-N application was statistically significant at six of the seven demonstration sites. Zero-N application (control) treatment strips yielded from 93 to 207 bu/acre across sites, with an average yield of 141 bu/acre (Table 7). Reduced pre-N application (90 lb N/acre) treatment strips yielded from 160 to 228 bu/acre across sites, with an average yield of 184 bu/acre. Average corn yield response to the first 90 lb N/acre was statistically significant ($P \leq 0.10$). Agronomic pre-N application (180 lb N/acre) treatment strips yielded from 180 to 228 bu/acre across sites, with an average yield of 195 bu/acre. Average corn yield response to increasing pre-N from 90 to 180 lb N/acre was not statistically significant ($P \leq 0.10$), but was statistically significant at four of the seven sites (16 bu/acre yield difference at those four sites). At four sites the 90 lb N/acre pre-N rate was not sufficient (yield was lower than 180 or 270 lb N/acre pre-N rates), but was sufficient at three sites. The difference in response between individual sites and the average could be due to considerable variation in yield within some of the sites, several sites having a manure history and thus lower response to applied N, and there being only seven corn-corn sites. The non-N limiting reference pre-N application (270 lb N/acre) treatment strips yielded from 167 to 226 bu/acre across sites, with an average yield of 196 bu/acre. Corn yield response to increasing pre-N beyond 180 lb N/acre was not statistically significant ($P \leq 0.10$).

The 90+ treatment strips (26 lb N/acre average post-N rate) yielded from 158 to 221 bu/acre, with an average yield of 183 bu/acre (Table 7). Post-N was applied to 90+ treatment strips at four of seven demonstration sites, as prescribed by plant N stress sensing with the SPAD meter. Sensing at one site indicated post-N should be applied, but due to wet soils the application could not be made. Average corn yield response to post-N (vs. pre-N application of 90 lb N/acre with no post-N) was not statistically significant ($P \leq 0.10$). The 90+ treatment yielded similarly to the 180 lb N/acre pre rate (average 12 bu/acre less). Of the four sites with post-N applied, none had a yield increase from the post-N, with one having an unexplained yield decrease. The need to apply post-N in addition to the pre-N 90 lb/acre rate was correctly identified by plant N stress sensing at four of seven sites (including two sites where N sensing correctly predicted no corn yield response beyond 90 lb N/acre). Sites with minimal increase in yield with N rates above 90 lb N/acre confirmed that rainfall deficits near the time of post-N application may have limited corn plant uptake of post sensing applied N. Also, yield response to the post-N may have been limited due to irreversible loss of yield potential as a result of early-season plant N stress.

The 180+ treatment strips (0 lb N/acre average post-N rate) yielded from 172 to 226 bu/acre, with an average yield of 194 bu/acre. At no site was there a yield increase with pre-N applied at 270 lb N/acre compared to the 180 lb N/acre rate, and the average yield for both rates were statistically the same (Table 7). Post-N was not prescribed for 180+ treatment strips at any of the seven corn-corn demonstration sites. Plant N stress sensing correctly predicted that post-N was not needed in addition to the pre-N 180 lb/acre rate at all of the seven corn-corn sites.

Nitrogen application rate treatment comparisons, N rate differences, and resulting corn grain yield differences are summarized across all corn-corn sites in Table 8. A cost/benefit economic analysis of the of treatment comparisons that includes the total N and corn grain yield differences is summarized in Table 9. The economic analysis incorporates expected N cost ($/lb N), corn price ($/bu), an $8.00/acre estimated charge for post-N applications, and a $3.75/acre estimated charge for N stress sensing with a SPAD chlorophyll meter. Focusing on the 90+ vs. 180 pre-N comparison, the average total-N application rate in 90+ treatment strips was 116 lb N/acre, resulting in an N application rate difference of 64 lb N/acre (116 vs. 180 lb N/acre). Average corn yield for the 180 lb pre-N treatment was 12.0 bu/acre greater than 90+ treatment. Reduced yield potential and total sensing/post-N application costs of $11.75/acre contribute to the $27.92/acre net return advantage for 180 lb pre-N application vs. 90 lb pre-N + 26 lb post-N application. Additional net return calculations using low- and high-N costs and corn prices at price ratios of 0.05, 0.10, and 0.20 ($/lb N:$/bu) are presented in Table 10. The net gains/losses for the comparisons change somewhat as the price ratio changes. In general, the in-season strategy that includes N stress sensing has lower net returns than just a one-time pre-N (preplant or sidedress) application. Except when N costs are very high, the pre-N application of 180 lb N/acre has highest net returns. The lowest net return comparison was for application of 270 lb N/acre, especially with higher N prices. If the in-season N stress sensing strategy were to be practiced, doing so following an agronomic rate strategy of 180 lb N/acre returned more net income that using the reduced pre-N rate strategy of 90 lb N/acre. Despite sites on average needing no more than 90 lb N/acre (but several individual sites had statistically significant yield increase to 180 lb N/acre), overall it was more economical to use the 180 lb N/acre rate than starting with the reduced 90 lb N/acre rate due to higher yield with the 180 lb N/acre rate.

Summary

A specific goal of this project was to demonstrate emerging N management practices that have potential to improve N use and economic return to corn production, including monitoring corn plant N stress and high-clearance N application during mid-to-late vegetative growth stages. Successful use of the SPAD chlorophyll meter to sense corn plant N deficiency resulted in creation of ISU Extension Publication PM 2026, “Sensing Nitrogen Stress in Corn”. We also successfully demonstrated the ability of high-clearance applicators to make mid-to-late vegetative stage UAN applications to tall corn.

We demonstrated two overall strategies designed to improve N fertilization rates via corn vegetative growth stage N stress sensing and post-sensing N application. Results suggest a yield and economic advantage for simply applying a one-time recommended or “agronomic N rate” of 120 lb N/acre in corn-soybean or 180 lb N/acre in corn-corn as a preplant or typical early sidedress application (called pre-N in this project). Applying those pre-N rates, with the in-season strategy of corn plant monitoring and applying N as indicated by N stress sensing, produced greater yield and net return than the second in-season strategy of applying a reduced pre-N rate, 60 lb N/acre (corn-soybean) or 90 lb N/acre (corn-corn), plus monitoring and applying N as indicated by N stress sensing. The second strategy – applying a reduced rate of pre-N, expecting that post-N application will be required most years – allowed for a closer match between corn N fertilization need and total-N application. However, at most sites corn yield performance, especially for the corn following soybean sites, with that strategy did not recover fully from N deficiency and therefore yields did not match or exceed that of the one-time agronomic pre-N application rate. Results of the project indicate that if producers are interested in further testing the strategy of vegetative stage plant N monitoring followed by post-sensing N application they should apply a pre-N rate close to recommended agronomic rates in order to limit severity of N stress development and potential irreversible yield loss.

Assessing corn N fertilization need differentially each season could improve corn N use efficiency and reduce nitrate susceptible to loss compared to application of an average agronomic rate each year. Environmental costs were not included in the analysis of project results. Perhaps plant N stress sensing during corn vegetative growth stages can help identify or confirm those situations when corn N response in a particular field, or field area, is suspected to be much different than normal because of previous years' management practices, such as manure application or greater than recommended N application rates. These situations could provide the greatest opportunity for avoidance of over-application.

Economic analyses of both corn-soybean and corn-corn rotations indicate definite advantages for using agronomic pre-N rates (120 lb N/acre in corn-soybean and 180 lb N/acre in corn-corn) and using vegetative growth stage sensing as a backup strategy in case N deficiency problems develop during early vegetative growth (examples are unexpected large N losses, or a year of greater than expected N fertilization need). This approach does not allow for adjusting rates if less than an agronomic rate would suffice in a particular year. Applying a reduced rate of pre-N, expecting that post-N application will be required most years, could allow for a closer match between corn N fertilization need and total-N application each year. However, our results suggest that use of this strategy may be best reserved for fields with a manure application history, high N rate history, or other suspected reason for less than normal N fertilization need.

Education Benefits

An important project outcome was educating producers about economic optimum N application rate targets and demonstrating environment-dependent variability in optimum N application rates (year-to-year and field-to-field variability). Several cooperators stated their intention to more intensively manage N inputs, as opposed to using the same N application rate regardless of field history or weather conditions. Our results generally support cooperator reluctance to rely on high-clearance N application for more than rescue situations.

Project visibility was highlighted at selected demonstration sites by field signage (Figure 5) and field days. Producers and project personnel participating in field days shared experiences and frustrations regarding N management for corn production. Project personnel addressed producer questions about N management in light of higher corn yield plateaus afforded by genetic improvements. Producers learned that environment-friendly N rates are able to produce top-end corn yields.

A concern identified during this project is the ability to make timely high-clearance N applications. Several cooperators encountered problems with heavy mid-summer rains delaying post-N application. As a result, corn became too tall or too far advanced in growth stage, making post-N application impossible or less effective. Another concern identified is that too few local fertilizer suppliers or farmer cooperatives have resources available to purchase dedicated high-clearance applicators and toolbars equipped with drop nozzles or coulter-injector capability. While yield response to post-N application was erratic at demonstration sites, we noted a definite interest among producers for local high-clearance applicator availability.

A success demonstrated during this project has been corn productivity levels achieved with use of agronomic N application rates. Many cooperators and neighboring producers learned about the ability to produce top-end (200+ bu/acre) corn yields without excessive N application.

Four individual corn-soybean sites produced yields ranging from 220-262 bu/acre with optimum N near 120 lb total N/acre.

This and other IFLM on-farm projects have demonstrated improved corn N use efficiency and refuted yield goal-based N application rate recommendations. However, producers prefer testing agronomic practices like N application rate "on their own soils". Most project cooperators expressed their preference for more replicated on-farm demonstrations as provided by this and similar IFLM projects. They were surprised (in fact, disappointed) to learn that 2006 marked the last year of funding for the demonstration project. Cooperators in this project understand the need, and advocate, for continued on-farm N rate studies across Iowa that provide comparison of a full compliment of rates, from zero to excess as was utilized in this project.

Another success demonstrated in this project has been reinforcement of the usefulness of the SPAD chlorophyll meter to monitor N deficiency stress in corn. While SPAD meters are relatively expensive (costing approximately $1,500 each), making them a "luxury" item for most individual producers, local independent crop consultants and farmer cooperatives can justify the purchase price for producer or crop scout use in individual fields.

Acknowledgements

Appreciation is extended to the cooperating producers, everyone who assisted with N applications, especially providing time and equipment for the high clearance applications, and the extension, agribusiness, and agency personnel who assisted with coordination and implementation of project sites. This project was supported in part by the Iowa Department of Agriculture and Land Stewardship, Division of Soil Conservation through funds appropriated by the Iowa General assembly for the Integrated Farm and Livestock Management Demonstration Program.

Additional Project Partners

Iowa Crop Producers
Iowa State University and ISU Extension
Division of Soil Conservation, Iowa Department of Agriculture and Land Stewardship
HAGIE Manufacturing, Clarion, IA, providing HAGIE NTB High-Clearance N Toolbar
Platte Valley Equipment, Fremont, NE, providing NITRO High-Clearance N Toolbar

Report Prepared By

John Lundvall
Extension Program Specialist
Department of Agronomy
Iowa State University
2505 Agronomy Hall
Ames, IA 50011
(515) 294-5429
jlundval@iastate.edu

Dr. John Sawyer
Extension Soil Fertility Specialist
Department of Agronomy
Iowa State University
2104 Agronomy Hall
Ames, IA 50011
(515) 294-1923
jsawyer@iastate.edu

Figure 1. In-season N management demonstration project sites, 2004-2006.

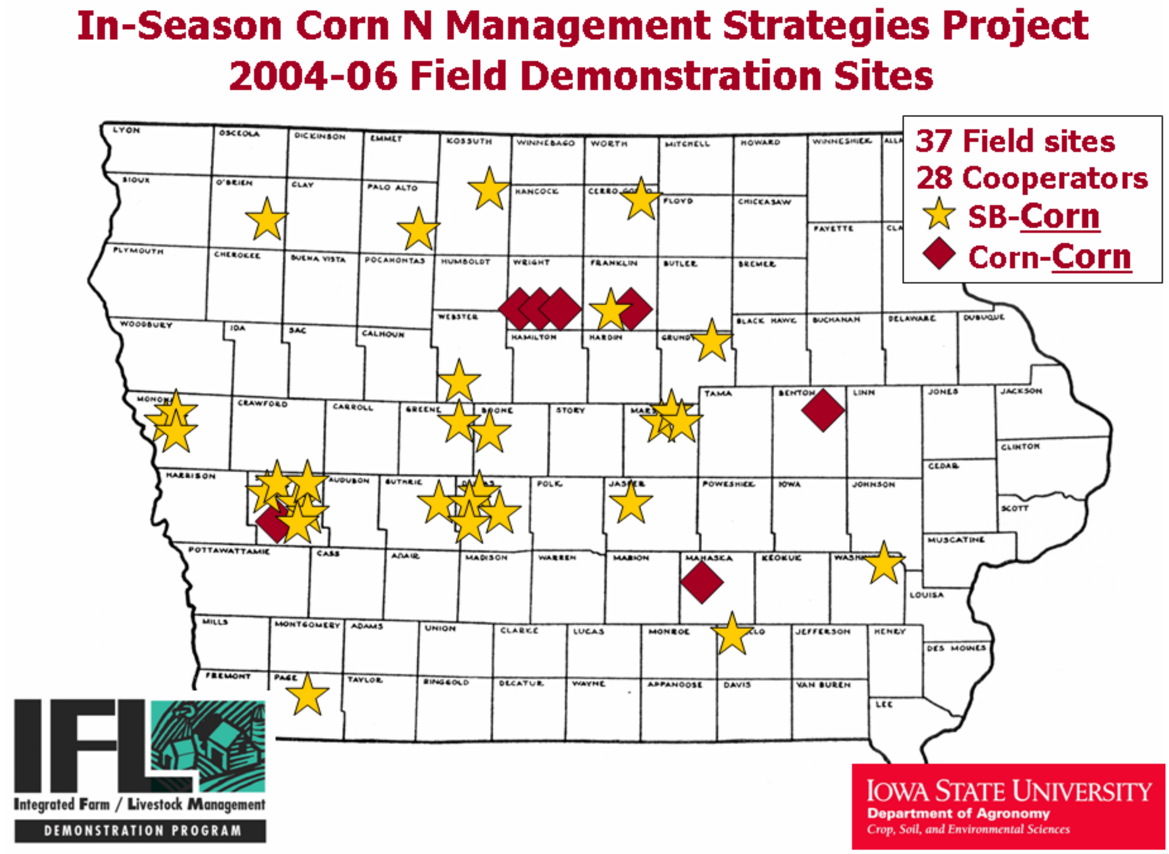

Figure 2. Demonstration of a SPAD chlorophyll meter measuring corn leaf greenness (N status).

Figure 3. Twelve row-wide, high-clearance applicators and toolbars, used to apply post-sensing N fertilizer at project demonstration sites.

Figure 4. Mid-July view of corn response (plant greenness) to field-length N rate strips.

Figure 5. Example signage at an in-season N management demonstration project field site.

Table 1. Nitrogen application strategies, 2004-2006 in-season N management demonstration project.

Pre-sensing N rate†	Post-sensing N Application	N Application Treatment	Treatment Identifier
lb N/acre			
0	- - - - -	Control	0
60 (90)	- - - - -	Pre reduced N rate	60 (90)
60 (90)	At rate determined in-season	Pre reduced N + post-sensing N rate	60+ (90+)
120 (180)	- - - - -	Pre agronomic N rate	120 (180)
120 (180)	At rate determined in-season	Pre agronomic N + post-sensing N rate	120+ (180+)
240 (270)	- - - - -	Pre non N-limiting, reference N rate	240 (270)

† Corn-soybean N rate (corn-corn N rate). Pre-sensing refers to N applied preplant or early sidedress.

Table 2. Chlorophyll meter relative SPAD (RSPAD) value ranges used to determine post-sensing N application rate.

Chlorophyll Meter Relative SPAD (RSPAD) Value†	N Rate to Apply‡
	lb N/acre
< 0.88	100
0.88 - 0.92	80
0.92 - 0.95	60
0.95 - 0.97	30
> 0.97	0

† Readings taken from V10 to VT corn growth stages.
‡ Suggested N rate restricted to a minimum of 30 lb N/acre and a maximum of 100 lb N/acre.

Table 3. Total fertilizer N applied and corn grain yield response to pre- and post-sensing N application strategies for the corn-soybean sites, 2004-2006.

N Application Treatment	Mean[†] Total N Applied	Number of Sites with Post-Sensing N Applied	Mean Yield[‡]
	lb N/acre	n	bu/acre
0	0		141d
60	60		177c
60+	115	28	185b
120	120		192a
120+	131	9	193a
240	240		197a

† Sum of pre-sensing and post-sensing N rate, averaged across all 30 corn-soybean sites.

‡ Mean yields are not significantly different when followed by the same letter ($P \leq 0.10$).

Table 4. Summary of the N application rate and corn grain yield difference for several treatment comparisons, 2004-2006 corn-soybean sites.

N Application Treatment Comparison[†]	N Application Rate Difference	Yield Difference
	lb N/acre	bu/acre
60 pre vs. 60+	55	8.0
120 pre vs. 120+	11	0.9
60 pre vs. 120 pre	60	14.9
60+ vs. 120 pre	5	6.9
60+ vs. 120+	16	7.8
120 pre vs. 240 pre	120	5.1

† Calculations compare N rate and yield differences by subtracting the first listed N treatment from the second.

Table 5. Economic analysis for several treatment comparisons, 2004-2006 corn-soybean sites.

N Application Treatment Comparison†	N Application Rate Difference	Yield Difference	Gain/Loss‡ N Cost	Gain/Loss‡ Income	Gain/Loss‡ Net
	lb N/acre	bu/acre	$/acre		
60 pre vs. 60+	55	8.0	30.47	28.00	(2.47)
120 pre vs. 120+	11	0.9	10.00	3.15	(6.85)
60 pre vs. 120 pre	60	14.9	21.00	52.15	31.15
60+ vs. 120 pre	5	6.9	(9.47)	24.15	33.62
60+ vs. 120+	16	7.8	0.53	27.30	26.77
120 pre vs. 240 pre	120	5.1	42.00	17.85	(24.15)

† Calculations compare the change in values by subtracting the first listed N treatment from the second.

‡ Nitrogen cost, corn price, post-sensing N application charge, and N stress sensing cost used in calculations:

N Cost ($/lb N):	0.35	N Application Charge ($/acre):	8.00
Corn Price ($/bu):	3.50	Sensing Cost ($/acre):	3.75

Table 6. Economic analysis net returns for several treatment comparisons based on multiple corn price and N cost scenarios, 2004-2006 corn-soybean sites.

N Application Treatment Comparison†	Corn price: / N cost: / $/lb N:$/bu:	Net Gain/Loss $2.20/bu $0.11/lb 0.05	$2.20/bu $0.22/lb 0.10	$2.20/bu $0.44/lb 0.20	$4.40/bu $0.22/lb 0.05	$4.40/bu $0.44/lb 0.10	$4.40/bu $0.88/lb 0.20
		$/acre					
60 pre vs. 60+		0.33	(5.72)	(17.82)	11.88	(0.22)	(24.42)
120 pre vs. 120+		(5.38)	(6.59)	(9.01)	(4.61)	(7.03)	(11.87)
60 pre vs. 120 pre		26.18	19.58	6.38	52.36	39.16	12.76
60+ vs. 120 pre		25.85	25.30	24.20	40.48	39.38	37.18
60+ vs. 120+		20.47	18.71	15.19	35.87	32.35	25.31
120 pre vs. 240 pre		(1.98)	(15.18)	(41.58)	(3.96)	(30.36)	(83.16)

Table 7. Total N applied and corn grain yield response to pre- and post-sensing N application strategies for the corn-corn sites, 2004-2006.

N Application Treatment	Mean† Total N Applied	Number of Sites with Post-Sensing N Applied	Mean Yield‡
	lb N/acre	n	bu/acre
0	0		141c
90	90		184ab
90+	116	4	183b
180	180		195ab
180+	180	0	194ab
270	270		196a

† Sum of pre-sensing and post-sensing N rate, averaged across all 7 corn-corn sites.

‡ Mean yields are not significantly different when followed by the same letter ($P \leq 0.10$).

Table 8. Summary of the N application rate and corn grain yield difference for several treatment comparisons, 2004-2006 corn-corn sites.

N Application Treatment Comparison†	N Application Rate Difference	Yield Difference
	lb N/acre	bu/acre
90 pre vs. 90+	26	-1.2
180 pre vs. 180+	0	-1.3
90 pre vs. 180 pre	90	10.8
90+ vs. 180 pre	64	12.0
90+ vs. 180+	64	10.7
180 pre vs. 270 pre	90	0.7

† Calculations compare N rate and yield differences by subtracting the first listed N treatment from the second.

Table 9. Economic analysis for several treatment comparisons, 2004-2006 corn-corn sites.

N Application Treatment Comparison†	N Application Rate Difference	Yield Difference	Gain/Loss‡		
			N Cost	Income	Net
	lb N/acre	bu/acre	- - - - - - - - $/acre - - - - - - - -		
90 pre vs. 90+	26	-1.2	17.42	(4.20)	(21.62)
180 pre vs. 180+	0	-1.3	3.75	(4.55)	(8.30)
90 pre vs. 180 pre	90	10.8	31.50	37.80	6.30
90+ vs. 180 pre	64	12.0	14.08	42.00	27.92
90+ vs. 180+	64	10.7	17.83	37.45	19.62
180 pre vs. 270 pre	90	0.7	31.50	2.45	(29.05)

† Calculations compare the change in values by subtracting the first listed N treatment from the second.

‡ Nitrogen cost, corn price, post-sensing N application charge, and N stress sensing cost used in calculations:

N Cost ($/lb N):	0.35	N Application Charge ($/acre):	8.00
Corn Price ($/bu):	3.50	Sensing Cost ($/acre):	3.75

Table 10. Economic analysis net returns for several treatment comparisons based on multiple corn price and N cost scenarios, 2004-2006 corn-corn sites.

N Application Treatment Comparison†		Net Gain/Loss					
	Corn price:	$2.20/bu			$4.40/bu		
	N cost:	$0.11/lb	$0.22/lb	$0.44/lb	$0.22/lb	$0.44/lb	$0.88/lb
	$/lb N:$/bu:	0.05	0.10	0.20	0.05	0.10	0.20
		- - - - - - - - - - - - - - - - - - $/acre - - - - - - - - - - - - - - - - - - -					
90 pre vs. 90+		(13.82)	(16.68)	(22.40)	(19.32)	(25.04)	(36.48)
180 pre vs. 180+		(6.61)	(6.61)	(6.61)	(9.47)	(9.47)	(9.47)
90 pre vs. 180 pre		13.86	3.96	(15.84)	27.72	7.92	(31.68)
90+ vs. 180 pre		27.68	20.64	6.56	47.04	32.96	4.80
90+ vs. 180+		21.07	14.03	(0.05)	37.57	23.49	(4.67)
180 pre vs. 270 pre		(8.36)	(18.26)	(38.06)	(16.72)	(36.52)	(76.12)