IN-SEASON NITROGEN MANAGEMENT FOR CORN PRODUCTION

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Introduction

Water quality impairment related to nitrogen (N) continues to be a concern in Iowa, including the nitrate drinking water standard, USEPA proposed surface water quality nutrient criteria, and the Gulf of Mexico hypoxia. Addressing these issues could include strict guidance for N input to corn and resultant N use practices that require very high level of management and risk, with unknown economic consequences. Rate of N application is an important management factor in corn production related to nitrate reaching surface water systems. Rate is also important in regard to economic return. While applying only the needed fertilizer N rate in a given year will not stop nitrate from leaving corn fields, nor necessarily achieve proposed water quality goals, 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 would improve corn N use efficiency and reduce nitrate susceptible to loss compared to application of an average agronomic rate each year.

Monitoring corn to determine the plant N status has advantages in that the plant integrates N supply over a period of time, and hence can reflect available N 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. Therefore, the total crop N need (and season-long soil N supply) is better reflected in the crop late in the season. This is a limitation with corn plant sensing 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 easily 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. 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. 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.

Several technologies now allow in-season N application and rate adjustment to be practiced. One, high clearance equipment can move through tall corn, some at full growth height. Two, high clearance equipment has been developed that can inject urea-ammonium nitrate (UAN) fertilizer solutions into the soil. Three, plant N status sensors are available to determine N stress in corn. One sensor, the handheld Minolta SPAD 502 chlorophyll meter (CM), has been long-researched in regard to sensing plant N stress and the relationship with optimal N rate. Extensive research in the sensing area continues, with handheld, machine-mounted, and remote aerial sensors being commercially developed, along with research for determination of efficacy and N-rate prediction. Because of these developments, it is feasible for producers to begin investigating in-season N management systems based on plant sensing. However, field-scale research is needed to study several issues, including corn productivity and economic return compared to traditional preplant and sidedress N application. Other issues for producers, crop advisers, and agribusinesses include crop sensing integration into corn production systems and feasible strategies for in-season N management.

The objectives of this study include: one, demonstrate corn plant N deficiency/sufficiency sensing to determine need and rate of N applied after plant sensing (hereafter referred to as "Post-sensing N"), and effect on corn yield; two, determine the effect of selected preplant or early-sidedress N rates (hereafter referred to as "Pre-N") on corn plant N stress development, rate of needed Post-sensing N application, and corn yield; and three, compare corn yield response and economic return of Pre-N versus Pre-N plus Post-sensing N applications.

Field Study Description

Study sites were located on producer fields, with fertilizer N treatment applications in replicated and randomized strips across field lengths. Field activities were completed as normal by the producer. The N treatment strips were applied by the producer and/or cooperating agribusiness. A total of 30 sites were established from 2004 to 2006 across Iowa with corn following soybean (SC). Sites varied in soil type, tillage system, and recent yield, N application rate, and manure history.

The N application treatments and management strategies are listed in Table 1. Selected Pre-N rates were either fall or spring preplant, or early sidedress fertilizer N application: no-N control; non-N limiting "reference" rate at 240 lb N/acre; "agronomic" N rate, 120 lb N/acre; and "reduced" N rate, 60 lb N/acre. The Pre-N was applied at three sites in late fall, at five sites spring preplant, and at 22 sites preemergence or early sidedress. Nine sites had Pre-N applied as anhydrous ammonia and 21 sites as UAN solution. Post-sensing N application and rates varied between sites and were determined from corn plant N stress sensing when corn was between the V10 and VT growth stages. Post-sensing N applications were made when needed to one of two duplicate strips per replicate for each Pre-N reduced and agronomic rate, identified as "60+" and "120+" (Table 1). The Post-sensing N was applied from approximately the V13 to R1 growth stages, with applications at most sites near the VT to R1 stages. The Post-sensing N fertilizer was UAN solution surface-dribbled onto the soil or coulter-injected with high-clearance equipment.

The non-N limiting reference rate was included because research has shown that sensor readings should be adjusted (normalized) to an adequately N-fertilized reference to reduce effects other than from N deficiency (drought, hybrid greenness, diseases, and other nutrient deficiencies). The agronomic Pre-N rate was set at 120 lb N/acre across all sites. This rate is the approximate midpoint of the current Iowa State University published recommended N rate range for the SC rotation. Also, economic analysis of over 150 site-years of corn yield response data from across Iowa indicated an economic optimum N rate near 120 lb N/acre for SC with prevailing corn and N prices. The reduced Pre-N rate was set at one-half of the agronomic rate across all sites. Two Pre-N rates were used to demonstrate two overall strategies of in-season plant N stress monitoring and potential need for Post-sensing N application. One strategy was to apply an agronomic N rate and then monitor to see if a problem developed in regard to N sufficiency. This is a management strategy where Post-sensing N applications might be infrequent across years. It would allow producers to confidently use agronomic N rates while having a backup system available in case N deficiency problems develop during early vegetative growth or more than expected N is needed. This approach does not allow for adjusting rates if less than an agronomic rate would suffice in a particular year. The second strategy was to apply a reduced rate of N, where plant sensing and Post-sensing N application might 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 could also help limit severity of N stress development and therefore irreversible yield potential loss.

Twenty corn plants were monitored within 30 feet of multiple flagged points (5 to 10 points depending upon strip length) approximately 150 feet apart throughout each strip to determine N deficiency development and Post-sensing N application rate. A handheld Minolta SPAD 502 CM was used to monitor plant N status. Implementation of the Minolta CM and rate determination followed the suggestions in ISU Extension Publication PM 2026, Sensing Nitrogen Stress in Corn, and Hawkins et al. (2007). Relative CM values were calculated by dividing the mean of readings at each strip location by the corresponding reading from the N reference strip within that replicate. Once relative values were calculated for each location within a treatment strip, the mean of those values was used as the N sufficiency/deficiency indicator for each treatment and to determine Post-sensing N applications at each site. Post-sensing N rates were applied at 100 lb N/acre for relative CM values less than 0.88, 80 lb N/acre for values at 0.88 - 0.92, 60 lb N/acre for values at 0.92 - 0.95, 30 lb N/acre for values at 0.95 - 0.97, and zero lb N/acre for values greater than 0.97. Corn was harvested by the cooperating producers using combines equipped with a yield monitor and GPS positioning equipment or by weigh wagon, with yields adjusted to 15.5% grain moisture.

Results

Corn response to nitrogen rate and timing

Across the 30 SC sites, mean relative CM values for the respective Pre-N rates were: 0.82 (0 lb N/acre), 0.93 (60 lb N/acre), 0.97 (120 lb N/acre), and 1.00 (240 lb N/acre). From these overall means it would be expected that most sites would receive Post-sensing N applications in conjunction with the 60 lb N/acre Pre-N rate, which was the case for 28 sites (Table 2), and it would be expected that few sites would receive Post-sensing N applications with the 120 lb N/acre Pre-N rate, which was the case for only nine sites (Table 2). The 240 lb N/acre rate was the reference or normalizing rate for calculating relative CM value, therefore the mean relative CM value was 1.00.

As would be expected, corn grain yield level and response to N fertilizer rate and timing varied across the 30 sites. Corn yield increase from N application was statistically significant at all sites (data not shown). This means that all sites were responsive to N. Across all sites, corn yield response to the reduced Pre-N 60 lb N/acre rate was statistically significant, with a yield increase of 36 bu/acre (compared to the no-N rate), and the agronomic Pre-N rate (120 lb N/acre) yielded an additional 15 bu/acre compared to the 60 lb N/acre rate (Table 2). At 25 sites, grain yield with 60 lb N/acre was statistically lower than yield with the 120 or 240 lb N/acre, and at five sites was the same (data not shown). This means that at 83% of the sites (25 of the 30 total) the 60 lb N/acre rate applied as Pre-N was not sufficient to produce maximum yield. Conversely, at 17% of the sites (5 of the 30 total) there was opportunity to improve N use compared to the 120 lb N/acre rate. The mean corn yield response to increasing the Pre-N rate from 120 to 240 lb N/acre was not statistically significant across all sites (Table 2). At six sites the yield was statistically lower with the 120 lb N/acre rate compared to the 240 lb N/acre rate (although not large yield differences), but was the same at 24 sites (data not shown). Therefore, there was opportunity to improve yield at 20% of sites (6 of the 30 total) with additional N application (compared to 120 lb N/acre rate), but potential yield increases would be small.

Post-sensing N was applied to 60+ treatment strips at 28 of 30 sites, as determined by plant N stress sensing with the CM. The mean Post-sensing N rate was 55 lb N/acre (Table 2). Corn yield response to Post-sensing N (vs. only Pre-N application of 60 lb N/acre) was statistically significant, with an 8 bu/acre yield increase (Table 2). The 60+ treatment yielded statistically less than the 120 lb N/acre Pre-N rate (7 bu/acre), even though the mean total N rate was similar. Several observations can be made about individual site responses with the 60 lb N/acre Pre-N rate (data not shown) that relate to the observed yield response. One, N stress sensing tended to overestimate the need for additional N application (18% occurrence). That is, Post-sensing N was applied but no yield increase would occur (misidentification of N deficiency). Two, the need to apply Post-sensing N was correctly identified at 13 of 30 sites by plant N stress sensing. Three, many sites that needed additional N did not have yield recovery with Post-sensing N application (61% occurrence). This means corn did not respond well to the Post-sensing N applications. Four, there were no instances when N stress sensing missed the need for additional N. Five, one site had an unexplained yield decrease with Post-sensing N application. The lack of consistent corn yield response to Post-sensing N could be due to rainfall deficit near the time of Post-sensing N applications limiting corn plant uptake of applied N or to irreversible loss of yield potential resulting from early-season plant N stress and late-vegetative stage Post-sensing N application.

Post-sensing N was applied to 120+ treatment strips at nine of 30 sites (Table 2). Mean corn yield response to Post-sensing N (vs. only Pre-N application of 120 lb N/acre) was not statistically significant (Table 2). Several observations can be made about individual site responses with the 120 lb N/acre Pre-N rate (data not shown) that relate to the observed yield response. One, the N stress sensing tended to overestimate the need for additional N application (67% occurrence). That is, N was applied but no yield increase would occur (misidentification of N deficiency). Two, the need to apply Post-sensing N was correctly identified at one of 30 sites by plant N stress sensing, and the need to not apply N was correctly identified at 18 of 30 sites. Three, several sites that needed additional N did not have yield recovery with Post-sensing N applications (89% occurrence). This means corn did not respond well to the Post-sensing N applications. Four, there were three instances when N stress sensing missed the need for additional N. Five, one site had an unexplained yield decrease with Post-sensing N application.

In some instances, Post-sensing N applications were quite successful. One site in 2005 is a good example where there was a yield increase of 32 bu/acre for the 60+ treatment (85 lb N applied Post-sensing) compared with the 60 lb N/acre Pre-N rate. Precipitation of 0.58 and 2.87 inches, respectively, were recorded at the nearby National Weather Service (NWS) station two weeks before and after the V13 stage Post-sensing N application. Post-sensing N applications in many instances were unsuccessful. One site in 2006 represents an example where lack of precipitation near the time of Post-sensing N application likely was the reason for lack of yield response (only 0.82 and 0.64 inch of precipitation, respectively, were recorded at the nearby NWS weather station two weeks before and after the VT stage Post-sensing N application. Early Post-sensing N application and timely rainfall appear critical for successful corn response to late-vegetative N application in rain-fed corn production.

Economic analysis

An economic analysis based on the mean results (Table 2) was conducted for selected treatment comparisons that incorporated N cost, corn price, estimated charge for Post-sensing N application ($8.00/acre), and estimated charge for N stress sensing ($3.75/acre) (Table 3). The Post-sensing N application charge was based on conversations with industry representatives, and was only assigned to the number of sites where a Post-sensing N application was made. The plant sensing cost represented the average per-acre crop scouting charge reported in the 2007 Iowa Farm Custom Rate Survey (ISU Extension Publication FM 1698, March 2007). The net return (gain or loss) associated with the various comparisons was calculated by subtracting the applied N, sensing, and Post-sensing N application costs from income (corn yield difference times expected corn price). Focusing on the 60+ vs. 120 Pre-N comparison, the mean total-N application rate in the 60+ treatment was 115 lb N/acre, resulting in a total N application rate difference of only 5 lb N/acre (115 vs. 120 lb N/acre). The mean corn yield for the 120 lb Pre-N was seven bu/acre greater than 60+ treatment. The reduced yield plus total sensing/Post-sensing N application costs contributed to the large net return advantage for the 120 lb Pre-N vs. 60 lb Pre-N + Post-sensing N. For all comparisons and both sets of fertilizer/corn prices, the greatest net return was for application of 120 lb N/acre as a one-time Pre-N (preplant or sidedress) application.

The in-season N management (that is, reduced or agronomic Pre-N rate followed with N applied as indicated by N stress sensing) had low net returns. The lowest net return comparison was for application of 240 lb N/acre. If in-season N stress sensing were to be practiced, doing so following a Pre-N agronomic rate strategy of 120 lb N/acre returned more net income that using the reduced rate strategy of 60 lb N/acre. Despite a few 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.

Summary

Overall results indicated a yield and economic net return advantage for simply applying a one-time recommended (agronomic) N rate of 120 lb N/acre (in SC) as a preplant or early sidedress application (called Pre-N in this study) across all sites. Applying this Pre-N rate, with the in-season strategy of applying N as indicated by N stress sensing, produced greater yield and net return than a second in-season strategy of applying a reduced Pre-N rate (60 lb N/acre), and applying N as indicated by N stress sensing. The reduced Pre-N rate plus N stress sensing strategy also had considerable errors with incorrect identification of N stress and poor yield performance where yields did not recover fully from N deficiency, and therefore did not match or exceed the economic return with a one-time agronomic application rate.

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. However, environmental costs were not included in the economic analysis performed in this study. Perhaps plant N stress sensing during corn vegetative growth stages could 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 or high N rate history. These situations would provide the greatest opportunity for avoidance of over-application.

Economic analysis indicated a definite advantage for using an agronomic Pre-N rate, with an alternative then for using plant mid- to late-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, however, 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 would require Post-sensing N applications most years, as found in this study. This could allow for a closer match between corn N fertilization need and total-N application each year. However, due to identified problems, this strategy may be best reserved for fields suspected for some reason to need much less than normal fertilization.

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Table 1. Nitrogen application treatments, 2004-2006 soybean-corn (SC) sites.

Pre-N Rate†	Post-Sensing N Application‡	N Application Treatment	Treatment Identifier
lb N/acre			
0	- - - - -	Control	0
60	- - - - -	Pre reduced rate	60
60	At rate determined in-season	Pre reduced + post-sensing rate	60+
120	- - - - -	Pre agronomic rate	120
120	At rate determined in-season	Pre agronomic + post-sensing rate	120+
240	- - - - -	Pre non-limiting reference rate	240

† Pre-N refers to N applied preplant or early sidedress.

‡ Post-sensing refers to the N rate applied with high-clearance equipment after N stress sensing.

Table 2. Total fertilizer N applied and corn grain yield response to Pre-N and Post-sensing N applications, 2004-2006 soybean-corn (SC) sites.

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-N and Post-sensing N rate, averaged across all 30 SC sites.

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

Table 3. Economic analysis of several treatment comparisons, 2004-2006 soybean-corn (SC) sites.

N Application Treatment Comparison†	Gain/Loss‡ ($0.35/lb N and $3.50/bu) N Cost	Income	Net	Gain/Loss‡ ($0.50/lb N and $3.00/bu) N Cost	Income	Net
	- - - - - - - -	- - -	$/acre	- - -	- - -	- - -
60 vs. 60+	30.47	28.00	(2.47)	38.72	24.00	(14.72)
120 vs. 120+	10.00	3.15	(6.85)	11.65	2.70	(8.95)
60 vs. 120	21.00	52.15	31.15	30.00	44.70	14.70
60+ vs. 120	(9.47)	24.15	33.62	(8.72)	20.70	29.42
60+ vs. 120+	0.53	27.30	26.77	2.93	23.40	20.47
120 vs. 240	42.00	17.85	(24.15)	60.00	15.30	(44.70)

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

‡ Nitrogen fertilizer cost, post-sensing N application charge ($8.00/acre), and N stress sensing charge ($3.75/acre) included in the N cost.

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