Crop Response to Shallow Placement of Anhydrous Ammonia in Corn

Final Project Report

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Introduction

Demand for corn has increased substantially due to processing for ethanol biofuel. With narrow windows for nitrogen (N) fertilizer application, custom applicators, agribusiness, and producers need anhydrous ammonia equipment that provides increased application productivity and efficiency. Anhydrous ammonia is an important N fertilizer, comprising approximately half of the N used for corn production in Iowa. Also, with the desire to improve water quality, N application will move more to spring and sidedress application and corn production with no-tillage practices will increase. Therefore, ammonia application equipment with low soil disturbance, higher application speed, and high ammonia retention with shallow placement is needed. This project will supply information to help gain producer acceptance of new ammonia application technologies and help increase ammonia application closer to time of crop N uptake.

The objectives of the project are 1) compare the application of anhydrous ammonia with a proprietary, shallow placement, low soil disturbance injection system to a conventional type ammonia injection system; 2) compare corn plant stand, growth, and grain yield response between the two application systems; and 3) evaluate the impact of ammonia application method, timing, and rate on plant N status and grain yield.

Materials and Methods

The research sites were located at the Iowa State University Agronomy and Agricultural Engineering Research Farm, located near Boone, IA. The predominant soils at each site varied between years: Nicollet loam with some Clarion loam and Webster silty clay loam in 2007 and 2009; and Harps loam and Webster clay loam in 2008. The site used in 2009 encompassed approximately the same area as in 2007, with the specific location moved to avoid wet areas encountered in 2007 and the additional fall treatment in 2009 that was not included in 2007. The previous crop each year was soybean, with the sites maintained for each study year with no tillage.

Routine soil tests for each site are listed in Table 1. In 2007, since soil test P and K were in the High interpretation category for corn, no P or K fertilizer was applied. In 2008, because the soil test P was in the Low category, P fertilizer (0-46-0) was broadcast applied in the spring at 75 lb P_2O_5/acre across the entire study area. Since the soil test P and K were in the Optimum to High categories for the 2009 crop year, no P or K was applied. However, P and K fertilizer had been broadcast applied across the entire study area before the 2008 soybean crop. In 2007 and 2009, the soil pH was slightly acidic and at an optimal level for corn production. In 2008, the soil pH was basic with free lime in the upper soil profile.

The experimental treatments were a split-plot arrangement with four replications in a randomized complete block design. One replicate was lost in 2007 and 2008 due to excessively wet soil conditions at corn emergence and early growth that severely affected plant stand. The main plot was time of anhydrous ammonia application (late fall, spring preplant, and sidedress) and the split plot was method of application and N rate.

Anhydrous ammonia was applied spring preplant on May 14, 2007 and sidedress applied June 11, 2007 at the V2-V3 corn growth stage. Only spring preplant and sidedress applications were made in 2007 due to the project initiation in the spring of 2007. Anhydrous ammonia was applied in the fall on October 31, 2007, spring preplant on April 30, 2008, and sidedress on June 18, 2008 (at the V2-V4 corn growth stage – early corn growth across the site was variable due to wet spring conditions). Anhydrous ammonia was applied in the fall on November 3, 2008, spring preplant on April 16, 2009, and sidedress on June 5, 2009 (at the V4 corn growth stage). Fall applications were made after the soil temperature was below 50˚F.

The rates of anhydrous ammonia-N were 0, 80, 120, 160, and 200 lb N/acre for the spring and sidedress applications in 2007 and the fall and spring preplant applications in 2008 and 2009. As per the project team decision on February 27, 2008 to add 20 lb N/acre as a preplant application to the sidedress timing, ammonium nitrate was applied at 20 lb N/acre to the sidedress plots on April 9, 2008 and April 16, 2009 before planting (not including the zero N rate). Therefore, the sidedressed anhydrous ammonia rates were 60, 100, 140 and 180 lb N/acre in 2008 and 2009.

Two methods of anhydrous ammonia injection were used. One method was a newly developed proprietary system from John Deere, the High Speed Low Draft opener system (HSLD) (Figure 1). The intended speed for the fall and spring preplant applications with the HSLD was 10 mph, but due to tractor horsepower limitation and to improve speed consistency, the fall and spring preplant applications were made at 9.0 mph. The sidedress application was at the intended 8.0 mph speed. The depth of injection was 4 in. for all applications. The second method of ammonia injection was a John Deere conventional till knife injection system with covering disks (CTKS) (Figure 2). The speed for the fall, spring preplant, and sidedress applications with the CTKS was at the intended 6.0 mph. The depth of injection was 7 in. for all CTKS applications. Both applicators were run through the zero N rate plots at each application timing, with no ammonia being applied.

Applications were made with HSLD and CTKS tool bars supplied by John Deere. For fall and spring preplant applications, each tool bar had four injectors set on 30-in. spacing. The injection tracks were placed under future corn rows. This orientation with the corn rows provided the greatest chance for ammonia damage to corn seedlings/roots. The sidedress applications were made with tool bars using only two of the HSLD openers or CTKS knives (60-in. spacing), with the injection tracks placed between every other row (between rows 1-2 and 3-4). This arrangement was required due to the use of 4-row plots.

Individual plots were four 30-in. rows (10 ft. plot width) and 50 ft. length. Ample room (50 to 100 ft.) was used for ramp-up of tractor speed and ammonia flow to operating conditions before application to each plot.

The HSLD openers were upgraded before the spring 2008 preplant application with production cast parts for the opener “shoe/boot” and closing wheel arm that replaced fabricated parts developed for experimental units. These upgrades provided a slightly wider shoe, a greater vertical distance of the ammonia delivery tube outlet from the bottom of the shoe, and less angle on the first closing wheel.

In 2007, the flow rate of anhydrous ammonia was regulated with a Kontro-Flo II controller, a Sky-Trak GPS, and an Equa-Flo distributor (Squibb-Taylor, Dallas, TX). The regulation of anhydrous ammonia flow rate was changed for the 2008 and 2009 years. For all 2008 and 2009 crop-year applications, the flow rate was regulated with a Continental C-2500 Meter Matic and distribution through a CDS-John Blue Company Impellicone flow divider. The applicators were equipped with a 120 gal. ammonia tank and load cells to record the quantity of ammonia applied during calibration. For each application timing, N rate, and method of injection each year, the ammonia flow rate was calibrated by ammonia weight difference in set-length calibration areas.

In 2007, the corn hybrid was Pioneer brand 34A18 (HXX, Herculex I corn borer and corn rootworm insect protection; LL, Liberty Link) and in 2008 and 2009 the hybrid was Dekalb brand DK61-69 (YieldGuard VT Triple corn borer and corn rootworm insect protection, and Roundup Ready). Each year the corn seed was planted no-till with a John Deere series 7100 mounted planter. The planter was equipped with a no-till coulter and trash whippers. The trash whippers were moved to the highest setting and soil was moved only with the CTKS application where the soil had been mounded by the closing disks. Planting dates were May 21, 2007 (7 days after spring preplant ammonia application), May 15, 2008 (15 days after spring preplant ammonia application), and May 5, 2009 (20 days after spring preplant ammonia application). The intended corn planting date was to be a minimum of 7 days after spring preplant ammonia application. Each year the corn was planted at least that many days after planting, with actual planting date dependent on rainfall and soil conditions conducive to planting. The seeding rate was approximately 29,000 (2007), 35,000 (2008) and 33,000 (2009) seeds/acre. The planting depth, checked prior to planting plots, was 2 in.

At the V2-V4 corn growth stage (June 8, 2007, June 16, 2008, and June 3, 2009) the corn plant stand was determined by counting all plants in a 40 ft. marked length in each of the center two rows. This was before the sidedress ammonia application. Approximately 14 days after the sidedress ammonia application (June 26, 2007, June 30, 2008, and June 18, 2009), corn plants (V4-V6 growth stage) were counted in the same row areas as before sidedress application. At approximately the same date as the plant stand count, plant height was determined by measuring from the soil surface to the tallest extended leaf tip in the plant whorl on 20 plants per plot.

At the V9-V14 corn growth stages (V11 - July 11, 2007; V14 - July 21, 2008; and V9 - July 1, 2009) the leaf N status was measured with a Minolta SPAD-502 meter (the uppermost leaf with the collar fully visible). On the same date, the plant canopy N status/vegetative biomass (NDVI, normalized difference vegetative index) was measured with a Holland Scientific Crop Circle ACS-210 optical, active light, canopy sensor. Corn grain yield was determined by harvesting the center two rows of each plot with a plot combine, with yields adjusted to 15.5% moisture.

Statistical analyses were conducted across years with PROC GLIMMIX (SAS Institute Inc., 2006), with treatments considered fixed and year and replicates random. The ANOVA sources of variation were modeled for a split-plot design with appropriate errors to test significance of the main and interaction terms. Treatment effects were considered significant at $p \leq 0.10$. Across-year least squares means (LSMEANS) were computed for each treatment. Individual-year data were reported in each crop year report and are not repeated here.

Results and Discussion

In two of the three years (2007 and 2008), repeated spring and early summer rainfall events (Figure 3) resulted in wet soils and water ponding in some of the study areas. This caused poor corn plant stand in one replicate each of those years. Therefore, only three replications were used in 2007 and 2008. Along with cold temperatures, the wet conditions and landscape/soil variation also resulted in uneven corn growth and production across the entire site in 2008. Throughout the growing season each year, corn plants did not show signs of moisture deficit stress and in no year were there dry conditions that adversely affected plant growth and production. Each year corn grain yields were high (190, 180, and 220 bu/acre with an adequate N rate in 2007, 2008, and 2009, respectively).

Soil conditions affected the operation of the HSLD system. If soil was moist at application (surface or below the surface within the operating depth), soil would build up on the depth control wheel and closing wheels. Application date was adjusted as much as possible to avoid these conditions (for example, delayed into mid-May in 2007). However, the continual wet conditions in the spring of 2008 necessitated application when soil below the surface was still very moist. Also, if the surface soil was loose (soft), the HSLD system would sometimes push soil on the surface, which also resulted in noticeable ammonia loss and potentially reduced the effective ammonia injection depth.

Certain soil and application conditions influenced ammonia loss during application with the HSLD system (visible condensed water vapor, white puffing). These conditions were not quantified in this study, but appeared to be related to the shallow ammonia injection point (4 in. depth), high ammonia-N rate, and more moist/plastic (firm) soil that did not fracture within the operating depth, that is, the HSLD opener "shoe/boot" sliced through the soil rather than fracturing soil. Ammonia losses appeared to be related to the size of the void created by the HSLD, the tendency for ammonia to move up the seam created by the disc-opener, dry soil at the injection depth, and a lower potential for ammonia to move downward and laterally in less fractured soil. Visible ammonia loss was not noted with all applications, but occurred some with fall, spring, and sidedress applications. Despite the doubling of ammonia rate per knife with sidedress application (due to injection between every other row), ammonia loss was not always observed with that timing. When ammonia loss was observed, the white puffing occurred at the point of release from the delivery tube before the closing wheels, with no loss visible after the closing wheels. Visible ammonia loss (with the highest N rates) occurred with the HSLD at the 2007 and 2008 sidedress application, and 2009 fall and spring preplant applications. At no application was there visible loss with the CTKS knife system.

In 2008 and 2009, there was visual seedling/root damage (root burn) and delayed emergence due to ammonia toxicity with the spring HSLD application at the highest three N rates (Figures 4-6 in 2009). The effect of this ammonia damage on reduced growth rate and plant development persisted throughout the growing season. There was no visible root damage with the CTKS application with any timing or N rate. However, in 2009 with the fall CTKS application at 200 lb N/acre there was a slight visible reduction in early plant growth, and in 2009 with the fall HSLD application at 200 lb N/acre there was also visual evidence of reduced early plant growth and root injury. That was not as severe as with the spring preplant application at that rate.

This visual seedling/root damage and delayed emergence with the HSLD system indicates negative effects from the shallow ammonia placement with the HSLD when ammonia is applied directly under the corn row. Conditions that would lead to this effect are a small vertical distance from the point of ammonia release to the seed (4 in. ammonia depth and 2 in. seed depth), dry soil, and higher N rates resulting in a greater ammonia concentration and more ammonia movement toward the soil surface. The apparent greater separation distance between the ammonia release point and the corn seed eliminated the potential for ammonia damage to corn seedlings/roots with the CTKS. Visual observation of excavated injection tracks also indicated a larger "void" and greater soil fracturing created at the point of ammonia release with the CTKS vs. the HSLD, thus a greater tendency for ammonia to move upward in the injection track with the HSLD.

Corn Plant Stand

Plant stands were good each year with good emergence, except as affected by the ammonia damage noted earlier. That damage is evident from the lower plant population with the highest two N rates (160 and 200 lb N/acre) for the HSLD opener with the spring preplant application (Table 2). That reduction in stand influenced the populations when averaged for method, N rate, and timing by method. In all other instances the populations were adequate for good corn production each year and would not be expected to result in any yield differences. Because the sidedress application had not yet been made when these stand counts were taken, any differences for that timing would indicate variation due to other factors at the site. The plant injury with the spring HSLD application at the highest N rates occurred in 2007 and 2009. Some corn rows had more obvious ammonia injury than others with those applications. It appears that if the corn row was offset a small distance from the ammonia injection track (the attempt was to plant all rows directly over the injection track, but may not have been exact for all rows in a plot), then damage from the HSLD was less severe (Figures 4 and 5). This indicates that lateral soil separation between the seed and ammonia band provides safety from ammonia damage.

Corn plant population was not affected by the sidedress ammonia application (Tables 3 and 4), and there was no effect from sidedress application with either the HSLD or CTKS systems. This means there was no coverage of plants from soil moved by the HSLD or CTKS during application or ammonia loss damage from the HSLD severe enough to damage plant growth. Any differences in plant population measured before sidedress application persisted to the stand count after sidedress application. For example, the lower plant population with the spring preplant HSLD application at the highest N rates. The plant population at this later stand count (after sidedress application) was still greater for the CTKS than the HSLD. The change in population before and after sidedress application was small, and the only difference was a slightly greater increase in population with lower N rates.

Corn Plant Height

Overall, applying N at any time or rate resulted in a similar and taller plant height than the zero N control (Table 5), except for the spring preplant HSLD applications where ammonia toxicity with the shallow-placed ammonia had negatively affected plant rooting. Corn plant height was considerably shorter with the spring preplant HSLD ammonia application with the 160 and 200 lb N/acre rates. These reduced plant heights influenced the main effects of method and N rate, and interactions of time, method, and rate. That is, the heights are shorter whenever the HSLD was a part of the main treatment means.

Planting corn seed directly along/over the anhydrous ammonia injection track provides the situation for the greatest chance of seed/seedling damage from free ammonia in the soil. This is what happened in two of the three years with the shallower ammonia placement with the HSLD opener, especially with higher N rates where the ammonia band would be larger and ammonia movement toward the soil surface greater. A solution to this potential problem is to offset the corn row from the injection track, with untreated soil between the seed and ammonia band buffering potential ammonia injury. Deeper ammonia placement, as with the CTKS injection, also helps provide soil separation.

Plant N Status

The N status of corn plants was measured with the Minolta SPAD-502 meter and the Holland Scientific Crop Circle ACS-210 canopy sensor (Tables 6 and 7). The SPAD meter readings were taken from just one leaf per plant, not the entire plant. Therefore, only the greenness of the leaf is reflected in the SPAD reading, and not the overall plant. Average SPAD meter readings increased with N rate, up to 120 – 160 lb N/acre, with that response similar for all applications (Table 6). The SPAD reading differences between time of application were quite small, with the fall CTKS 80 and 120 lb N/acre rates having a low SPAD reading which influenced the significant difference in means for time with the different application methods. The negative influence of the HSLD application at the highest N rates on plant growth did not affect the plant N status as measured with the SPAD meter. This indicates N being supplied to plants from those applications, but also does not reflect the effect of ammonia root damage on plant growth.

The Crop Circle canopy sensor provides a canopy NDVI value (Table 7), which incorporates plant biomass and N status. All treatment effects were significant. The NDVI results were quite similar to the plant height measurements (Table 5). The effect of ammonia damage on corn roots and plant growth rate were evident in the reduced canopy NDVI values with the spring preplant HSLD at 160 and 200 lb N/acre. That effect on plant growth is reflected in the biomass, and therefore NDVI values. At the 160 and 200 lb N/acre rates with the HSLD application, the NDVI values were approximately the same or lower as with the zero N rate. This indicates small corn plants, with low plant biomass and reduced leaf area index, and likely considerable soil background effect on the readings. Those NDVI values with the spring HSLD indicate a similar response as with earlier season plant height. The NDVI values were low with the fall CTKS at 80 and 120 lb N/acre (Table 7), as found with the SPAD readings. The reason for that is not known and was not seen in the plant height measurements. The NDVI values were not affected with other injection method-timings. The NDVI values increased with applied N, and to the same N rate as found with the SPAD readings.

Corn Grain Yield

Main differences in corn grain yield are influenced by the reduced yield with the HSLD spring preplant ammonia applications at 160 and 200 lb N/acre (especially at the 200 lb N/acre rate) and with the fall CTKS applications at 80 and 120 lb N/acre (Table 8). These yield responses are similar to the responses measured with the NDVI canopy sensing. That is, the differences between yields when comparing time by method, time by N rate, and method by N rate means are a result of those specific lower yields. Across years compared to the CTKS system, the HSLD had higher yield with fall application, lower yield with spring application, and no difference with sidedress application. Across N rates, the HSLD had a lower yield with the 160 and 200 lb N/acre rates compared to the CTKS, but the same yield with the lower rates of 80 and 120 lb N/acre.

With the spring HSLD applications, the reduced yield with the highest N rates can be explained by the ammonia seedling/root damage and delayed growth in two years (2007 and 2009). For the fall CTKS applications, the reason for the reduced yield is not clear, but comes from lower yield with those rates in 2008, a year with several large rainfall events during the growing season and extended flooding/standing water in part of the study area. The yields for those fall applications could be a reflection of variability in soil moisture and drainage (excessively wet soils) across the study site affecting plant growth or nitrate loss. The SPAD values for those N rates with the CTKS were also low, indicating reduced available N. When seedling ammonia damage did not occur, yields with the HSLD system were equivalent to the CTKS system, indicating the shallow ammonia placement can be a viable system for anhydrous ammonia application.

There was a positive yield response to N rate with both ammonia application methods and all application timings. The plant growth problem with the spring preplant HSLD caused the overall spring application timing yield with the HSLD to be lower than fall or sidedress.

The sites were N responsive each year of the study. Based on the individual yields for each timing/method/N rate, response was generally maximized at 160 lb N/acre. Fitting a regression model to the mean N rate yield response (yield across all application times and both application methods), the maximum response rate was 162 lb N/acre and the economic optimum N rate (at a 0.10 price ratio, $0.40/lb N ad $4.00/bu) was 133 lb N/acre. Using the mean of the 160 and 200 lb N/acre rates, and both application methods (except the HSLD for the spring timing), the fall application had 6% lower yield than spring preplant and sidedress applications, which had similar yield level. The lower yield with the fall application reflects the wet spring conditions in the years of this study.

Summary

The shallow placement of anhydrous ammonia with the newly developed HSLD opener system was achieved with fall, spring preplant and sidedress applications. However, with some applications, especially the 160 and 200 lb N/acre rates, there were visual observations of ammonia loss during application with the HSLD opener and corn plant stand loss, seedling/root injury, and delayed plant growth with spring preplant application. The seedling/root injury delayed plant growth and development throughout the growing season and resulted in reduced plant biomass and lower grain yield. The root injury and sustained effect on plant growth and yield was greatest at the highest two N rates. This injury did not occur with the CTKS knife injection system.

From study results across the three years, it appears that shallow (4 in.) placement of anhydrous ammonia with the HSLD opener system can provide a viable alternative to deeper knife injection (7 in.) with fall, spring preplant, and sidedress application, both in regard to retaining N in the soil and providing N supply to a corn crop. Specifically, when soil conditions are conducive for proper HSLD operation, ammonia is not lost from the soil during application, and shallow placement is not near corn seed/seedlings. However, in two of the three years corn seedling/root damage, plant stand reduction, reduced plant growth, and lower yield occurred with the HSLD system with spring preplant application when the ammonia injection tracks were placed in the same orientation/location as the corn rows.

During this study there were no problems related to ammonia loss at application, seedling/root injury, plant growth, or grain yield with the CTKS injection system. With the deeper ammonia placement, ammonia was better retained in the soil and farther away from planted seed and early seedling root growth, even with placement in the same orientation/location as the corn rows.

With use of the HSLD system for sidedress application, high N rates (greater than 120 lb N/acre) should be avoided due to potential ammonia loss during injection when openers are only

used between every other corn row (doubles the N rate per opener) rather than every row. This sidedress issue would be reduced with an opener between every corn row.

Consideration should be made to avoid high N application rates with the HSLD opener when preplant application might put injection tracks at future corn rows. Guidance and auto steer equipment used with anhydrous ammonia application could be utilized to place HSLD injection tracks between (away) from planted corn rows, and thus eliminate potential seedling injury.

Table 1. Routine soil tests (0-6 inch depth) from across each site, 2007-2009.

Year	pH	OM†	STP†	STK†
		%	- - - - - - ppm	- - - - - -
2007	6.6	4.3	30 (H)‡	177 (H)
2008	7.6	8.2	13 (L)	182 (H)
2009	6.7	4.4	16 (O)	178 (H)

† OM, organic matter; STP, Mehlich-3 soil test P; STK, Mehlich-3 soil test K.

‡ Letter in parenthesis indicates soil test interpretation class (Iowa State University Extension publication PM 1688, A General Guide for Crop Nutrient and Limestone Recommendations in Iowa): L, Low; O, Optimum; H, High.

Table 2. Effect of anhydrous ammonia timing, application method, and N rate on corn plant stand before sidedress N application, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD[†]	CTKS[†]	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre	plants/acre											
0	31844	32186	32015	31596	32315	31956	31596	32402	31999	31679	32301	31990
80	32217	32404	32310	32163	32054	32108	31988	31879	31934	32123	32112	32117
120	32622	31097	31859	31618	32467	32043	31683	32293	31988	31974	31953	31964
160	31719	32622	32171	30600	32555	31607	32511	31727	32119	31630	32301	31966
200	31906	31128	31517	29048	31487	30268	31683	32032	31858	30879	31549	31214
Method Mean	32062	31887		31017	32176		31892	32067		31657	32043	
Timing Mean			31975			31596			31980			

Statistical Analysis

Source	$p > F$
Time (T)	0.503
Method (M)	0.029
N Rate (R)	0.011
TxM	0.006
TxR	0.183
MxR	0.481
TxMxR	0.037

[†] HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 3. Effect of anhydrous ammonia timing, application method, and N rate on corn plant stand approximately two weeks after sidedress N application, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD[†]	CTKS[†]	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre	- -					plants/acre -						
0	32158	32532	32345	32508	32661	32584	31855	32573	32214	32174	32589	32381
80	32625	32656	32640	32378	32256	32367	32247	32138	32192	32416	32383	32400
120	32749	31536	32143	31833	32704	32268	32007	32160	32084	32197	32133	32165
160	31785	32718	32251	30831	32508	31670	32552	31855	32203	31722	32360	32041
200	31785	31318	31551	29132	31789	30461	31877	32247	32062	30931	31785	31358
Method Mean	32220	32152		31336	32404		32107	32195		31888	32250	
Timing Mean			32186			31870			32151			

Statistical Analysis

Source	$p > F$
Time (T)	0.537
Method (M)	0.029
N Rate (R)	<0.001
TxM	0.009
TxR	0.051
MxR	0.308
TxMxR	0.035

[†] HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 4. Effect of anhydrous ammonia timing, application method, and N rate on corn plant stand change from before and after sidedress N application (before minus after), 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD[†]	CTKS[†]	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre	plants/acre											
0	-304	-335	-320	-911	-345	-628	-257	-170	-214	-491	-283	-387
80	-397	-242	-320	-214	-301	-258	-257	-257	-257	-290	-267	-278
120	-117	-428	-273	-214	-236	-225	-323	135	-94	-218	-177	-197
160	-55	-86	-70	-170	47	-61	-39	-127	-83	-88	-55	-71
200	132	-179	-23	-83	-301	-192	-192	-214	-203	-48	-231	-140
Method Mean	-148	-254		-318	-227		-214	-127		-227	-203	
Timing Mean			-201			-272			-170			

<u>Statistical Analysis</u>

<u>Source</u>	$p > F$
Time (T)	0.589
Method (M)	0.684
N Rate (R)	0.010
TxM	0.347
TxR	0.405
MxR	0.362
TxMxR	0.283

[†] HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 5. Effect of anhydrous ammonia timing, application method, and N rate on corn plant height approximately two weeks after sidedress N application, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD†	CTKS†	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - - cm	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -	- - - - - -
0	75	71	73	73	72	73	77	76	77	75	73	74
80	76	75	76	77	79	78	77	79	78	77	78	77
120	73	74	73	74	81	78	77	79	78	75	78	76
160	76	73	74	64	81	73	79	79	79	73	78	75
200	71	73	72	54	79	67	79	81	80	68	78	73
Method Mean	74	73		68	79		78	79				
Timing Mean			74			73			78	74	77	

Statistical Analysis

Source	$p > F$
Time (T)	0.467
Method (M)	0.001
N Rate (R)	0.087
TxM	<0.001
TxR	0.026
MxR	0.009
TxMxR	0.019

† HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 6. Effect of anhydrous ammonia timing, application method, and N rate on the corn mid-vegetative growth stage leaf SPAD reading, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD[†]	CTKS[†]	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre												
0	45	45	45	44	46	45	45	44	44	45	45	45
80	52	49	50	52	54	53	52	53	53	52	52	52
120	53	51	52	53	54	54	53	53	53	53	53	53
160	54	53	54	55	55	55	54	54	54	54	54	54
200	54	54	54	54	55	54	54	54	54	54	54	54
Method Mean	52	50		52	53		52	52		52	52	
Timing Mean			51			52			52			

Source	Statistical Analysis
	p > F
Time (T)	0.046
Method (M)	0.860
N Rate (R)	<0.001
TxM	<0.001
TxR	0.044
MxR	0.794
TxMxR	0.656

[†] HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 7. Effect of anhydrous ammonia timing, application method, and N rate on the corn mid-vegetative growth stage plant canopy active sensor NDVI reading, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD†	CTKS†	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre												
0	0.687	0.687	0.687	0.671	0.682	0.676	0.677	0.676	0.676	0.678	0.681	0.680
80	0.726	0.712	0.719	0.720	0.724	0.722	0.723	0.728	0.726	0.723	0.721	0.722
120	0.728	0.713	0.720	0.715	0.729	0.722	0.728	0.731	0.730	0.723	0.724	0.724
160	0.731	0.728	0.729	0.690	0.737	0.713	0.723	0.732	0.727	0.714	0.732	0.723
200	0.723	0.728	0.726	0.643	0.734	0.688	0.730	0.732	0.731	0.699	0.731	0.715
Method Mean	0.719	0.714		0.688	0.721		0.716	0.720				
Timing Mean			0.716			0.704			0.718	0.708	0.718	

Statistical Analysis

Source	$p > F$
Time (T)	0.009
Method (M)	<0.001
N Rate (R)	<0.001
TxM	<0.001
TxR	0.001
MxR	<0.001
TxMxR	0.001

† HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Table 8. Effect of anhydrous ammonia timing, application method, and N rate on corn grain yield, 2007-2009.

	Fall			Spring Preplant			Sidedress			Method Mean		N Rate
N Rate	HSLD[†]	CTKS[†]	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean	HSLD	CTKS	Mean
lb N/acre	bu/acre											
0	135	130	132	119	137	128	123	122	122	126	130	128
80	179	158	168	172	181	176	180	183	181	177	174	175
120	184	169	176	177	189	183	188	192	190	183	183	183
160	189	180	185	178	202	190	194	197	195	187	193	190
200	185	188	186	155	193	174	196	198	197	178	193	186
Method Mean	174	165		160	180		176	178		170	174	
Timing Mean			170			170			177			

Statistical Analysis

Source	$p > F$
Time (T)	0.174
Method (M)	0.023
N Rate (R)	<0.001
TxM	<0.001
TxR	<0.001
MxR	0.040
TxMxR	0.516

[†] HSLD, high speed low draft opener system; CTKS, conventional till knife injection system.

Figure 1. The high speed low draft opener system (HSLD).

Figure 2. The conventional till knife injection system with covering disks (CTKS).

Figure 3. Temperature and rainfall at the nearby weather station, 2007-2009.

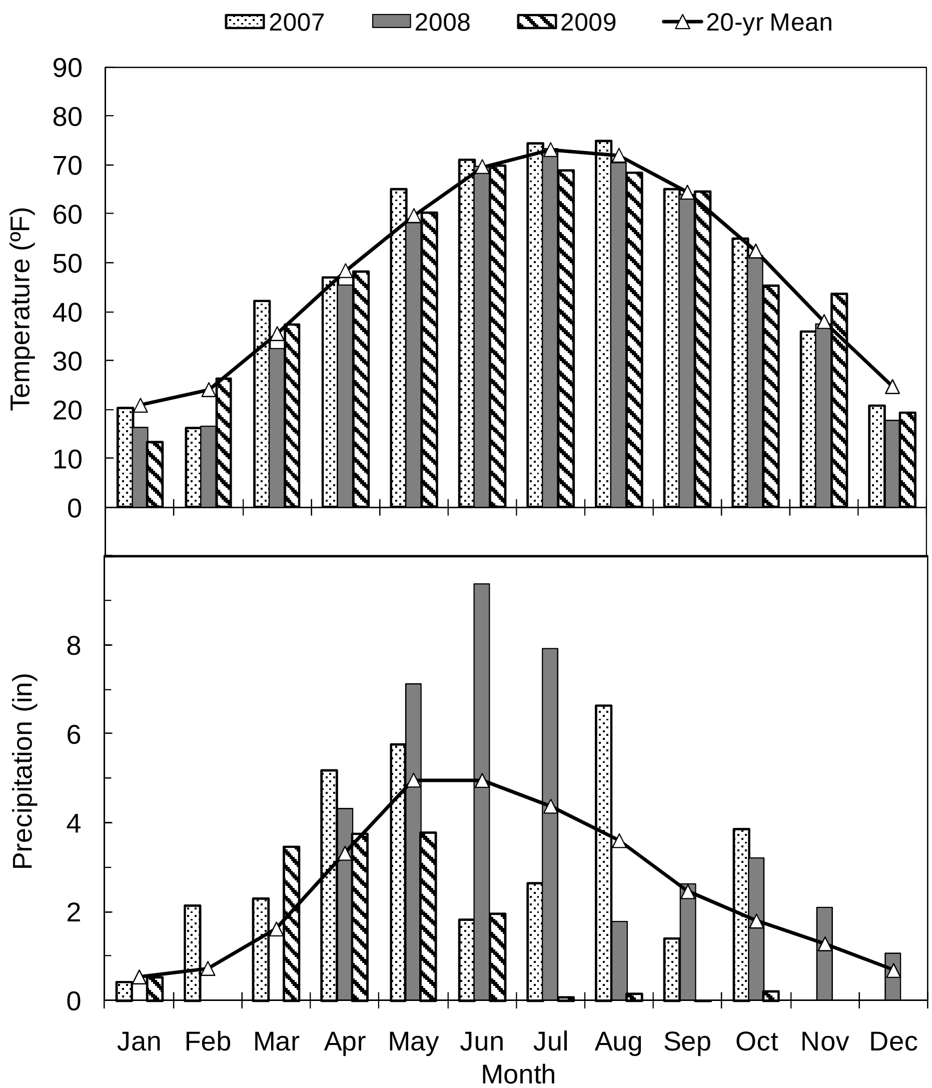

Figure 4. Reduced corn plant growth from spring preplant HSLD ammonia application at 120, 160, and 200 lb N/acre with ammonia placement under each corn row (May 29, 2009).

120 lb N/acre

160 lb N/acre

200 lb N/acre

Figure 5. Reduced corn plant growth from spring preplant HSLD ammonia application at 120 and 200 lb N/acre with ammonia placement under each corn row (June 26, 2009).

120 lb N/acre

200 lb N/acre

Figure 6. Early season corn seedling root damage (brown/dead radical and unusual root proliferation at the mesocotyl) from spring preplant HSLD ammonia application, 2009.