Demonstration of In-Season Nitrogen Management Strategies For Corn Production

2004 Crop Year Report

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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 N 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 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 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 (after R1). This is a limitation with corn plant monitoring to determine N status as the best time to closely determine crop N need is likely 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 sense the crop before the R1 stage, 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 in-season 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 in-season N application and rate adjustment to be practiced. One, high clearance equipment can move through tall corn, 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 N rate and N status. Other handheld, machine-mounted, and remote aerial sensors are being commercially developed, with research for determination of efficiency and N-rate prediction underway. Therefore, it is feasible for producers to begin implementing 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, feasible strategy for in-season N management, corn productivity, 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 to determine need and rate of in-season N application and effect on corn yield; two, demonstrate the impact of set preplant or early-sidedress N rates (referred to as pre-applied N) on corn plant N sufficiency and N stress development, frequency and rate of needed in-season N application, total fertilizer N applied, and corn yield; and three, compare corn yield response and economic return using pre-applied N versus pre-applied plus in-season monitoring and additional N application.

Field Demonstration Description:

Demonstrations use cooperating producer fields, with fertilizer applications in replicated strips across field lengths. At each site cooperators are asked to avoid making broadcast applications of manure or N fertilizer to the site area, other than replicated N treatment strips. All other field activities are completed as normal by the cooperator, including grain harvest of treatment strips. Each demonstration strip is replicated three times in order to compare demonstration effects.

A summary of the application strategies is given in Table 1. Set pre-applied N rates are either fall- or spring-applied preplant or early-sidedress (hereafter referred to as pre): 1) a no-N control; 2) reference N 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). In-season N applications vary and are determined from corn plant N stress sensing at the V15-VT vegetative growth stages: 5) reduced pre N rate (see number 3 for rate) plus in-season N applied near R1 corn growth stage (applied if needed and rate determined from corn plant sensing); and 6) agronomic pre N rate (see number 4 for rate) plus in-season N applied near R1 corn growth stage (applied if needed and rate determined from corn plant sensing). The in-season applications are applied to one of two strips of the reduced and agronomic pre rates in each replication. The in-season fertilizer N source is UAN solution surface-dribbled or coulter-injected with high-clearance equipment.

The agronomic N rate, set at 120 lb N/acre (corn-soybean) or 180 lb N/acre (corn-corn), is based on the approximate mid-point of current Iowa State University published recommended ranges for each rotation. A recent economic summary of 100 site-years of corn yield response data from across Iowa (Sawyer, 2004) indicated an economic N rate near 125 lb N/acre for the corn-soybean rotation. The demonstration allows for the following comparisons: 1) field response to applied N and relative magnitude of response with each strategy; 2) rates of application; 3) pre N application and in-season application of additional N; 4) frequency and rate of needed in-season N with each strategy; 5) timing of N deficiency development between pre N rates; 6) ability of the monitoring system to determine needed in-season N rate; and 7) economics of using pre N rates versus pre N rates plus in-season N application adjustment strategies.

Two pre N rates are used to demonstrate two overall strategies of in-season monitoring and potential for in-season 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 in-season 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 (for example, 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 N, expecting that more N will be applied in-season most years. This approach could allow for a closer match between corn N need and N application each year. Having some N pre applied can help limit severity of N stress and therefore potential development of irreversible yield loss.

Corn plants are sensed throughout each strip before in-season N application to monitor N deficiency development and to determine in-season N rate. A Minolta SPAD 502 chlorophyll meter is used to monitor N deficiency development. The SPAD chlorophyll meter is hand held, 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. In addition, work being 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 average N rate difference (lb N/acre) between an applied rate and the economic N rate (ND). This relationship can be 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 being 0.97 when the average N rate is at the economic rate, ND=0). This equation is used to determine the in-season N rate to be applied to each of the planned in-season strategies.

The reference N rate is included in the demonstration because research with chlorophyll meters and with remote imagery has shown that readings should be adjusted (normalized) to an adequately N-fertilized reference area to reduce color effects other than from N deficiency (drought, hybrid greenness differences, and diseases). Each strip is sensed after all N applications are completed (R3, corn milk growth stage) to monitor plant response to applied N.

Corn is harvested by cooperators using combines equipped with a yield monitor and GPS positioning equipment, with grain yields adjusted to 15.5% moisture. Combines equipped with GPS positioning equipment allow strip yield determination and comparison of within-field differences in response to applied N using GIS technology.

Ten demonstration sites were established with nine cooperators in nine Iowa counties in 2004 (Figure 1). Additional field sites were identified prior to the 2004 growing season; however, the sites were abandoned for various reasons. Three sites in Webster County were abandoned before planting because of producer concerns with no-N control strip treatments. In early April, a Monona County cooperator planning two field sites decided to wait and evaluate fall 2004-applied encapsulated urea treatments as part of our crop year 2005 project. Two sites in Story County with a cooperator planning early-sidedress N application were abandoned because heavy rains in late May led to extended wet field conditions and large field areas requiring corn replant.

Crop year 2004 demonstration sites varied in soil type, tillage system, yield history, recent N application rate history, and manure application history (Table 2). In 2004, all sites were corn following soybean.

Planting dates at 2004 demonstration sites ranged from April 17 to May 5 (Table 3). Pre N application (preplant or early sidedress) timing at 2004 demonstration sites ranged from early April to late June, with no fall 2003 applications. Early-sidedress N applications were delayed beyond mid-June at two 2004 field sites because extended rainy, wet weather prevented field operations during late May and early June. The pre-applied fertilizer N source at nine of 10 sites was UAN solution, with one cooperator using spring-applied anhydrous ammonia as a preplant N source.

Preliminary 2004 Results:

Late-Vegetative Growth Stage Leaf Greenness Measurement and In-Season N Application Rates

Corn plant N status (leaf greenness) was monitored at all 2004 demonstration sites using a SPAD chlorophyll meter (Figure 2); preliminary chlorophyll meter data collection was targeted for approximately V15 corn growth stage (15 fully-developed, or collared, corn leaves present on the majority of corn plants at a site). Chlorophyll meter (SPAD) readings were collected from twenty corn plants surrounding multiple pre-flagged points throughout each treatment strip. Readings were collected from the uppermost developed leaf with a collar fully visible until the corn reached tassel emergence (VT), when readings were collected from the ear shoot leaf. Within each treatment strip, an average SPAD reading was calculated; relative chlorophyll meter (RSPAD) values, normalized relative to chlorophyll meter readings collected from the 240 lb N reference treatment strip, were calculated for each treatment. As expected, measurements of V15 stage corn leaf greenness increased with higher pre N rates at most sites. SPAD readings and leaf chlorophyll (leaf greenness) will not indicate excess N, but will show deficiency; therefore, those readings do not increase once maximum greenness is reached, even with more N.

In-season N application rates for planned in-season treatments (60+ and 120+) were calculated for each demonstration site by entering RSPAD data into the aforementioned quadratic-plateau equation that describes the positive relationship between RSPAD readings and the average N rate difference (lb N/acre) between an applied N rate and the economic N rate. Equation-prescribed in-season N application rates at 2004 demonstration sites ranged from 30 to 115 lb N/acre for the 60+ treatment. The 120 lb N/acre pre rates exhibited N deficiency at only two of 10 field sites in 2004. Equation-prescribed in-season N application rates were 30 and 45 lb N/acre (Table 3). Equation-prescribed in-season N application rates at the Wapello site were 80 and 30 lb N/acre for the 60+ and 120+ treatment strips, respectively; however, double N rates (160 and 60 lb N/acre) were applied because of improper boom width calibration (a 60-ft wide sprayer boom was used to apply N on 30-ft wide treatment strips).

At six of 10 demonstration sites high-clearance N toolbars equipped with coulter-injectors were used to apply in-season UAN treatments (Figure 3). At three other demonstration sites (Marshall, O’Brien, and Wapello counties) in-season UAN treatments were surface-applied using high-clearance spray booms equipped with drop nozzles to direct UAN solution below the leaf canopy. Extreme corn height prevented in-season N application at the Johnson County demonstration site. Corn yellowing from N deficiency was apparent before in-season UAN application, with Figure 4 showing an example of extreme deficiency in the zero N strips.

Corn response to in-season N application was monitored at all 2004 demonstration sites by collecting follow-up SPAD chlorophyll meter readings from the same pre-flagged strip points throughout each treatment strip. Follow-up chlorophyll meter data collection was targeted for approximately 10-14 days after in-season N application (typically R3 corn reproductive growth, or milky kernel, stage). Relative SPAD values for before and after the in-season N applications are summarized for all 2004 demonstration sites in Table 4. Generally, in-season N applications did not result in significant increases in corn leaf greenness at 2004 sites; however, reductions in corn leaf greenness between V15 and R3 were less where in-season N was applied. 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 in-season N.

Growing Season Precipitation

Growing season (March 15 to October 15) precipitation totals and precipitation totals recorded two weeks before and two weeks after in-season N application are summarized for all 2004 demonstration sites in Table 5. Precipitation was recorded at nearby National Weather Service weather stations for all ten demonstration sites. Weather stations were generally within 5 to 10 miles of demonstration sites. Precipitation to maintain moist soil during the critical period two weeks before and after UAN application at R1 growth stage (silking), and move applied N into the rooting zone, should increase response to the in-season N application. Based on that assumption, we would expect greater response to in-season N at the Cerro Gordo, O'Brien, and Shelby County field sites in 2004 relative to Palo Alto and Wapello County sites, which received less precipitation during the two weeks after in-season N application.

Corn Grain Yield Response to N Fertilizer Rate and Timing

Corn yield level and response to N fertilizer rate/timing varied between sites in 2004 (Table 6). Corn yield increase with pre N application was statistically significant at all 2004 demonstration sites. Zero-N application (control) produced strip-length yields ranging from 91 to 206 bu/acre. The reduced pre N application rate (60 lb N/acre) produced strip-length yields ranging from 158 to 233 bu/acre. Corn yield response to the first 60 lb N/acre was statistically significant ($P \leq 0.10$) at all demonstration sites, with yield response ranging from 18 to 69 bu/acre. The agronomic pre N application rate (120 lb N/acre) produced strip-length yields ranging from 187 to 256 bu/acre. Corn yield response to increasing pre N from 60 to 120 lb N/acre was statistically significant ($P \leq 0.10$) at eight of 10 demonstration sites, with yield increase ranging from 12 to 32 bu/acre at those sites. The reference area pre N application rate (240 lb N/acre) produced strip-length yields ranging from 190 to 262 bu/acre. Corn yield response to increasing pre N from 120 to 240 lb N/acre was statistically significant at only the Dallas site. Overall, the Shelby-NW site was least N-responsive in 2004, with 23 bu/acre separating zero-N and adequate-N rate yield averages (yield response to N application above 60 lb N/acre was statistically not significant, which was also seen at the 2004 Cerro Gordo site); Wapello (107 bu/acre separating zero-N and adequate-N rate yield averages), Marshall (99 bu/acre), and Dallas (93 bu/acre) sites were most N-responsive in 2004.

The 60+ treatment (with 30 to 160 lb N/acre applied in-season, resulting in total-N rates ranging from 90 to 220 lb N/acre) produced strip-length yields ranging from 171 to 232 bu/acre. In-season N was applied in addition to the 60 lb N/acre pre rate at nine demonstration sites, as called for by plant N stress sensing. Corn yield response to the additional in-season N was statistically significant ($P \leq 0.10$) at only four of the nine sites. In-season N at 30 lb N/acre was applied at four sites, with corn yield response to added N ranging from 0 to +11 bu/acre; at the Kossuth site corn yield response to 35 lb N/acre was -8 bu/acre (not statistically significant). In-season N rates of 55, 80, and 115 lb N/acre were applied in addition to 60 lb N/acre pre rate at the Marshall, Palo Alto, and Dallas sites, respectively. Corn yield response to these in-season N applications was statistically significant (+13 to +17 bu/acre at each site); however, the yields with additional in-season N were less than the 120 lb N/acre pre rate (average 15 bu/acre less). In-season N was applied at a rate of 160 lb N/acre in addition to the 60 lb N/acre pre rate at the Wapello site. Corn yield response to this in-season N was statistically significant (+38 bu/acre), and the same yield as the 120 lb N/acre pre rate. The need for application of additional N in-season to the 60 lb N/acre pre rate was correctly identified by plant N stress sensing at eight of the ten sites. However, the yield increase from in-season application was significant at only four sites, and this strategy (60+ treatment) returned yield as high as the 120 lb N/acre pre rate at only one site. This means full yield recovery from the N stress was achieved at only one site. Two sites were identified as requiring additional N, but there was no increase in yield with N rates above 60 lb N/acre at those sites, therefore the in-season N application was not needed.

Plant sensing in the 120+ treatment indicated need for in-season N application only at the Dallas (+45 lb N/acre; 165 lb total-N/acre) and Wapello (+60 lb N/acre; 180 lb total-N/acre) sites. Corn yield response to this in-season N was statistically significant ($P \leq 0.10$) at both sites, with 7 and 15 bu/acre yield increases at the Dallas and Wapello sites, respectively. At the other sites, plant sensing of the 120 lb N/acre pre agronomic rate did not indicate additional N need, which was correct as no statistical difference in yield was measured between the pre 120 and 240 reference N rates.

One of our project objectives is to evaluate corn yield response and economic returns using strategies of pre N rates versus pre rates plus in-season N application. We will make economic analyses of N application strategies after additional field sites are included in the dataset; however, some preliminary conclusions can be drawn from 2004 results. Corn yield response to increasing the pre N rate from 60 to 120 lb N/acre was statistically significant ($P \leq 0.10$) at eight of 10 demonstration sites, with yield increase averaging 20 bu/acre. At nine of 10 demonstration sites the pre N rate of 120 lb N/acre produced top yields, or yields that were statistically the same as the site’s top-yielding N treatment. The 120 lb N/acre pre rate produced yields that were statistically higher than the 60+ treatment (60 lb N/acre pre plus in-season N application strategy) at six of nine sites where the in-season N was applied, with no yield differences at the other three sites. Yield advantage for the 120 lb N/acre pre rate ranged from 12 to 31 bu/acre at those six sites. These 2004 results indicate an economic advantage to using the 120 lb N/acre preplant or early-sidedress application. These results, in conjunction with the measured yield enhancement (11 bu/acre average) at two sites when additional in-season N was applied as called for by plant sensing (120+ treatment), indicates that a pre application of 120 lb N/acre is desirable with the strategy of N stress sensing in-season to determine if additional N is required.

Site history differences likely accounted for variable corn yield response to N at 2004 demonstration sites. The Shelby-NW site, which was treated with beef manure in the spring of 1999, demonstrated minimal response to added N in 2004; however, the Shelby-SE site, which was similarly treated with beef manure in the fall of 2000, demonstrated significant response to added N in 2004. The Cerro Gordo site had a history of year-to-year seed corn production rotated with soybean production. Perhaps the reduced corn yield levels associated with seed corn production impacted that site’s corn yield response to applied N in 2004.

Education Component and Outreach Activity:

The following outreach activities occurred at the project sites in 2004. Field signs indicating the project name, program, and cooperating organizations were located at many sites (Figure 5).

An important educational multiplier is the extensive use of the project information in extension programs. Between November 2004 and February 2005 the project leader made presentations integrating results of this project to over 1800 people at 22 ISU Extension and agribusiness meetings.

2004 Field Days

In cooperation with our Shelby County site cooperator (who manages seed production for a large soybean company) the Iowa Department of Agriculture and Land Stewardship, and Iowa State University Extension staff a field day was conducted on September 8, 2004 at our "Shelby County NW" demonstration site. Local crop farmers, seed producers, dealers, certified crop advisors (CCA's), and the general public attended the field day and viewed the site.

Expected Benefits:

One, producer recognition of the demonstration project and importance of corn N rate/timing management as a result of visibility through field signage and field days; two, multiple cooperating and neighboring producers consider use of in-season N application as a direct result of their participation in the project; and three, enhanced and refined information about corn response to N rate application by producers, crop consultants, and N suppliers across Iowa.

Several project outputs are expected: 1) increased awareness of demonstration activities that reinforce the economic and environmental importance of corn N management; 2) through a strong producer-field specialist-agbusiness-agency cooperative practice demonstration program, extensive outreach information transfer mechanism to producers and agbusiness via field days and meetings, promotion of experiences learned through the demonstrations, and use of information learned for corn N management educational literature; and 3) improved understanding of corn yield response and economic return to in-season corn N management practices.

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
John Deere Ag Management Solutions, coordination of in-season aerial imaging efforts

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Figure 1. In-season corn nitrogen management strategies project demonstration sites, 2004.

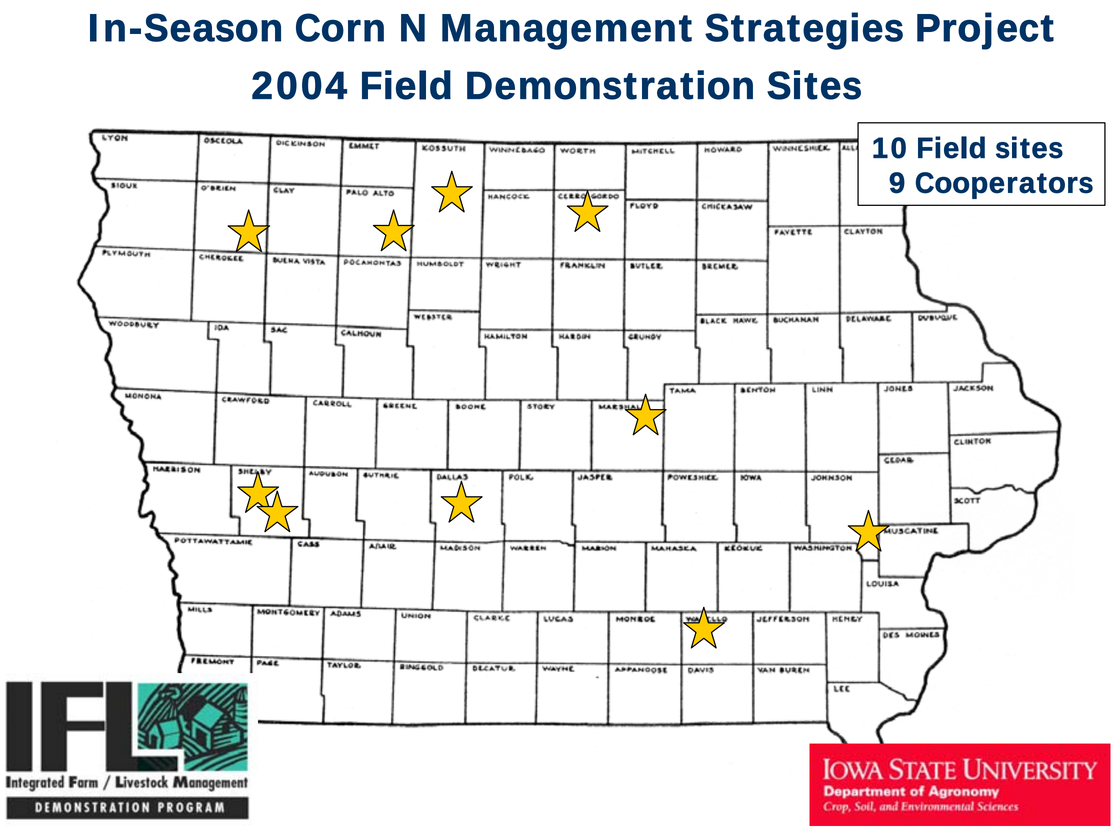

Figure 2. Demonstration of a SPAD chlorophyll meter measuring corn leaf greenness (N status).

Figure 3. Twelve row-wide, high-clearance nitrogen toolbar used to apply at-tassel N fertilizer in selected N treatment strips at the 2004 Dallas County (Adel) demonstration site on July 21, 2004.

Figure 4. Mid-July view of corn response (leaf greenness) to field-length N rate strips, 2004 Marshall site.

Figure 5. Example project demonstration signage at a 2004 field site.

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

Pre N rate†	In-season N Application	N Application Treatment	Treatment Identifier
lb N/acre			
0	- - - - -	Control	0
60 (90)	- - - - -	Pre reduced N rate	60
60 (90)	At rate determined in-season	Pre reduced + in-season N rate	60+
120 (180)	- - - - -	Pre agronomic N rate	120
120 (180)	At rate determined in-season	Pre agronomic + in-season N rate	120+
240 (270)	- - - - -	Pre well-fertilized reference N rate	240

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

Table 2. Site characteristics, management, recent years' corn N application rate and crop yield history, 2004 in-season corn N project sites.

County-Site	Soil	Tillage†	Yield History‡ Corn	Soybean	Average N-Rate History§	Manure History
			- - - bu/acre - - -		lb N/acre	
Cerro Gordo	Floyd, Kenyon, Clyde	Conservation Tillage	85 - seed corn	46	135	None
Dallas	Coland, Spillville	Conservation Tillage	146	42	140	None
Johnson	Givin, Clinton	Conservation Tillage	181	50	150	None
Kossuth	Canisteo, Clarion	Conservation Tillage	190	48	165	None
Marshall	Tama	No-Tillage	177	55	120	None
O'Brien	Sac, Primghar	Fall Strip Tillage	170	51	120	None
Palo Alto	Canisteo, Clarion, Nicollet	Conservation Tillage	140	41	130	None
Shelby-NW	Monona	No-Tillage	185	50	100	Beef - Spring 1999
Shelby-SE	Zook	Conservation Tillage	146	41	100	Beef - Fall 2000
Wapello	Richwood, Nevin	Conservation Tillage	163	42	120	Beef/Swine - Fall 1999

† Tillage system for the current crop year.

‡ Yield history is average of last five to six crop years. All 2004 demonstration sites were corn following soybean.

§ Nitrogen application history for the last two or three corn crops.

Table 3. Planting dates, and pre-applied N and in-season N application details, 2004 in-season corn N project sites.

	Planting	Pre N		In-Season N (UAN solution) Application, lb N/acre		
County-Site	Date	Application Timing	N Source	Application Timing	60+ Treatment	120+ Treatment
Cerro Gordo	April 28	Early-sidedress, June 12 (V3)	Injected UAN solution	Coulter-injected July 23 (R2)	30	- - -
Dallas	April 17	Preplant, early April	Anhydrous ammonia	Coulter-injected July 21 (R2)	115	45
Johnson	April 18	Early-sidedress, May 28 (V3)	UAN solution	In-season N not applied	- - -†	- - -
Kossuth	April 28	Early-sidedress, June 25 (V7)	Injected UAN solution	Coulter-injected July 23 (R1)	35	- - -
Marshall	May 3	Early-sidedress, June 18 (V5)	UAN solution	Drop nozzle-applied July 30 (R1)	55	- - -
O'Brien	April 27	Pre-emergence, late April	UAN solution	Drop nozzle-applied July 27 (R1)	30	- - -
Palo Alto	May 5	Pre-emergence, early May	Injected UAN solution	Coulter-injected July 23 (R1)	80	- - -
Shelby-NW	April 22	Pre-emergence, late April	UAN solution	Coulter-injected July 22 (R1)	30	- - -
Shelby-SE	April 27	Pre-emergence, late April	UAN solution	Coulter-injected July 22 (R1)	30	- - -
Wapello	April 28	At-planting/early-sidedress, May 27 (V4)	UAN solution	Drop nozzle-applied July 15 (R2)	160‡	60‡

† Leaf greenness data collected at V17 corn growth stage suggested adding 45 lb N/acre; corn height made high-clearance N application at R1 reproductive stage impossible.

‡ Leaf greenness data collected at VT corn growth stage suggested adding 80 and 30 lb N/acre to 60+ and 120+ treatments, respectively; double N rate resulted from improper boom width calibration.

Table 4. Effect of N application rate on average corn relative leaf greenness in field-length strips, 2004 in-season corn N project sites.

	N Application Treatment†					
Site, Corn Stage‡	None	60	60+	120	120+	240
	- - - - - - - corn leaf greenness, relative to 240 lb reference N rate - - - - - - -					
Cerro Gordo, V15	90	97	96	97	98	100
Cerro Gordo, R2	75	94	93	93	100	100
Dallas, V15	57	86	85	92	95	100
Dallas, R4	51	77	82	91	96	100
Johnson, V18	84	95	93	96	96	100
Johnson, R4	76	95	92	97	98	100
Kossuth, VT	88	95	94	98	98	100
Kossuth, R3	84	97	95	99	99	100
Marshall, VT	66	94	93	99	99	100
Marshall, R3	51	82	84	95	95	100
O'Brien, VT	83	95	96	103	101	100
O'Brien, R3	76	88	95	98	97	100
Palo Alto, V13	84	87	93	99	101	100
Palo Alto, R3	76	91	93	100	95	100
Shelby NW, V15	89	96	97	98	98	100
Shelby NW, R3	84	94	95	98	99	100
Shelby SE, V15	91	94	96	96	98	100
Shelby SE, R4	83	89	90	97	98	100
Wapello, VT	76	89	91	98	94	100
Wapello, R3	59	83	86	94	94	100

† Refer to Tables 1 and 3 for description of N applications.

‡ Vegetative ("V") corn growth stages designate the number of fully-developed leaves present when "early" leaf chlorophyll meter data was collected; VT corn stage stage designates the tassel emergence stage. Reproductive ("R") corn growth stages designate the stage of reproductive grain development when "late" leaf chlorophyll meter data was collected.

Table 5. Precipitation totals, 2004 in-season corn N project sites.

	Precipitation		
County-Site	2 weeks before In-season N†	2 weeks after In-season N‡	March 15 to October 15
	- - - - - - - - - - - - - - - -	inches - - - - - - - - - - - - - - - -	
Cerro Gordo	2.71	3.48	38.74
Dallas	2.47	1.39	16.67
Johnson	"no in-season N applied at this site"		25.53
Kossuth	3.41	1.53	27.44
Marshall	0.40	2.37	18.50
O'Brien	2.42	2.60	29.47
Palo Alto	2.44	0.71	23.75
Shelby-NW	2.10	2.98	27.92
Shelby-SE	2.10	2.98	27.92
Wapello	1.42	1.02	26.09

† Precipitation totals recorded at nearby weather stations during 2- week interval before in-season UAN application.

‡ Precipitation totals recorded at nearby weather stations during 2-week interval after in-season UAN application.

Table 6. Effect of N application rate on field-length treatment strip corn grain yield, 2004 in-season corn N project sites.

	N Application Treatment†					
Site-Year	None	60	60+	120	120+	240
	bu/acre					
Cerro Gordo	153a‡	191b	199b	191b	200b	211b
Dallas	121a	178b	195c	207d	214e	218e
Johnson	175a	224b	223b	236c	238c	238c
Kossuth	190a	233b	225b	256c	252c	262c
Marshall	91a	158b	171c	190d	190d	195d
O'Brien	121a	163b	174b	191c	191c	200c
Palo Alto	142a	160b	173c	187d	179d	190d
Shelby NW	206a	226b	232b	229b	232b	232b
Shelby SE	187a	209b	209b	226c	227c	233c
Wapello	121a	190b	228cd	220c	235d	218c

† Refer to Tables 1 and 3 for description of N applications.

‡ Yields at each site are not significantly different when followed by the same letter ($P \leq 0.10$).