FINAL REPORT –
R2008-03
(B12514)
RECEIVED
MAR 25 2011
BY: RMD

Minimizing Nitrate Loss to Drainage by Optimizing N Rate and Timing for a C-C-S Rotation

R2008-03 (2010 Report and 2007-2010 Summary)

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Introduction

From the mid-80's until the early 2000's, 97% of the tillable acres in south-central Minnesota were planted to approximately a 50:50 corn-soybean rotation. Within the last few years many growers have converted some of their acreage to a corn-corn-soybean (C-C-S) rotation to meet the growing demand for corn from the ethanol industry as well as for livestock and export markets. With this "new" C-C-S rotation, knowledge gaps in yield responses, nitrate losses, and profitability exist compared to the "older" C-S rotation. Moreover, transgenic hybrids possessing pest protection traits now occupy a majority of the corn acreage. Will these transgenic hybrids require different amounts of N, resulting in different production and environmental characteristics compared to non-transgenic hybrids? The overall purpose of this study is to determine the effects of N management in a C-C-S rotation on nitrate concentration and losses in tile drainage water, corn yield, N use efficiency, remote sensing signals, and profitability.

This report contains information from the third and final year and the multi-year (2008-2010) summary of this AFREC funded project as well as the 2007-2010 summary including funding from the Minnesota Corn Growers Association.

Experimental Procedures

Thirty-six individual tile line plots were installed on a poorly drained Canisteo clay loam soil at the Southern Research and Outreach Center in 1976. Each 20' x 30' plot is completely surrounded by plastic sheeting to a depth of 6 feet to prevent lateral flow and contains a 4-foot deep tile line 5 feet from one end. This design simulates a 50-foot drain spacing. Drainage from the 36 plots flows to six sumps where flow volumes are measured and water samples are collected. This site has been used for various N management research objectives with the last study concluding in 2003.

Twenty-eight treatments were established in 2005 and 2006 to set the C-C-S crop rotation up for full-scale measurement in 2007 and beyond. The treatments consist of three crops each year (soybean, first year corn after soybean, and second year corn after soybean; a Sb-C-C rotation) and 9 N management treatments for each crop, totaling 27 treatments. Continuous corn is the 28th treatment. Each treatment is replicated three times for a total of 84 plots. Ten of the treatments are located directly on 30 tile drainage plots. The other 18 treatments are located between and adjacent to the 30 drainage plots. These plots also measure 20 feet wide (8 rows) by 30 feet long and are located within 25' of tile lines used to drain the border areas around the 36 tile drainage plots. Thus, all plots have adequate drainage with 30 plots designed to collect tile drainage for this study and 54 plots designed to not collect drainage water.

A listing of all agronomic procedures connected with the C-C-S portion of the study is found in Table 1. Stover yields were determined by selecting and harvesting 6 plants that represented the average plant growth for each plot and determining the harvest index (ratio of grain yield to remaining stover yield). The combine-harvested grain yield was then multiplied by the harvest index to get the actual stover yield per acre. All grain yields were harvested with a plot combine with a weigh cell and grain moisture system. Grain N (protein), oil, and starch content were determined by NIR analyses. Tile flow for each plot was determined using an instrumented system where drainage water from each plot flows into a dedicated separate sump, and is then emptied via a sump pump when the water level exceeds a preset level. Flow from each pump goes through a flow meter where the flow volume is recorded with a data logger. Cumulative drainage for any specific period of time was calculated by summarizing the discharge volume from each plot and dividing by the plot area. Flow-weighted (FW) water samples were collected in plastic bottles connected by a small diameter tube to each sump pump outlet such that a proportional sample was collected each time water was pumped. The bottles were kept in an ice chest, containing ice, located in each collection culvert. Sub samples of water were taken periodically from the larger bottles, placed in plastic vials, and frozen until delivery to the University of Minnesota Research Analytical Laboratory where they were thawed and analyzed for nitrate-N concentration. Total NO_3-N lost was calculated by multiplying the NO_3-N concentration for each sample by the total calculated flow for the same period. Flow-weighted average NO_3-N concentrations were calculated by dividing total NO_3-N lost for the period of interest by total flow volume. Eighty two water samples from six drainage plots (two plots from each crop in the C-C-S rotation) were collected periodically from March 23 through June 28 and analyzed for ortho-phosphate and total P by the UM Research Analytical Lab.

Results and Discussion

Weather

Weather data characterizing the period during which the experiment was conducted are presented in Table 2. The soil froze on December 7 and remained frozen until March 10 when soil in the top 4" thawed. Precipitation for May-September, totaling 34.61", set a 96-yr record at Waseca. This was 14.19" above normal, resulting in abundant tile drainage. Rainfall in April and May was almost 2.5" below normal, but June more than made up for it with a record-setting amount of 9.64" --- 5.42" above normal. Measurable precipitation occurred on 19 days with the greatest 10-day rainfall totaling 5.75" from June 11-20. Coupled with 6.61" in July, the June & July total also set a 96-yr record. After a dry August, September rainfall of 12.66" (9.47" above normal) broke another 96-yr record. These record setting rainfall amounts created saturated soils, making N management for corn a challenge due to significant denitrification and leaching. Available soil water (ASW) in the 0-5' profile was measured bi-weekly 12 times from mid-April to early October. The ASW was >90% of field moist capacity on 10 of 12 dates and >95% on 5 of 12 times during the season, which is highly unusual. Air temperatures were above normal for much of the season, especially in April and August. Growing degree units form the May-September season were almost 6% above normal.

Soil Nitrate-N

Preplant NO_3-N in the 0-2' layer on April 30 was greater for first-year corn (36 lb/A) compared to second-year corn (18 lb/A) for the 0-lb control and 28 lb/A for the previous 120-lb N treatment (Table 1). Similar results were found in the 0-1' layer on June 10 for the zero-N control plots (Table 3). Nitrate-N concentrations generally increased linearly with increasing fertilizer N rate for both first-year and second-year corn; although NO_3-N for first-yr corn was much more inconsistent. Similar to last year NO_3-N concentrations for first-yr corn were not different between the 60-and 90-lb N rates or between the 120-, and 150-, and 180-lb N rates. Nitrate-N concentations for second-year corn were not different between the 120- and 160-lb N rates.

First-Year Corn

Grain, stover, and total dry matter (DM) yields were increased significantly by fertilizer N (Table 4). The Economic Optimum N Rate (EONR) using the quadratic-plateau model and a 1:10 fertilizer N price: corn grain price for all of the preplant N rates was 179 lb N/A at a yield level of 200 bu/A for this data set because yields for the highest N rate (180 lb N/A) were 11 bu/A greater than those with the 150-lb rate. Fifty three percent of the crop yield was supplied by soil N. This was substantially less than the long-term average of about 70% for first-yr corn following soybeans. Based on the U of M data set from 1990-2009, the MRTN (maximum return to N), calculated by the Corn N Rate Calculator on the Iowa State website, would be 114 lb N/A and the optimum profitability would range from 104-127 lb N/A with N at $0.40/lb and corn at $5.00/bushel. Obviously, the yield data in this study did not fit the model predicted from our long-term data set. Moreover, the sidedress and split-applied N treatments showed considerably inconsistency. When the 90-lb N rate was used, a significant 11.4 bu/A response to N sidedressed at the V3 stage was found. However, when using the 120-lb N rate, yields were not significantly different between preplant and V3-applied N. The split-applied treatment (60 lb at preplant and 40 lb at V3) did not produce grain yields greater than the 90-lb preplant treatment. These results are considerably different than in 2009 when grain yields were greater for sidedressed N. In 2010, the V3-N was applied on June 3 --- just before the record-setting June rainfall, which led to similar levels of denitrification and leaching of the preplant urea and sidedress-applied UAN. Simply said, there was no yield advantage to sidedress or split-applied N in 2010 unless the lesser and insufficient rate (90 lb/A) was used. Grain moisture and plant population were not affected by the N treatments.

Nitrogen concentration in the grain and uptake in the grain and total dry matter also exhibited similar characteristics (Table 5). The advantage for the 90-lb V3 treatment was consistently seen for grain and total DM uptake on N and for apparent N recovery in the total DM and grain. However, there was no affect of time of N application on grain N and stover N concentration. Rate of N application affected both grain and stover N concentration, but the range for grain N was small (1.03% for the 0-lb control and only 1.19% for the 180-lb rate).

NDVI measurements at the V8-V9 growth stage showed a highly significant difference ($P<0.01$) among the treatments when using the Crop Circle and GreenSeeker instruments (Table 6). Both instruments clearly separated the zero-N control treatment from the other treatments. However, when using the Crop Circle at V9, there were no NDVI differences between preplant and sidedress application and among the 60, 90, and 120-lb preplant N rates. Highest NDVI was obtained with the 150 and 180-lb N rates. When using the GreenSeeker at V8, sidedress-applied UAN resulted in smaller NDVI values than for preplant N, but there was no significant difference in NDVI among the 60, 90, 120, 150, and 180-lb preplant N rates. Somewhat similar results were found at the V10 stage.

Relative leaf chlorophyll (RLC) measured at the R1 stage related quite well with grain yield for all of the preplant treatments (Table 7). RLC for the 90-lb sidedress treatment was significantly greater than for the similar N rate applied preplant, which is similar to 2009. Agronomic nitrogen use efficiency (NUE) in terms of bushels produced per pound of fertilizer N was much greater for the 90-lb sidedress treatment than for all other rates of application. When using the 120-lb N rate, there was no difference in NUE between the preplant and sidedress treatments.

When summarizing the 2010 N response data for first-year corn, one needs to first consider the amount and timing of rainfall. The fact that rainfall for the June & July period set a 96-year record and that the sidedress N had been applied prior to this wet period probably explains both (1) the general lack of an advantage for sidedressing or split-applying N in this year (except at the lower 90-lb N rate) and (2) the grain yield response up through the 180-lb N rate.

Second-Year Corn

Grain, stover, and total DM yields were increased significantly by fertilizer N (Table 8). The EONR using a quadratic-plateau model and a 1:10 fertilizer price to corn grain price ratio for all of the preplant rates was 317 lb N/A at a yield of 196 bu/A. The EONR was considerably more than the 153-lb MRTN and 145 to 162-lb optimum profitability range suggested by the Corn N Rate Calculator based on previous data for second-year corn when N is $0.40/lb and corn is $5.00/bushel. We suspect that the high amount of rainfall in June and July (16.25") had a substantial effect on both the N rate response curve and the similarity of yield for preplant and sidedress N. Based on these data, 32% of the crop yield was supplied by soil N compared to 53% for first-year corn. The highest yield (182.8 bu/A) was obtained with the preplant 240-lb N rate. Similar to first-year corn, highest yields tended to occur at the highest N rates. A notable difference between first and second-yr corn was the advantage for split application for second-year corn, where the yield for the 140-lb N split-applied (169.7 bu/A) was significantly greater than the 158.0 bu/A yield for 160 lb preplant applied N. Grain moisture content was affected by N rate and time of N application with moisture being greatest for the zero-N treatment, and all treatments receiving sidedress N. Plant population was not affected by N rate or time of application.

Grain and stover N concentrations were minimally affected by N rate and were not affected by time of N application (Table 9). In an experiment where the N rates range from 0 to 240 lb N/A, this is very unusual. Grain N uptake was greatest for the 240-lb N rate followed closely by the 200-lb preplant and 140-lb split treatments. Stover N uptake was greatest for the V3 sidedress treatments and the 240-lb preplant treatment. Nitrogen uptake in the total plant DM was greatest for the 240-lb preplant rate but was also increased markedly by the two sidedress treatments and the split N treatment. Apparent N recovery (ANR), sometimes called "Recovery Efficiency", in the total DM was substantially greater for the treatments receiving sidedress N. The ANR's were 51, 49, and 49% respectively, compared to 41% as the highest for all other treatments. In the grain, only the split-applied 140-lb rate increased ANR markedly.

NDVI measurements at the V8-V9 growth stages showed a significant difference between the zero-N control treatment and all the N rate treatments (Table 10). There was no significant NDVI difference among the 140, 160, 200, and 240-lb preplant N rates for the Crop Circle and the 120, 140, 160, 200, and 240-lb preplant N rates for the GreenSeeker at the V8 and V10 stages. Plants that received all their N at the V3 stage were still smaller and showed less biomass (NDVI) than plants receiving preplant N. However, the split N treatment, which received 60 lb N/A preplant, did not show decreased growth compared to the 100% sidedress N treatments. The Crop Circle provided slightly less variable NDVI measurements as shown by the LSDs and CVs. However, in contrast to 2009, the NDVI measurements provided information that would have been helpful when making in-season N rate decisions for corn after corn.

Relative leaf chlorophyll (RLC) at the R1 stage related very well to the grain yields from the preplant treatments found in Table 11. Sidedress-applied N at V3 resulted in significantly greater RLC values compared to similar preplant N rates even though the yields were not different. NUE was very high (0.80 bushels of corn per pound of fertilizer N) for the 140-lb split treatment. Treatments receiving only sidedress N had NUE values ≤ 0.88 bu/lb fertilizer N; whereas, NUEs for the preplant treatments ranged from 0.60 for the 120-lb treatment to 0.52 for the 240-lb treatment. Grain oil and starch content were not meaningfully affected by the N treatments.

First- and Second-Year Corn

Late-season basal stalk nitrate samples were not taken in 2010 due to the 12.66" of rain occurring in 14 daily events during September. Not only did the rain hamper timely collection of samples in the 3-week period after physiological maturity, we were also concerned that the rainfall may have significantly altered the NO_3-N concentration in the stalks.

Soil samples to determine the residual soil nitrate (RSN) in the 0-4' profile after harvest were not taken because of the wet conditions in September that likely compromised finding any potential residual nitrate associated with the treatments.

Economic return to fertilizer N shown in Table 12 indicates that the return for first-yr corn was optimized with the 120 to 180-lb preplant N treatments, regardless of the fertilizer N: corn price ratio. A single sidedress application at V3 produced slightly less economic return. The split application treatment used in this study (60 lb preplant + 40 lb at V3) yielded less economic return than any treatment except the 60-lb preplant rate. For second-yr corn, economic return was greatest for the 240-lb preplant N rate and the split-applied 140-lb rate, regardless of fertilizer N: corn price. Furthermore, there was very little difference in economic return between preplant and V3 sidedressed N. Under the high rainfall induced N stress in 2010, these data show that a high N rate was more beneficial to increasing economic return than was application timing (split or sidedress). The economic return to fertilizer N was generally greater for second-year corn because of the greater Δ yield.

Soybeans

Soybean yields were variable, ranging from 50.6 to 55.6 bu/A, but were not significantly affected by the fertilizer N rates applied for corn in the two previous years (Table 13). Nitrogen content in the seed was not affected by the N treatments. Nitrogen removal in the seed yields ranged from 136 to 149 lb N/A, but was not significantly related to the fertilizer N treatments. Note that these N removal rates in the harvested soybean seed are somewhat greater than N removal in the corn grain for first-year corn (about 135 lb N/A) and second-year corn (about 125 lb N/A) for the highest yielding treatments.

Drainage

Tile flow data for the entire 2010 season are shown in Table 14. Drainage started on March 11 and ended on October 10. Drainage averaging 6.1 inches, which occurred in March and early April, was primarily due to a thick covering of snow that contained about 4.5" of water. The snow began to melt and infiltrate the unfrozen soil a few days before the tiles began to flow. Even though snow melt was continuous and rather rapid due to the continuous warm temperatures, very little surface runoff occurred on this nearly level site. However, since the depth of snow pack was not uniform due to wind-caused drifts, there was more plot-to-plot variability than occurred after April. Fortunately, tile drainage did not occur from April 15 until May 14, during which the preplant N treatments were applied (April 30). This allowed us to consider all March and April drainage as pre-N application and all drainage occurring after May 14 as post-N application. Tile drainage for the May-October season totaled 14.8" across the 27 plots with 9.6" (65%) occurring in September and 4.4" (30%) occurring in June. Slightly more drainage occurred from the second-yr corn (15.9") and soybean (15.0") plots than from the first-yr corn (13.6") plots. Drainage among the three N treatments within each cropping system varied by <3". Thus, drainage variability within the three cropping systems and among the three N treatments within each cropping system is considered to be minimal and excellent for determining the effects of N treatments and cropping system on nitrate losses. However, the temporal distribution of drainage in 2010 was much different compared to a 15-yr historic record at Waseca that showed 71% of our annual drainage occurring from April 1 – June 30. In 2010, only about 4.8" of drainage occurred during this 3-month period, which was 23% of the 2010 drainage total. Furthermore, 65% of the post-N application drainage occurred after the corn reached physiological maturity.

Nitrate-N Concentrations in Drainage

Flow-weighted NO_3-N concentrations for each N treatment within each crop are shown in Table 15 for each month and across the 2010 drainage season. Nitrate-N concentrations for 2010 will be separated into the pre-N application period, which reflects the contribution of the 2009 crop and N treatment, and the post-N application period, which reflects the 2010 N treatments for each of the crops. Pre-N application nitrate-N levels were greatest when soybean was the 2009 crop with average flow-weighted (FW) concentrations ranging from 4.9 mg/L for the zero-N control plots for 4 years to 9.4 mg/L for the 60 lb preplant + 40 lb V3 split treatment. Markedly lower nitrate-N concentrations were found when the 2009 crops were first-yr corn and second-yr corn with no difference between the two corn crops. These data highlight the significant contribution of a previous crop of soybeans on nitrate losses, especially in early-season tile drainage. It should be noted that 7" of rain occurred in October, 2009 and 65% of the 2009 drainage occurred that month. This rather unusual set of circumstances (wet October 2009 and substantial snowmelt in March of 2010) likely contributed to low nitrate-N concentrations in the pre-N application drainage and the very small differences in nitrate-N concentrations between the zero-N and N treatments.

In the post-N application period, nitrate-N concentrations increased about 1 mg/L in May and another 2 to 3 mg/L in June and July for the 100- and 120-lb rates for first-yr corn and 140- and 160-lb rates for second-yr corn. Interestingly, the nitrate-N concentrations were consistently greater for the split treatment than for the preplant treatment in both crops. Nitrate-N concentrations increased slightly for the zero-N control in first-yr corn (probably a result of hysteresis from the previous soybean crop) but not for the second-yr corn. Nitrate-N concentrations from soybeans remained consistently lower throughout the whole 2010 drainage season except for slightly elevated levels in May-July where N had been applied in 2008 and 2009. High amounts of drainage in September resulted in significantly lower nitrate-N concentrations in all three N rates for the two corn crops. For the entire post-N application drainage season, nitrate-N concentrations averaged ≤ 3.6 mg/L for the zero-N treatment in the three crops. Concentration ranged between 5.1 and 7.6 mg/L for the two fertilizer N treatments with no consistent advantage for the 100- and 140-lb split-N rates compared to the 120- and 160-lb preplant rates. Nitrate-N concentrations were consistently less for all three treatments for second-yr corn than for first-yr corn. For the entire drainage year (March-October), nitrate concentrations for the two fertilizer N treatments were greatest for first-yr corn (soybean in 2009), intermediate for second-yr corn (first-yr corn in 2009), and least for soybean (second-yr corn in 2009).

Nitrate-N Losses in Drainage

Nitrate-N losses from each of the crops as influenced by N rate are found in Table 16. Losses of nitrate in the pre-N application period were about two times greater for first-yr corn due to soybeans in the previous year compared to second-yr corn and soybeans in 2010. Beginning in June, nitrate losses were twice as high for the two N treatments compared to the zero-N control in both first- and second-yr corn with no consistent difference between the split-applied N rate and the preplant N rate. For the May-October post-N application period, nitrate-N losses ranged from 9 to 11 lb/A for the zero-N control plots in all three crops. When the two fertilizer N rates were applied to first- and second-yr corn, nitrate-N losses averaged 21 lb/A for both crops with no consistent difference between the preplant and split-applied treatments. Residual effects of the two fertilizer N treatments were seen in the soybeans in 2010 with losses ranging from 13.4 for the split-applied treatment to 17.5 lb/A for the preplant treatment. For the post-N application period, nitrate-N losses averaged across the three N rates averaged 17.9, 16.8, and 14.0 lb/A for first-yr corn, second-yr corn, and soybean, respectively. When averaged across the three crops, nitrate-N losses averaged 10.6, 18.2 and 20.0 lb/A for the zero-N control, split N, and preplant N treatments, respectively. For the total 2010 drainage period (the 4^{th} consecutive year of this suite of N treatments), nitrate-N losses averaged across the three N treatments averaged 28.7, 23.7, and 18.9 lb N/A for first-yr corn, second-yr corn, and soybean, respectively. When averaged across the three crops, nitrate-N losses averaged 15.7, 26.0 and 29.5 lb/A for the zero-N control, split N, and preplant N treatments, respectively.

Ortho- and Total Phosphate Concentrations in Drainage

Periodic water samples were collected from six drainage plots in March - June to determine the concentrations of ortho-phosphate (OP) and total phosphate (TP) in the drainage water. The average OP and TP concentrations shown in Table 17 indicate very low, but detectable levels of OP and somewhat greater levels of TP in all 82 samples. Neither crop nor N rate affected the concentration of OP or TP. No "high-concentration" spikes were found.

2010 Summary

A study was continued at the University of Minnesota Southern Research and Outreach Center in 2010 to determine the effects of nitrogen (N) rate and timing in a corn-corn-soybean rotation on corn yield, N use efficiency (NUE), profitability, and nitrate concentrations and losses in tile drainage water. Record-breaking precipitation in the growing season (34.61"), especially in June (9.64") and the June + July period (16.25"), exerted a huge influence on corn production. Corn grain yields were quite high, but an extraordinary N rate was required to achieve the high yields. Yields for the highest N rates applied were 12-14 bu/A greater than for the second highest N rates. In short, the yields did not fit a normal N response curve for either first-yr or second-yr corn as evidenced by EONRs of 179 and 317 lb N/A, respectively. Yield response to split and single sidedress (V3) N application compared to preplant application relative to cropping system was most revealing. Yields of first-year corn were decreased by the split-N treatment, increased by the 90-lb V3 application, and not changed by the 120-lb V3 rate. On the other hand, second-yr yields were significantly increased by the split-N treatment but were not affected by the V3 sidedress applications. Grain and stover N concentrations were uncharacteristically low for both cropping systems. Apparent N recovery and NUE were greatest for the 90-lb V3 application for first-yr corn and for the 60 + 80 lb split application for second-yr corn. Economic return was greatest for the 180-lb and 240-lb preplant N rates for first- and second-yr corn, respectively. Tile drainage was substantial, totaling 6.1" prior to N application (April 30) and 14.8" after N application. Temporal distribution differed considerably from normal (71% of annual drainage occurs in April-June) when 65% occurred in September (after physiologic maturity) and 30% in June. Nitrate-N concentrations were greatest in the pre-N application tile water when soybean was the crop in 2009, especially from the plots that received N in 2007 and 2008. Nitrate-N concentrations rose about 3-4 mg/L by July, reflecting

the effect of the April 30 preplant treatments. Concentrations of nitrate-N in July were consistently greater for the split-N treatment in both 1st and 2nd-yr corn. Flow-weighted nitrate-N concentrations during the post-N application period averaged from 2.9 to 3.6 mg/L for the zero-N treatments in all three crops; 5.1 to 7.6 mg/L for the split-N treatment (85% N rate) for both corn crops; and 5.7 to 6.3 mg/L for the preplant (100%) N rate for both corn crops. With soybeans, nitrate-N concentrations ranged from 3.9 to 4.9 mg/L when N was applied in 2008 and 2009. Losses of nitrate in the post-N application period for the two fertilizer N treatments were 85% greater than for the zero-N control for first-yr corn, 127% greater for second-yr corn, and 38% greater for the residual N when soybean was grown. Nitrate-N losses were slightly less (2 lb/A) for split-applied N than for preplant N. Detectable concentrations of OP and TP were found in all 82 samples, but the concentrations were very low (OP = 0.01 mg/L and TP = 0.07 mg/L) and did not vary with N rate or crop grown.

Future

This 4-year study was terminated at the end of 2010.

Three-Year (2008-10) Results

First-Year Corn

Three-yr average corn grain yields shown Table 18 indicate an 80 bu/A response to N. The highest yields were obtained with the 120-lb to 180-lb N rate (no statistical difference between the three N rates). Fifty-nine percent of the crop yield was supplied by soil N, considerably below the long-term average. A significant Yr x N treatment interaction (alpha = 0.05) occurred for grain yield but not for total DM. The 7.2 bu/A difference between the 100-lb (split N rate and the 120-lb (preplant) rate was not statistically significant. Also, a 7.0 bu/A advantage for the two single V3 sidedress treatments was also not significant at the alpha level of 0.05. Stover N concentration was greatly different among N rates with evidence of luxury consumption for the 150- and 180-lb N rates. However, time of N application did not affect stover N. Grain N concentration was also highly influenced by N rate but was not influenced by time of application. A significant interaction between year and N treatment occurred for grain N.

Three-yr average N uptake into the grain, stover and total DM was highly influenced by N rate (Table 19). The significant Yr x N treatment interaction for N uptake in grain and total DM indicates the N response varied among years. Sidedressing N at the V3 stage significantly increased grain N uptake compared to preplant N when similar N rates were compared. Apparent N recovery in the total DM and grain were slightly greater for the single sidedress application compared to preplant application. NUE, expressed in bu/lb of fertilizer N, was also greater for the single sidedress and split-applied treatments than for the comparable preplant treatments.

Although the Crop Circle and GreenSeeker instruments showed a significant NDVI response to fertilizer N, there was no significant difference between the 60-lb and 180-lb N rates (Table 20). These data indicate that NDVI measurements made on first-yr corn at the V8 and V9 stages did not provide useful information to assist growers in making decisions on an appropriate in-season N application rate. Plant growth at V8-V9 as indicated by the NDVI measurements was significantly smaller for the 90-and 120-lb V3 sidedress treatments than for the 60-lb preplant treatment. Relative leaf chlorophyll (RLC) content was greatly affected by N treatment and tracked fairly well with the N rates, but did vary among years. The RLC at R1 was also significantly greater for the V3 sidedress treatments (96.1%) compared to the similar preplant N rates (93.0%). Again, there was no difference in NDVI or RLC between the 100-lb split N rate and the 120-lb preplant N rate.

Second-Year Corn

Three-yr average corn yields were increased almost 120 bu/A over the zero-N control by the 240-lb N rate, which statistically was the highest yielding preplant treatment (Table 21). The single V3 sidedress 160-lb treatment yielded statistically similar to the 240-lb preplant treatment. A significant Yr x N treatment interaction occurred for both grain and total DM yield, indicating that the response curves were different among the three years. Across the 3-yr, 34% of the grain yield was supplied by soil N, which is well below the long-term average. Grain and stover yields were not different between the preplant 160-lb rate and the split 140-lb N rate. Total DM for the two V3 sidedress treatments was significantly greater (0.42 T/A) than for the comparable preplant rates, but this was not true for grain yield. Unlike first-yr corn, grain H_2O was significantly reduced about 5 percentage points by all of the preplant rates compared to the zero-N control. Delaying application of all N to the V3 stage resulted in grain H_2O content being 2.3 points wetter than the comparable preplant N rates. Grain and stover N concentrations were increased substantially by the higher N rates indicating some luxury consumption in the stover with the 240-lb N rate. Stover N concentration for the 160-lb preplant rate was greater than for the 140-lb split N rate. Grain N was not significantly different between the 200- and 240-lb N rates.

Nitrogen uptake averaged across the 3-yrs was substantially increased by the greater N rates for grain, stover, and total DM (Table 22).Uptake for the 240-lb rate was statistically greater than all other rates. Similar to yields, a significant Yr x N treatment interaction was found for grain, stover and total DM. Nitrogen uptake in the total DM was 7.2 lb/A greater for the two V3 sidedress treatments compared to the similar preplant rates. Highest ANR for total DM and grain and the highest NUE tended to occur with the V3 sidedress and split N treatments, when excluding the low 80-lb rate.

Similar to first-yr corn, NDVIs taken with the Crop Circle and GreenSeeker instruments were significantly greater for all N treatments compared to the zero-N control (Table 23). However, NDVI was not different among the 80- to 240-lb preplant N rates when using the GreenSeeker at V8 or among the 120- to 240-lb preplant N rates when using the Crop Circle at V9. These data indicate that NDVI measurements made on second-yr corn did not provide useful information to assist in arriving at a "correct" in-season application rate. Plant growth at V8-V9 as indicated by the NDVI measurements was significantly smaller for the 90- and 120-lb V3 sidedress treatments compared to similar preplant N rates. Relative leaf chlorophyll at R1 was significantly increased by N with the greatest RLC values obtained with the 240-lb preplant rate, the 140-lb split rate, and the 90- and 120-lb V3 sidedress rates. There was no difference in NDVI or RLC between the 140-lb split treatment and the 160-lb preplant treatment.

First- and Second-Year Corn

Economic return to fertilizer N for first-yr corn was greatest for the two single 90- and 120-lb V3 sidedress applications of UAN, regardless of the fertilizer N: corn price scenario used (Table 24). Split application of N (60-lb preplant + 40-lb V3) decreased economic return by $30 to $50/A compared to the 120-lb preplant rate, depending on N price: corn price scenario. For second-yr corn, economic return was greatest for the 160-lb V3, 140-lb split, and 240-lb preplant treatments when using the 0.1 ratio of N price: corn price. When using actual recent average prices for urea and UAN and corn prices of $4.50 to $6.50/bu, economic return was greatest for the 240-lb preplant and 160-lb V3 treatments. Economic return was similar for the 140-lb split treatment and the 160-lb preplant treatment.

Soybeans

Three-yr average soybean yields, seed N concentration, and N removal in the grain were not affected by the residual effects of the N applied for corn (Table 25). Contrary to corn, there was no Yr x treatment interaction. Nitrogen removed in the soybean seed averaged about 130 lb N/A, which was similar to 185 bu/A of first-yr corn receiving 120 lb preplant N/A or 167 bu/A of second-yr corn receiving 200 lb preplant N/A.

Acknowledgement

Financial support from the Agricultural Fertilizer Research and Education Council for 2008, 2009, and 2010 is greatly appreciated by the authors.

Four-Year (2007-2010) Results

First-Year Corn

Four-yr average corn grain yields shown in Table 26 indicate a 75 bu/A response to N. Sixty percent of the crop yield was supplied by soil N, which is below the long-term average (76%) following soybeans for southern Minnesota. Yields were not statistically significant among the 90-, 100-, 120-, 150-, and 180-lb N rates. Using a quadratic-plateau model and a N price: corn price ratio of 0.10, the EONR was calculated to be 129 lb N/A at the yield of 187 bu/A. Grain moisture content at harvest was not different among any of the treatments that received N, but grain moisture was significantly greater for the zero-N control. Nitrogen continued to accumulate in the stover and grain as the N rate increased with significantly higher concentrations found for the 180-lb N rate. Stover and grain N concentrations were not different between the 100-lb split treatment and the 120-lb preplant treatment. Significant Yr x treatment interactions were found for grain yield, total DM yield, and grain N concentration.

Nitrogen uptake into the grain, stover, and total DM during the 4-yr period was always greatest for the 180-lb N rate, but was not significantly different from the 150-lb rate. Although uptake of N was not different between the 100-lb split treatment and the 120-lb preplant treatment, apparent N recovery was considerably greater for the split N treatment. Highly significant Yr x treatment interactions were found for grain and total DM N uptake.

Although the Crop Circle and GreenSeeker instruments showed a significant NDVI response to fertilizer N, there was no significance among the 60-through 150-lb N rates (Table 28). For an unexplained reason, the 180-lb N rate gave a slightly lower NDVI when the GreenSeeker was used. Similar to the 3-yr findings, NDVI measurements at the V8-V9 stage would not have assisted growers when making in-season N rate decisions. Relative leaf chlorophyll tracked corn yield quite well with no differences in RLC among the 100-lb through 180-lb N rates. Significant Yr x treatment interactions were found for both NDVI measurement systems and for RLC.

Second-Year Corn

Four-yr average corn yields were increased about 110 bu/A over the zero-N control by the 240-lb N rate (Table 29). Across the 4-yr, 37% of the grain yield was supplied by soil N, which is below the long-term average of 60% for corn after corn. Statistically speaking, grain yields were not different among the 200- and 240-lb preplant rates and the 140-lb split N rate. Using a quadratic plateau model and a N price: corn price ratio of 0.10, the EONR was calculated to be 181 lb N/A at the yield of 171 bu/A. The 7.1 bu/A advantage for the 140-lb split N treatment was not statistically superior to the 160-lb preplant rate. Grain moisture content was reduced about 4 points from the zero-N control by all of the N treatments. Stover and grain N concentrations continued to increase with increasing N rate with no difference in grain N between the 200- and 240-lb N rates. Stover N concentrations was greater with the 160-lb preplant rate compared to the 140-lb split rate. Highly significant Yr x treatment interactions were found yield, grain moisture, and N concentrations.

Nitrogen uptake in the grain, stover, and total DM averaged across the 4-yrs was substantially increased by fertilizer N and was statistically greatest for the 200- and 240-lb N rates (Table 30). No difference existed in N uptake between the 140-lb split treatment and the 160-lb preplant treatment. Apparent N recovery in the total DM and grain and NUE were consistently higher for the 140-lb split rate compared to either the 120-lb or 160-lb preplant rates. Again, highly significant Yr x treatment interactions were found for N uptake.

Similar to first-yr corn the GreenSeeker and Crop Circle instruments showed substantial NDVI differences between the zero-N control and all of the N treatments with no significant difference among the treatments receiving N (Table 31). Relative leaf chlorophyll was greatly affected by the N rates with the two treatments having the highest RLC also being the two highest yielding treatments (240-lb preplant N and 140-lb split N). Highly significant Yr x treatment interactions were found for the NDVI and RLC measurements.

First- and Second-Year Corn

Economic return to fertilizer N as affected by previous crop and N treatment is shown on Table 32. For the three fertilizer N and grain price scenarios used, economic return for first-yr corn after soybeans was greatest for the 120- and 150-lb N rates. Depending on the scenario used, split-applying the 100-lb N rate reduced economic return by $18 to $32/A compared to the 120-lb preplant N rate. Second-yr corn presented a different picture as the economic return was greatest for the 140-lb split treatment and the 240-lb preplant treatment.

Drainage

Annual and the 4-yr total tile drainage discharge for each of the crops and N treatments is shown in Table 33. Although 4-yr drainage across the 27 plots of the C-C-S rotation averaged 36.7", variation among years was great with 32, 9, 2, and 57% of the total drainage occurring in 2007, 2008, 2009, and 2010, respectively. Four-yr drainage among the three crops was very uniform with deviations of -0.2" (<1%) for first-yr corn, + 2.7" (+7%) for second-yr corn, and -2.5" (-7%) compared to the 36.7" overall C-C-S average. Drainage deviations among the three N treatments within each of the three crops was more variable and ranged from -5.6" (-15%) to + 4.2" (+11%) for first-yr corn, from -3.5" (-9%) to +4.2" (+11%) for second-yr corn, and from -1.9" (-6%) to +1.3" (+4%) for soybeans. Four-yr total drainage averaged across crops for each of the three N treatments averaged 36.3" (-1%) for the zero-N control, 35.0 (-5%) for the split-N treatment, and 38.8" (+6%) for the preplant-N treatment. Even though the 4-yr average drainage amounts shown above are quite uniform in general for small field drainage plots, drainage deviations among N treatments ranging from -15% to 11% for first-yr corn and from -9% to 11% for second-yr corn present some challenges when interpreting the nitrate-N loss data, especially when comparing the split-N and preplant-N treatments (as will be seen later).

Nitrate-N Concentrations in Drainage
Annual flow-weighted nitrate-N concentrations and the 4-yr average nitrate-N concentration in the tile drainage are shown in Table 34. Annual concentrations were generally less than 10 mg/L except for 2008 and the two fertilizer N treatments for second-yr corn in 2007. The low concentrations in 2009 were probably due to 89% of the annual drainage in this dry year (0.8" of tile drainage) occurring either before May 24, shortly after the preplant N treatments were applied, or after October 1 when N uptake by the crop had already occurred. Even though 2010 was a wet year with 20.9" of drainage, 75% of the annual drainage occurred before the N treatments were applied or after September 22 when the crop had taken up most of the nitrate in the soil profile. Four-yr average nitrate-N concentrations were lowest for the zero-N control plots, ranging from 4.6 mg/L for second-yr corn to 6.2 mg/L for first-yr corn where most of the nitrate probably was mineralized after soybean maturation the previous fall. Four-yr average nitrate-N concentrations did not indicate a consistent advantage (lower nitrate content) for either the split or the preplant N treatments; concentrations were greater for split N in first-yr corn and greater for preplant N in second-yr corn. In summary, the unexpected low nitrate-N concentrations found in this study were likely due to: (1) 70, 17, 89, and 75% of the annual drainage in 2007, 2008, 2009 and 2010, respectively, occurring either before the preplant N was applied or after crop N uptake had been completed, (2) the N rates applied were at the recommended N rate (preplant) or about 15% less (split-applied N), and (3) corn yields were quite high.

Nitrate-N Losses in Drainage
Annual and 4-yr total nitrate-N losses as affected by crop and rate and time of application are shown in Table 35. The majority of the 4-yr drainage total occurred in 2007 (38%) and 2010 (45%). Only 3% occurred in 2009. Because of this highly variable temporal distribution among years, all further discussion will center on the 4-yr totals. Although nitrate-N losses within each of the crops were always least for the zero-N control treatment, these losses, derived from the soil organic matter, comprised 77, 47, and 71% of the total nitrate-N loss from the preplant treatments for first-yr corn, second-yr corn, and soybean respectively. These data further show the influence of soybean ahead of corn as well as the year soybeans are grown. Nitrate-N losses from the preplant treatment were 7, 16, and 10% greater compared to the split-applied treatment for first-yr corn, second-yr corn, and soybean, respectively. These greater loss amounts for preplant N are considered to be due primarily to the higher preplant N rates (120 and 160 lb N/A for first- and second-yr corn, respectively) compared to the split-N rates of 100 and 140 lb N/A for first- and second-yr corn, respectively. The difference between rates carried over into the soybean year where N timing took place in the previous two years. When compared to the zero-N control, preplant N increased NO_3-N losses by 30% for first-yr corn, 114% for second-yr corn, and 41% for soybeans. When combining the nitrate losses from both the preplant and split treatments, nitrate losses from second-yr corn were 21% greater than from first-yr corn. Of the 400- (split) and 480 (preplant)-lb fertilizer N amounts added during the 4-yr period for first-yr corn, only 2.5% and 3%, respectively, was lost in the tile drainage as nitrate-N. Similar losses of 5.5% and 6.5% were found for the 560 (split) and 640 (preplant) lb N/A rates applied for second-yr corn. In the soybean year, nitrate-N losses were increased over the zero-N control by 28% for the split N treatment and 41% for the preplant N treatment.

Nitrate-N Loss Normalized for Drain Flow
Because of the variability in tile drain flow mentioned earlier in the "Drainage" section, deviations from the average ranging from -15% to +11% for first-yr corn, -9% to +11% for second-yr corn, and -6% to +4% for soybeans, we tried normalizing the nitrate loss data for the 4-yr drainage flow. The data in Table 36 were normalized for flow for each treatment (3 plots)

within each crop. Table 37 shows the flow data normalized across the three N treatments (9 plots) for each crop (average flow per crop) while Table 38 shows the flow data normalized across all 27 plots. These normalizations allow us to calculate: a) nitrate-N lost/inch of drainage, b) nitrate-N lost from the treatment – the zero-N control treatment (Δ NO_3-N lost/inch of drainage), c) the percent increase in loss over the zero-N control in each crop, and d) the ratio of Δ Yield (bu/A): ΔNO_3-N (lb/in). The larger this ratio number the less ΔNO_3-N lost in the drainage water per bushel of corn produced. The purpose of this exercise was to determine if we could more clearly distinguish the differences between the split-N and preplant-N treatment.

Although the data in Table 35 do not allow us to make a firm comparison of a C-S rotation with a C-C-S rotation with respect to nitrate losses in drainage water, we can conclude that annual nitrate losses from the preplant system would total (61.8 + 78.0 + 47.5) = 187.3 lb/A/4 yrs ÷ 4 = 46.8 lb/A yr for the three crop years of the C-C-S rotation. For the C-S rotation, the nitrate-N losses would total (61.8 + 47.5, assuming the loss after one year of corn is the same as after two years of corn) = 109.3 lb/A/4 yrs ÷ 4 = 27.3 lb/A yr for the two crop years of the rotation. To place the two crop rotations in an equal time basis (6 yrs), we can multiply 46.8 lb/A x 2 = 93.6 lb/A for 6 yrs of a C-C-S rotation and 27.3 lb/A x 3 = 81.9 lb/A for 6 yrs of a C-S rotation; a 14% increase in nitrate losses with the C-C-S system over the "assumed" C-S system. Since the nitrate-N loss in the soybean phase of the C-S system would likely be less than in the C-C-S system, the C-C-S rotation is likely to be as much as 20% higher.

Table 36 with drain flow normalized across only the three plots per N treatment within each crop presents ΔNO_3-N lost, % increase over control, and a ΔYield: ΔNO_3-N data does not show any consistency between the split-N and preplant-N data; the percent increase over control and ratio data suggest best performance for preplant N with first-year corn and best performance for split N with second-yr corn. For the C-C-S system, there is no difference in "percent increase over control" between the 85% split N treatment and the 100% preplant treatment. These findings do not agree with those in Table 35.

Table 37 with drain flow normalized across the three N treatments (9 plots) within each crop shows a consistent advantage (lower % increase in Δ NO_3-N/in and a higher ratio value) for the split-N treatment over preplant N for first-yr corn, second-yr corn, soybeans, and the C-C-S rotation. Normalizing drain flow across all 27 plots (36.7") presented slightly different data (Table 38) but an interpretation similar to Table 37. Based on these three approaches to drain flow normalization, it appears that normalization across all plots within a crop produces a more consistent data based that also agrees with the non-normalized data found in Table 35. Normalizing across three plots within each N treatment within each crop introduced greater variability into the results while normalizing across all 27 plots did not improve consistency over normalizing within each crop.

2007-2010 SUMMARY

The objectives of this study were clearly met and are summarized in the following primary and secondary bullet points:

Primary

- When considering the corn yield data (Tables 26 and 29), N uptake data (Tables 27 and 30), and economic return data (Table 32), applying a slightly reduced N rate (85% of recommended) split between preplant urea and V3 injected UAN did not perform well in first-yr corn, and thus would not be recommended. However, for second-yr corn, split application performed well with increased yield, N uptake, and economic return to N in addition to less nitrate loss to tile drainage water.
- Based on the data for the C-C-S system found in Tables 35, 37, and 38, split-applying a 85% of recommended N rate resulted in about 10% less nitrate loss to drainage water than from the 100% preplant rate in this C-C-S rotation.
- Also, nitrate losses from the C-C-S rotation were calculated to be at least 14% greater than from a C-S rotation.

Secondary

- The ENOR's across the 4-yr of first-yr and second-yr corn were 129 and 181 lb N/A at yields of 187 and 171 bu/A, respectively. Soil N contributed to 60 and 37% of the total grain yield for first- and second-yr corn, respectively.
- Grain yields for first-yr corn were similar for the split and preplant N applications; whereas for second-yr corn, yields for split-applied N were greater than for preplant N.
- Apparent N recovery (ANR) was greater for split-applied N compared to preplant N for both first- and second-yr corn.
- NUE was not different between split and preplant N for first-yr corn, but was greater for split-applied N for second-yr corn.
- NDVI data taken at the V8-V9 stage would not have been helpful as an aid to in-season N rate determination for either first-yr or second-yr corn.
- Economic return to fertilizer N was greatest with the 120-lb and 150-lb preplant N rates and reduced with the 100-lb split application for first-yr corn. For second-yr corn, the 140-lb split rate and the 240-lb preplant rates gave the highest economic return.
- Tile drainage across the 4-yr totaled 36.7" with 32, 9, 2, and 57% occurring in 2007, 2008, 2009, and 2010, respectively.
- Drainage amounts among the three crops were very uniform.
- Four-yr average nitrate-N concentrations were quite low due to: 1) most drain flow before preplant N application or after crop maturity, 2) modest rates of N application, 3) high yields and N uptake, and 4) significant denitrification potential in some years.
- In this C-C-S rotation, 77, 47, and 71% of the nitrate lost in the drainage water came from the soil organic matter in first-yr corn, second-yr corn, and soybean, respectively.
- When averaged across the two fertilizer N rates, (100 + 120 for first-yr corn and 140 + 160 for second-yr corn), nitrate losses were 21% greater for second-yr corn than for first-yr corn.
- Approximately 3% and 6% of the total N applied for first- and second-yr corn, respectively, was lost as nitrate-N in the drainage water.

ACKNOWLEDGEMENTS

1) Financial support from the Minnesota Corn Growers Association and the Agricultural Fertilizer Research an Education Council for these four years has been sincerely appreciated.
2) The authors greatly appreciate the dedication and commitment of David Groh, Wade Ihlenfeld, and other technicians in the collection of superb plant and water data - - sometimes under less-than-favorable conditions.

Table 1. Experimental procedures used in the agronomic portion of the crop rotation, N, and drainage study in 2010.

Parameter	Crop CS-**C**	SC-**C**	CC-**S**
Soil type	-------- Canisteo clay loam --------		
Soil test			
pH	----------- 7.4 -----------		
OM (%)	----------- 6.2 -----------		
Bray P_1 (ppm)	----------- 17 (H) -----------		
Exch. K (ppm)	----------- 124 (H) -----------		
PPNT (NO_3-N, lb/A,0-2')	36	18=Trt. 1 & 28 = Trt. 2	
Previous crop	Soybean	Corn	Corn
Fall Tillage	----------- Chisel/rip -----------		
Preplant N	Urea	Urea	--
Source & Date	4/30	4/30	--
Spr. Tillage	----------- Field cultivate -----------		
Hybrid/Variety	DKC 48-37	DKC 48-37	Pioneer 92Y20
Planting rate (seeds/A)	35,000	35,000	8 beans/ft
Planting date	4/30	4/30	5/4
Herbicides			
& dates	---- Roundup Weathermax (5/28 & 6/22) ----		
Apply SD N (V3)	6-3	6-3	
Record stand counts	6-1	6-1	
Thin to "uniform" stand	6-2	6-2	
PSNT soil samples (V6)	6-10	6-10	
Soil samples (0-6") for pH, OM, P & K	6-16	6-16	
NDVI (V8-9)	6-25, 28, & 7/1	6-25, 28, & 7/1	
Chlorophyll msmts (R1)	7-19	7-19	
Stover yield	9-13	9-13	
Grain yield	10-1	10-1	10-2

Table 2. Rainfall, air temperature, and growing degree units (GDUs) for the 2010 growing season at Waseca.

Month	Precipitation 2010	Normal[1/]	Air Temp. 2010	Normal[1/]	GDUs 2010	Normal[1/]
	----- inches -----		------ °F ------			
Apr.	1.60	3.23	53.7	44.9	-	-
May	3.27	3.96	59.2	58.4	362	337
June	9.64	4.22	67.0	67.8	509	532
July	6.61	4.47	72.5	71.3	691	644

Aug.	2.43	4.58	73.0	68.9	698	584
Sept.	12.66	3.19	58.9	60.2	320	322
Oct.	1.02	2.50	51.0	47.7	25	--
Apr.-Sept. Total	36.21	23.65			2580	2419

[1/] 30-Yr normal, 1971-2000.

Table 3. Pre-sidedress nitrate test (PSNT) concentrations as affected by crop and N rate in a C-C-S crop rotation, N, drainage study at Waseca in 2010.

N rate for		Crop	
CS-**C**	SC-**C**	CS-**C**	SC-**C**
----- lb N/A -----		--- NO_3-N (ppm, 0-1') ---	
0	0	10.5	5.2
60	80	27.8	18.2
90	120	20.8	28.8
120	160	46.8	30.7
150	200	49.0	43.2
180	240	50.0	58.5

Table 4. First-year corn grain, stover, and total DM yield, grain moisture, and plant population as influenced by N rate and time of application in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Yield			Grain	Plant
Preplant	SD	Total	Grain	Stover	Total	H_2O	Popl'n
------- lb N/A -------			bu/A	--- TDM/A ---		%	$p*10^3/A$
0	0	0	105.7	1.92	4.42	20.9	33.2
60	0	60	153.2	2.61	6.24	20.7	32.9
90	0	90	173.1	2.89	6.98	20.9	31.9
60	40 (V3)	100	169.9	2.62	6.64	20.6	33.3
120	0	120	187.8	2.87	7.32	21.0	33.1
150	0	150	190.0	2.61	7.11	20.3	33.1
180	0	180	201.5	2.82	7.59	20.5	33.3
0	90 (V3)	90	184.5	2.80	7.17	21.1	32.5
0	120 (V3)	120	182.7	2.95	7.27	21.9	33.2
Statistical Analysis							
P > F:			<0.001	0.008	<0.001	0.191	0.158
LSD (0.10):			10.9	0.38	0.56	NS	NS
CV (%):			4.5	9.9	5.8	2.9	1.9

Table 5. Nitrogen concentration in the grain and stover, N uptake in the grain, stover, and total DM, and apparent fertilizer recovery in the total DM and grain as influenced by N rate and time of application for first-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Grain	Stover	Nitrogen Uptake			Apparent N Recovery	
Preplant	SD	Total	[N]	[N]	Grain	Stover	Total DM	Total	Grain
- - - - lb N/A - - - -			- - - % - - -		- - - - lb N/A - - - -			%	%
0	0	0	1.03	0.39	51.5	15.1	66.6	--	--
60	0	60	1.04	0.45	75.4	23.5	98.9	54	40
90	0	90	1.07	0.43	88.1	24.8	112.9	51	41
60	40 (V3)	100	1.10	0.46	88.2	24.1	112.4	46	37
120	0	120	1.13	0.46	100.4	26.5	126.9	50	41
150	0	150	1.15	0.56	104.0	29.8	133.8	45	35
180	0	180	1.19	0.64	113.2	36.4	149.6	46	34
0	90 (V3)	90	1.10	0.44	96.5	25.2	121.7	61	50
0	120 (V3)	120	1.15	0.47	99.5	27.4	126.8	50	40
Statistical Analyses									
P > F:			<0.001	0.060	<0.001	0.021	<0.001		
LSD (0.10):			0.05	0.12	8.7	7.7	13.2		
CV (%):			13.4	17.7	6.7	21.0	7.9		

Table 6. NDVI measurements taken by the Crop Circle and GreenSeeker instruments as influenced by N rate and time of application for first-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Crop Circle	GreenSeeker	
Preplant	SD	Total	V9	V8	V10
- - - - lb N/A - - -			- - - - - - - - - - - NDVI - - - - - - - - - - -		
0	0	0	0.655	0.783	0.792
60	0	60	0.720	0.823	0.832
90	0	90	0.725	0.833	0.835
60	40 (V3)	100	0.730	0.828	0.838
120	0	120	0.728	0.834	0.837
150	0	150	0.736	0.826	0.841
180	0	180	0.742	0.830	0.843
0	90 (V3)	90	0.729	0.810	0.835
0	120 (V3)	120	0.721	0.808	0.829
Statistical Analyses					
P > F:			<0.001	<0.001	<0.001
LSD (0.10):			0.010	0.013	0.007
CV (%):			0.9	1.1	0.6

Table 7. Relative leaf chlorophyll (RLC), NUE, and oil and starch content of the grain as affected by N rate and time of application for first-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Relative leaf chlorophyll		Grain	
Preplant	SD	Total	R1	NUE	Oil	Starch
---- lb N/A ----			--- % ---	bu/lb FN	--- % ----	
0	0	0	67.1	--	3.65	69.5
60	0	60	86.0	0.79	3.71	69.4
90	0	90	89.5	0.75	3.60	69.4
60	40 (V3)	100	94.1	0.64	3.57	69.6
120	0	120	96.2	0.68	3.64	69.3
150	0	150	97.6	0.56	3.72	69.6
180	0	180	98.6	0.53	3.83	68.9
0	90 (V3)	90	95.9	0.88	3.79	68.5
0	120 (V3)	120	99.1	0.64	3.61	69.1
Statistical Analyses						
P > F:			<0.001		0.813	0.338
LSD (0.10):			3.6		NS	NS
CV (%):			2.7		5.0	0.7

Table 8. Second-year corn grain, stover, and total DM yield, grain moisture, and plant population as influenced by N rate and time of application in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Yield			Grain	Plant
Preplant	SD	Total	Grain	Stover	Total	H_2O	Popl'n
------- lb N/A --------			bu/A	--- TDM/A ---		%	$p*10^3/A$
0	0	0	57.6	1.06	2.42	26.7	33.3
80	0	80	116.7	2.02	4.78	20.4	33.3
120	0	120	129.9	2.13	5.20	20.2	32.2
60	80 (V3)	140	169.7	2.22	6.24	21.4	33.2
160	0	160	158.0	2.21	5.95	20.8	33.0
200	0	200	168.8	2.38	6.38	20.4	33.1
240	0	240	182.8	2.71	7.03	20.6	32.2
0	120	120	135.4	3.08	6.29	23.8	33.2
0	160	160	159.1	3.36	7.13	23.7	33.0
Statistical Analysis							
P > F:			<0.001	<0.001	<0.001	0.010	0.300
LSD (0.10):			11.4	0.65	0.78	1.2	NS
CV (%):			5.6	19.5	9.5	4.0	2.1

Table 9. Nitrogen concentration in the grain and stover, N uptake in the grain, stover, and total DM, and apparent fertilizer recovery in the total DM and grain as influenced by N rate and time of application for second-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Grain	Stover	Nitrogen Uptake			Apparent N Recovery	
Preplant	SD	Total	[N]	[N]	Grain	Stover	Total DM	Total DM	Grain
---- lb N/A ----			--- % ---		---- lb N/A ----			%	%
0	0	0	1.12	0.43	30.4	9.0	39.5	--	--
80	0	80	1.04	0.37	57.5	14.9	72.5	41	34
120	0	120	1.04	0.41	63.9	17.3	81.2	35	28
60	80 (V3)	140	1.11	0.47	89.0	21.5	110.4	51	42
160	0	160	1.11	0.48	82.9	21.1	104.0	40	33
200	0	200	1.13	0.52	90.2	25.7	115.9	38	30
240	0	240	1.15	0.57	99.2	31.4	130.6	38	29
0	120 (V3)	120	1.08	0.47	69.3	29.3	98.6	49	32
0	160 (V3)	160	1.15	0.46	86.4	31.7	118.0	49	35
Statistical Analyses									
P > F:			0.029	0.058	<0.001	0.015	<0.001		
LSD (0.10):			0.06	0.09	7.2	10.3	14.8		
CV (%):			3.5	14.3	6.8	32.1	10.7		

Table 10. NDVI measurements taken by the Crop Circle and GreenSeeker instruments as influenced by N rate and time of application for second-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Crop Circle	GreenSeeker	
Preplant	SD	Total	V9	V8	V10
---- lb N/A ---			------------ NDVI ------------		
0	0	0	0.478	0.532	0.546
80	0	80	0.660	0.763	0.786
120	0	120	0.686	0.784	0.804
60	80 (V3)	140	0.705	0.794	0.819
160	0	160	0.710	0.801	0.823
200	0	200	0.722	0.805	0.829
240	0	240	0.721	0.805	0.830
0	120 (V3)	120	0.615	0.664	0.720
0	160 (V3)	160	0.666	0.717	0.775
Statistical Analyses					
P > F:			<0.001	<0.001	<0.001
LSD (0.10):			0.027	0.033	0.038
CV (%):			2.9	3.1	3.4

Table 11. Relative leaf chlorophyll (RLC), NUE, and oil and starch content of the grain as affected by N rate and time of application for second-year corn in a C-C-S rotation/drainage study at Waseca in 2010.

N Rate			Relative leaf chlorophyll		Grain	
Preplant	SD	Total	R1	NUE	Oil	Starch
---- lb N/A ----			-- % --	bu/lb FN	----- % -----	
0	0	0	58.2	--	4.02	68.2
80	0	80	70.9	0.74	3.80	69.0
120	0	120	82.0	0.60	3.66	69.6
60	80 (V3)	140	94.9	0.80	3.84	68.8
160	0	160	88.5	0.63	3.92	68.7
200	0	200	93.1	0.56	3.67	69.5
240	0	240	94.8	0.52	3.74	68.8
0	120 (V3)	120	95.0	0.65	3.76	68.7
0	160 (V3)	160	100.0	0.63	3.78	68.5
Statistical Analyses						
P > F:			<0.001		0.307	0.014
LSD (0.10):			3.3		NS	0.6
CV (%):			2.7		4.6	0.6

Table 12. Economic return to fertilizer N as affected by N rates and method of N application for first-year and second-year corn in 2010.

N Rate/Method				Fert. N/Corn Grain Price[3/]	
Preplant	SD[1/]	Total	Δ Yield[2/]	$0.40/4.00	$0.45/6.50
------- lb N/A -------			bu/A	---------- $/A ----------	
			First-Year Corn		
0	0	0	0	--	--
60	0	60	47.5	166.	282.
90	0	90	67.4	234.	398.
60	40 (V3)	100	64.2	212.	367.
120	0	120	82.1	280.	480.
150	0	150	84.3	277.	480.
180	0	180	95.8	311.	542.
0	90 (V3)	90	78.8	274.	467.
0	120 (V3)	120	77.0	255.	442.
			Second-Year Corn		
0	0	0	0	--	--
80	0	80	59.1	204.	348.
120	0	120	72.3	241.	416.
60	80 (V3)	140	112.1	387.	661.
160	0	160	100.4	338.	581.
200	0	200	112.2	365.	633.
240	0	240	125.2	405.	706.
0	120 (V3)	120	77.8	258.	447.
0	160 (V3)	160	101.5	337.	583.

1/ A $5/A expense for sidedress application.

2/ Δ Yield = N treatment yield – zero-N control yield.

3/ Fert. N price in $/lb N / corn grain price in $/bu.

Table 13. Soybean yield, seed N concentration, and seed N removal as influenced by the residual effects of N rate and time of application from first and second-year corn at Waseca in 2010.

N rates for '08 corn			Soybean Seed		
Preplant	SD	Total	Yield	[N]	Removal
---- lb N/A ----			bu/A	%	lb N/A
0	0	0	55.6	5.14	149.
80	0	80	51.8	5.17	140.
120	0	120	51.4	5.20	140.
60	80	140	53.6	5.21	146.
160	0	160	52.7	5.23	144.
200	0	200	50.8	5.19	138.
240	0	240	53.3	5.18	144.
0	120 (V3)	120	50.6	5.16	136.
0	160 (V3)	160	52.4	5.19	142
Statistical Analyses					
P > F:			0.250	0.818	0.321
LSD (0.10):			NS	NS	NS
CV (%):			4.2	1.3	4.4

Table 14. Tile water discharge from the C-C-S and continuous corn plots for each of the N treatments in 2010.

N Rate/Time			Period/Month							
Preplant	SD	Total	Pre-N App. 3/11-4/30	May	June	July	Sept	Oct.	Post-N App. May-Oct.	Year Total
------ lb N/A ------			inches (SE)[1/]							
			First-Year Corn							
0	0	0	8.6 (1.8)	0.75 (0.49)	3.92 (1.26)	0.60 (0.41)	8.0 (0.72)	0.31 (0.27)	13.6 (3.1)	22.3 (4.5)
60	40	100	5.4 (1.2)	0.61 (0.21)	3.73 (0.88)	0.25 (0.13)	8.1 (1.15)	0.27 (0.12)	12.9 (2.4)	18.3 (3.6)
120	0	120	7.3 (2.6)	0.17 (0.10)	4.34 (0.85)	0.11 (0.06)	9.7 (1.39)	0.03 (0.03)	14.3 (2.2)	21.6 (4.7)
	Avg.		7.1	0.51	4.00	0.32	8.6	0.20	13.6	20.7
			Second-Year Corn							
0	0	0	3.4 (0.8)	0.62 (0.36	4.63 (0.81)	0.76 (0.31)	8.0 (0.51)	0.21 (0.18)	14.2 (1.5)	17.5 (1.8)
60	80	140	5.2 (0.8)	0.32 (0.31)	4.91 (0.88)	0.48 (0.44)	10.5 (0.33)	0.09 (0.09)	16.3 (1.5)	21.6 (1.7)
160	0	160	9.6 (2.1)	0.31 (0.24)	5.09 (0.84)	0.18 (0.12)	11.5 (0.42)	0.10 (0.08)	17.1 (0.9)	26.8 (2.7)
	Avg.		6.1	0.42	4.88	0.47	10.0	0.13	15.9	22.0
			Soybeans							
0	0	0	3.6 (2.4)	0.24 (0.23)	3.81 (0.97)	0.20 (0.19)	9.0 (0.64)	0.04 (0.04)	13.3 (2.0)	16.9 (3.5)
0	0	0	6.6 (1.4)	0.16 (0.07)	4.83 (0.97)	0.14(0.03)	10.3 (1.04)	0.04 (0.03)	15.5 (2.1)	22.1 (2.4)
0	0	0	5.4 (1.7)	0.14 (0.12	4.50 (0.74)	0.10 (0.04)	11.3 (0.49)	0.05 (0.05)	16.1 (1.0)	21.5 (2.5)
	Avg.		5.2	0.18	4.38	0.15	10.2	0.04	15.0	20.2
			Continuous Corn							
160	0	160	3.4 (1.9)	0.59 (0.58)	3.77 (1.87)	0.39 (0.34)	8.7 (1.35)	0.23 (0.23)	13.6 (4.4)	17.0 (6.1)

[1/] Standard error of the mean (SE).

Table 15. Flow-weighted NO_3-N concentrations from the C-C-S and continuous corn plots as affected by rate of N application in 2010.

N Rate/Time			Period/Month							
Preplant	SD	Total	Pre-N App. 3/11-4/30	May	June	July	Sept.	Oct.	Post-N App. May-Oct.	Year Avg.
------ lb N/A ------			mg NO_3-N/L (SE)[1/]							
			First-Year Corn							
0	0	0	4.9 (0.7)	6.4 (0.6)	6.0 (0.7)	6.2 (1.0)	1.8 (0.3)	2.4 (0.6)	3.4 (0.7)	4.0 (0.7)
60	40	100	9.4 (1.0)	10.3 (0.3)	12.8 (1.4)	11.7 (0.4)	5.0 (0.3)	6.0 (0.4)	7.6 (0.4)	8.2 (0.6)
120	0	120	6.4 (1.0)	8.7 (0.3)	11.4 (0.7)	7.5 (1.9)	4.0 (0.4)	6.4 (--)	6.3 (0.3)	6.4 (0.4)
			Second-Year Corn							
0	0	0	3.7 (1.0)	3.7 (0.7)	4.4 (1.2)	3.8 (1.0)	2.1 (0.4)	2.7 (0.30)	2.9 (0.5)	3.0 (0.4)
60	80	140	5.0 (1.1)	6.3 (1.1)	9.9 (0.6)	10.8 (0.5)	2.7 (0.2)	4.1 (0.1)	5.1 (0.4)	5.1 (0.1)
160	0	160	5.5 (0.1)	6.1 (0.5)	8.8 (0.1)	9.9 (0.2)	4.3 (0.4)	5.8 (1.3)	5.7 (0.4)	5.6 (0.3)
			Soybeans							
0	0	0	4.4 (1.8)	3.5 (2.6)	2.9 (1.1)	3.4 (1.2)	3.8 (0.5)	4.8 (--)	3.6 (0.6)	3.8 (0.7)
0	0	0	4.8 (1.4)	5.0 (1.3)	4.4 (1.0)	4.8 (1.0)	3.6 (1.0)	5.3 (0.5)	3.9 (1.0)	4.1 (1.0)
0	0	0	4.4 (0.4)	4.9 (0.2)	4.9 (0.6)	4.7 (0.7)	4.8 (1.1)	6.7 (0.3)	4.9 (0.9)	4.8 (0.8)
			Continuous Corn							
160	0	160	5.7 (1.0)	4.7 (3.3)	11.2 (0.5)	8.2 (1.6)	4.3 (0.8)	8.0 (--)	6.2 (1.1)	6.2 (0.9)

[1/] Standard error of the mean (SE).

Table 16. Nitrate-N losses from the C-C-S rotation and continuous corn plots as affected by rate of N application in 2010.

N Rate/Time			Period/Month							
Preplant	SD	Total	Pre-N App. 3/11-4/30	May	June	July	Sept.	Oct.	Post-N App. May-Oct	2010 Total
------ lb N/A ------			------ lb NO_3-N/A (SE)[1/] ------							
			First-Year Corn							
0	0	0	9.9 (3.2)	1.1 (0.8)	5.7 (2.4)	1.0 (0.8)	3.3 (0.7)	0.2 (0.2)	11.4 (4.9)	21.3 (8.1)
60	40	100	11.1 (1.4)	1.4 (0.5)	10.5 (2.1)	0.7 (0.3)	9.1 (0.9)	0.3 (0.1)	22.0 (3.4)	33.1 (4.8)
120	0	120	11.4 (4.9)	0.3 (0.2)	11.2 (2.2)	0.2 (0.1)	8.5 (0.6)	0.0 (0.0)	20.2 (2.4)	31.7 (7.3)
			Second-Year Corn							
0	0	0	2.4 (0.2)	0.4 (0.2)	4.2 (0.4)	0.5 (0.1)	3.8 (1.0)	0.1 (0.1)	9.1 (0.9)	11.6 (0.8)
60	80	140	6.0 (1.5)	0.4 (0.4)	10.9 (1.9)	1.2 (1.1)	6.5 (0.3)	0.1 (0.1)	19.2 (3.3)	25.1 (2.3)
160	0	160	12.1 (2.9)	0.4 (0.3)	10.1 (1.6)	0.4 (0.3)	11.1 (0.6)	0.1 (0.1)	22.2 (2.9)	34.3 (4.4)
			Soybeans							
0	0	0	3.1 (1.5)	0.3 (0.3)	2.9 (1.7)	0.2 (0.2)	7.7 (1.2)	0.0 (0.0)	11.2 (3.3)	14.3 (4.0)
0	0	0	6.2 (0.3)	0.2 (0.1)	4.6 (0.9)	0.2 (0.0)	8.4 (2.5)	0.0 (0.0)	13.4 (3.4)	19.7 (3.5)
0	0	0	5.1 (1.4)	0.2 (0.1)	5.1 (1.2)	0.1 (0.1)	12.0 (2.2)	0.1 (0.1)	17.5 (2.3)	22.6 (1.6)
			Continuous Corn							
160	0	160	5.2 (3.3)	1.0 (1.0)	9.8 (5.1)	0.9 (0.9)	8.7 (2.7)	0.4 (0.4)	20.9 (9.9)	26.1 (12.8)

[1/] Standard error of the mean (SE).

Table 17. Ortho- and total phosphate concentrations in tile drainage water from a C-C-S cropping system as affected by crop and N rate at Waseca from March 23 through June 28, 2010.

Crop	N rate	No. of Samples	Ortho-P[1/] Avg.	Ortho-P[1/] SE[3/]	Ortho-P[1/] Range	Total P[2/] Avg	Total P[2/] SE[3/]	Total P[2/] Range
			mg/L					
1st-Yr Corn	0	15	0.01	0.001	0.01-0.02	0.07	0.002	0.06-0.08
"	120	14	0.01	0.000	0.01	0.06	0.003	0.04-0.08
2nd-Yr Corn	0	15	0.01	0.001	0.01-0.02	0.07	0.004	0.05-0.10
"	160	14	0.01	0.001	0.01-0.02	0.08	0.004	0.06-0.12
Soybean	0	13	0.01	0.000	0.01	0.07	0.003	0.06-0.09
"	"0"	11	0.01	0.002	0.01-0.03	0.08	0.006	0.06-0.011

[1/] Detection limit is 0.01 mg/L.
[2/] " " " 0.02 mg/L.
[3/] Standard error of the mean (SE).

Table 18. Three-yr average first-year corn grain and total DM yield, grain moisture, and N concentrations in the stover and grain as influenced by N rate and time of application in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Yield		Grain	Stover	Grain
Preplant	SD	Total	Grain	Total	H_2O	[N]	[N]
------- lb N/A -------			bu/A	TDM/A	%	--- % ---	
Stats for RCB across years (all treatments)							
Year							
2008			181.7	7.10	20.1	0.537	1.25
2009			169.1	6.67	26.4	0.415	1.12
2010			172.1	6.75	20.9	0.479	1.11
P > F:			0.013	0.011	0.001	0.029	0.008
LSD (0.05):			6.5	0.22	1.7	0.077	0.07
Treatment							
0	0	0	112.4	4.76	23.7	0.36	1.01
60	0	60	157.8	6.42	22.6	0.41	1.06
90	0	90	176.9	7.09	22.5	0.45	1.14
60	40 (V3)	100	178.2	6.87	21.8	0.45	1.21
120	0	120	185.4	7.23	22.2	0.49	1.17
150	0	150	189.5	7.21	22.1	0.56	1.21
180	0	180	191.9	7.36	22.1	0.64	1.27
0	90 (V3)	90	187.4	7.30	22.9	0.45	1.13
0	120 (V3)	120	189.1	7.32	22.2	0.48	1.24
Statistical Analysis							
P > F:			<0.001	<0.001	0.044	<0.001	<0.001
LSD (0.05):			10.1	0.39	1.1	0.07	0.06
CV (%):			6.1	6.0	5.0	14.9	5.5
Interactions (P>F)							
Yr x treatment			0.022	0.094	0.480	0.104	0.001
Contrasts (P>F)							
Preplant vs split			0.162	0.073	0.508	0.252	0.202
PP vs Sidedress			0.052	0.274	0.629	0.852	0.198

Table 19. Three-yr average N uptake in the grain, stover, and total DM; apparent fertilizer recovery in the total DM and grain; and NUE as influenced by N rate and time of application for first-year corn in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Nitrogen Uptake			Apparent N Recovery		
Preplant	SD	Total	Grain	Stover	Total DM	Total	Grain	NUE
------- lb N/A -------			-------- lb N/A --------			%	%	bu/lb N
Stats for RCB across years (all treatments)								
Year								
2008			108.6	30.3	139.0	65	51	0.66
2009			90.6	22.3	112.9	48	40	0.59
2010			90.8	25.9	116.6	50	40	0.69
P > F:			0.007	0.036	0.002			
LSD (0.05):			8.6	5.4	8.1			
Treatment								
0	0	0	53.7	15.2	68.9	--	--	--
60	0	60	79.3	21.9	101.3	54	43	0.76
90	0	90	96.6	26.1	122.7	60	48	0.72
60	40 (V3)	100	101.7	24.0	125.7	57	48	0.66
120	0	120	102.9	28.0	130.9	52	41	0.61
150	0	150	109.1	30.7	139.8	47	37	0.51
180	0	180	115.0	36.4	151.4	46	34	0.44
0	90 (V3)	90	100.3	26.0	126.3	64	52	0.83
0	120 (V3)	120	111.2	27.2	138.4	58	48	0.64
Statistical Analysis								
P > F:			<0.001	<0.001	<0.001			
LSD (0.05):			7.3	4.1	8.5			
CV (%):			8.0	1.9	7.3			
Interactions (P>F)								
Yr x treatment			<0.001	0.248	<0.001			
Contrasts (P>F)								
Preplant vs split			0.754	0.061	0.231			
PP vs Sidedress			0.023	0.776	0.266			

Table 20. Three-yr average NDVI measurements taken by the Crop Circle and GreenSeeker instruments and relative chlorophyll content as influenced by N rate and time of application for first-year corn in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Crop Circle	GreenSeeker	Relative
Preplant	SD	Total	V9	V8	Chlorophyll
- - - - - - - lb N/A - - - - - - -			- - - - - - - NDVI - - - - - - -		%
Stats for RCB across years (all treatments)					
Year					
2008			0.654	0.765	93.7
2009			0.697	0.779	89.5
2010			0.721	0.819	91.6
P > F:			<0.001	<0.001	0.019
LSD (0.05):			0.006	0.009	2.3
Treatment					
0	0	0	0.641	0.758	70.0
60	0	60	0.698	0.805	87.0
90	0	90	0.700	0.798	91.1
60	40 (V3)	100	0.700	0.796	95.1
120	0	120	0.704	0.807	94.9
150	0	150	0.699	0.791	95.1
180	0	180	0.704	0.794	98.6
0	90 (V3)	90	0.685	0.770	95.0
0	120 (V3)	120	0.683	0.772	97.3
Statistical Analysis					
P > F:			<0.001	<0.001	<0.001
LSD (0.05):			0.008	0.016	2.2
CV (%):			1.3	2.2	2.6
Interactions (P>F)					
Yr x treatment			<0.001	0.139	<0.001
Contrasts (P>F)					
Preplant vs split			0.346	0.203	0.857
PP vs Sidedress			<0.001	<0.001	<0.001

Table 21. Three-yr average second-year corn grain and total DM yield, grain moisture, and N concentrations in the stover and grain as influenced by N rate and time of application in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Yield		Grain	Stover	Grain
Preplant	SD	Total	Grain	Total	H_2O	[N]	[N]
------- lb N/A -------			bu/A	TDM/A	%	--- % ---	
Stats for RCB across years (all treatments)							
Year							
2008			160.1	6.39	20.0	0.58	1.27
2009			149.4	6.01	27.9	0.48	1.18
2010			142.0	5.71	22.0	0.46	1.10
P > F:			0.031	0.044	0.001	0.007	0.009
LSD (0.05):			11.7	0.15	1.0	0.06	0.08
Treatment							
0	0	0	60.6	2.67	27.4	0.39	0.99
80	0	80	131.9	5.55	22.7	0.37	1.10
120	0	120	153.1	6.21	21.7	0.44	1.16
60	80 (V3)	140	169.7	6.51	22.0	0.49	1.23
160	0	160	166.7	6.48	22.1	0.56	1.20
200	0	200	166.9	6.57	22.6	0.59	1.28
240	0	240	177.2	6.83	22.9	0.72	1.29
0	120 (V3)	120	156.8	6.51	23.9	0.48	1.17
0	160 (V3)	160	171.4	7.00	24.4	0.54	1.24
Statistical Analysis							
P > F:			<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05):			9.2	0.45	1.6	0.06	0.05
CV (%):			6.5	7.8	7.4	12.2	4.6
Interactions (P>F)							
Yr x treatment			<0.001	<0.001	0.077	<0.001	<0.001
Contrasts (P>F)							
Preplant vs split			0.504	0.917	0.924	0.016	0.392
PP vs Sidedress			0.198	0.013	<0.001	0.728	0.217

Table 22. Three-yr average N uptake in the grain, stover, and total DM; apparent fertilizer recovery in the total DM and grain, and NUE as influenced by N rate and time of application for second-year corn in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Nitrogen Uptake			Apparent N Recovery		
Preplant	SD	Total	Grain	Stover	Total DM	Total	Grain	NUE
- - - - - - - lb N/A - - - - - - -			- - - - - - - lb N/A - - - - - - -			%	%	bu/lb N
Stats for RCB across years (all treatments)								
Year								
2008			98.1	31.1	129.2	67	52	0.72
2009			85.9	24.0	109.8	59	48	0.75
2010			74.3	22.4	96.7	43	33	0.64
P > F:			0.001	0.004	<0.001			
LSD (0.05):			5.1	3.3	6.2			
Treatment								
0	0	0	28.6	9.5	38.1	--	--	--
80	0	80	69.9	18.3	88.2	63	52	0.89
120	0	120	85.4	23.2	108.5	59	47	0.77
60	80 (V3)	140	98.4	24.5	122.9	61	50	0.78
160	0	160	95.3	28.9	124.1	54	42	0.66
200	0	200	101.2	31.7	132.9	47	36	0.53
240	0	240	107.7	38.0	145.8	45	33	0.49
0	120 (V3)	120	87.3	26.9	114.2	63	49	0.80
0	160 (V3)	160	101.1	31.5	132.7	59	45	0.69
Statistical Analysis								
P > F:			<0.001	<0.001	<0.001			
LSD (0.05):			6.3	5.2	9.0			
CV (%):			7.7	21.1	7.5			
Interactions (P>F)								
Yr x treatment			<0.001	0.001	<0.001			
Contrasts (P>F)								
Preplant vs split			0.313	0.095	0.782			
PP vs Sidedress			0.083	0.085	0.030			

Table 23. Three-yr average NDVI measurements taken by the Crop Circle and GreenSeeker instruments and relative chlorophyll content as influenced by N rate and time of application for second-year corn in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rate			Crop Circle	GreenSeeker	Relative
Preplant	SD	Total	V9	V8	Chlorophyll
----------- lb N/A -----------			------- NDVI -------		%
Stats for RCB across years (all treatments)					
Year					
2008			0.597	0.721	91.1
2009			0.660	0.699	87.2
2010			0.663	0.741	86.4
P > F:			0.001	0.022	0.032
LSD (0.05):			0.016	0.024	3.3
Treatment					
0	0	0	0.512	0.576	58.0
80	0	80	0.656	0.744	81.2
120	0	120	0.668	0.751	88.7
60	80 (V3)	140	0.676	0.764	94.7
160	0	160	0.673	0.762	92.3
200	0	200	0.671	0.756	92.5
240	0	240	0.677	0.766	96.0
0	120 (V3)	120	0.599	0.665	94.4
0	160 (V3)	160	0.627	0.698	96.4
Statistical Analysis					
P > F:			<0.001	<0.001	<0.001
LSD (0.05):			0.017	0.027	2.7
CV (%):			2.7	4.0	3.3
Interactions (P>F)					
Yr x treatment			<0.001	<0.001	<0.001
Contrasts (P>F)					
Preplant vs split			0.758	0.857	0.088
PP vs Sidedress			<0.001	<0.001	<0.001

Table 24. Three-yr average economic return to fertilizer N as affected by N rates and method of N application for first-year and second-year corn at Waseca, 2008-10.

N Rate/Method				Fert. N and Corn Grain Price Scenario[2/]		
Preplant	SD	Total	ΔYield[1/]	A	B	C
-------- lb N/ A ----------			bu/A	---------- $/A ----------		
			First-Year Corn			
0	0	0	0	--	--	--
60	0	60	45.4	158.	170.	261.
90	0	90	64.5	222.	242.	371.
60	40 (V3)	100	65.8	214	228.	360.
120	0	120	73.0	244.	267.	413.
150	0	150	77.1	248.	272.	426.
180	0	180	79.5	246.	269.	428.
0	90 (V3)	90	75.0	264.	283.	433.
0	120 (V3)	120	76.7	259.	277.	429.
			Second-Year Corn			
0	0	0	0	--	--	--
80	0	80	71.3	253.	285.	427.
120	0	120	92.5	322.	362.	547.
60	80 (V3)	140	109.1	371.	403.	621.
160	0	160	106.1	360.	405.	618.
200	0	200	106.3	345.	388.	601.
240	0	240	116.6	370.	417.	650.
0	120 (V3)	120	96.2	337.	363.	556.
0	160 (V3)	160	110.8	379.	409.	631.

[1/] ΔYield = N treatment yield – zero-N control yield.

[2/] Scenario =

A: N = $0.40/lb (extra application = $9.50/A) and corn = $4.00/bu.

B: Urea = $0.45/lb (application = $7.50/A), and corn = $4.50/bu.
UAN = $0.50/lb (application = $9.50/A).

C: Nitrogen = same as in B and corn = $6.50.

Table 25. Three-yr average soybean yield, seed N concentration, and seed N removal as influenced by the residual affects of N rate and time of application for first and second-year corn in a C-C-S rotation/drainage study at Waseca, 2008-10.

N Rates for Previous Corn			Soybean Seed		
Preplant	SD	Total	Yield	[N]	Removal
------- lb N/A -------			bu/A	%	lb N/A
Stats for RCB across years (all treatments)					
Year					
2008			48.2	4.96	125.
2009			46.0	5.27	126.
2010			52.5	5.19	142.
P > F:			0.004	<0.001	0.005
LSD (0.05):			2.4	0.04	7.
Treatment					
0	0	0	51.5	5.11	137.
80	0	80	46.5	5.10	124.
120	0	120	48.6	5.14	131.
60	80 (V3)	140	49.1	5.16	132.
160	0	160	48.8	5.16	131.
200	0	200	48.6	5.14	130.
240	0	240	49.5	5.18	134.
0	120 (V3)	120	48.8	5.13	130.
0	160 (V3)	160	48.4	5.14	130.
Statistical Analysis					
P > F:			0.269	0.218	0.202
LSD (0.05):			NS	NS	NS
CV (%):			7.0	1.3	7.0
Interactions (P>F)					
Yr x treatment			0.953	0.626	0.922

Table 26. Four-yr average first-year corn grain and total DM yields, grain moisture and N concentrations in the stover and grain as influenced by N rate and time of application in a C-C-S rotation/drainage study at Waseca, 2007-10.

N Rate			Yield		Grain	Stover	Grain
Preplant	SD	Total	Grain	Total DM	H_2O	[N]	[N]
- - - - - lb N/A - - - - -			bu/A	T DM/A	- - - - - - - % - - - - - - -		
Stats for RCB across years (all treatments)							
Year							
2007			170.7	7.14	15.7	0.52	1.30
2008			179.2	7.03	20.2	0.55	1.26
2009			163.0	6.47	26.4	0.40	1.10
2010			168.8	6.61	20.7	0.49	1.10
P>F:			0.018	0.010	<0.001	0.004	0.001
LSD (0.05):			8.4	0.35	1.4	0.06	0.07
Treatment							
0	0	0	112.7	4.85	21.7	0.37	1.02
60	0	60	159.0	6.48	20.8	0.41	1.09
90	0	90	180.4	7.25	20.8	0.46	1.19
60	40 (V3)	100	181.5	7.16	20.3	0.47	1.24
120	0	120	185.8	7.39	20.6	0.51	1.21
150	0	150	188.3	7.34	20.6	0.57	1.26
180	0	180	185.4	7.23	20.6	0.65	1.32
Statistical Analysis							
P>F:			<0.001	<0.001	0.019	<0.001	<0.001
LSD (0.05):			9.6	0.37	0.7	0.06	0.05
CV (%):			6.9	6.6	4.4	14.4	5.2
Interactions (P>F)							
Yr x treatment			0.012	0.034	0.271	0.400	0.005
Contrast (P>F)							
Preplant vs Split			0.377	0.204	0.475	0.189	0.328

Table 27. Four-yr average N uptake in the grain, stover, and total DM; apparent fertilizer N recovery in the total DM and grain; and NUE as influenced by rate and time of N application for first-year corn in a C-C-S rotation/drainage study at Waseca, 2007-2010.

N Rate			Nitrogen Uptake			Apparent N Recovery		
Preplant	SD	Total	Grain	Stover	Total DM	Total	Grain	NUE
------- lb N/A -------			-------- lb N/A --------			------- % -------		bu/lb N
Stats for RCB across years (all treatments)								
Year								
2007			106.6	32.8	139.4	66	53	0.64
2008			107.9	31.1	139.1	66	52	0.65
2009			85.5	21.3	106.8	42	36	0.53
2010			88.7	25.7	114.4	49	38	0.66
P>F:			0.002	0.002	<0.001			
LSD (0.05):			9.6	4.3	10.0			
Treatment								
0	0	0	54.6	16.3	70.9	--	--	--
60	0	60	82.4	22.4	104.8	57	46	0.77
90	0	90	102.4	27.3	129.6	65	53	0.75
60	40 (V3)	100	106.6	27.4	134.0	63	52	0.69
120	0	120	107.0	30.9	137.9	56	44	0.61
150	0	150	112.8	32.8	145.6	50	39	0.50
180	0	180	114.6	37.0	151.6	45	33	0.40
Statistical Analysis								
P>F:			<0.001	<0.001	<0.001			
LSD (0.05):			6.6	3.8	8.3			
CV (%):			8.2	16.8	8.1			
Interactions (P>F)								
Yr x treatment			0.001	0.240	0.003			
Contrast (P>F)								
Preplant vs Split			0.891	0.072	0.342			

Table 28. Four-yr average NDVI measurements taken by Crop Circle and GreenSeeker instruments and relative chlorophyll content as influenced by N rate and time of N application for first year corn in a C-C-S rotation/drainage study at Waseca, 2007-2010.

N Rate			Crop Circle	GreenSeeker	Relative
Preplant	SD	Total	V9	V8	chlorophyll
-------- lb N/A --------			---------- NDVI ----------		%
Stats for RCB across years (all treatments)					
Year					
2007			0.684	0.593	95.0
2008			0.666	0.772	93.9
2009			0.697	0.784	87.1
2010			0.719	0.822	89.9
P<F:			<0.001	<0.001	0.003
LSD (0.05):			0.007	0.016	3.3
Treatment					
0	0	0	0.642	0.707	72.9
60	0	60	0.697	0.754	89.2
90	0	90	0.698	0.752	92.7
60	40 (V3)	100	0.698	0.755	96.0
120	0	120	0.701	0.748	95.7
150	0	150	0.698	0.746	95.8
180	0	180	0.697	0.737	97.9
Statistical Analysis					
P<F:			<0.001	<0.001	<0.001
LSD (0.05):			0.008	0.015	2.6
CV (%):			1.4	2.5	3.5
Interaction (P>F)					
Yr x treatment			0.006	0.009	<0.001
Contrast (P>F)					
Preplant vs. Split			0.363	0.368	0.833

Table 29. Four-yr average second-yr corn grain and total DM yield, grain moisture, and N concentrations in the stover and grain as influenced by N rate and time of N application in a C-C-S rotation/drainage study at Waseca, 2007-2010.

N Rate			Yield		Grain	Stover	Grain
Preplant	SD	Total	Grain	Total DM	H_2O	[N]	[N]
-------- lb N/A --------			bu/A	T DM/A	----------- % -----------		
Stats for RCB across years (all treatments)							
Year							
2007			152.6	6.40	16.1	0.57	1.36
2008			158.9	6.36	20.0	0.60	1.28
2009			140.4	5.71	27.6	0.46	1.16
2010			140.5	5.43	21.5	0.46	1.10
P<F:			0.045	0.025	<0.001	0.002	<0.001
LSD (0.05):			14.0	0.64	1.3	0.06	0.07
Treatment							
0	0	0	65.9	2.95	24.5	0.39	1.03
80	0	80	135.8	5.71	20.9	0.39	1.13
120	0	120	154.4	6.34	20.4	0.45	1.21
60	80 (V3)	140	171.7	6.67	20.4	0.50	1.25
120	0	160	164.6	6.46	20.6	0.58	1.27
200	0	200	168.1	6.84	21.0	0.64	1.33
240	0	240	176.2	6.86	21.3	0.72	1.35
Statistical Analysis							
P<F:			<0.001	<0.001	<0.001	<0.001	<0.001
LSD (0.05):			8.6	0.36	1.3	0.05	0.05
CV (%):			7.1	7.3	7.4	12.6	4.9
Interaction (P>F)							
Yr x treatment			<0.001	0.002	0.001	<0.001	<0.001
Contrast (P>F)							
Preplant vs. Split			0.119	0.251	0.817	0.011	0.545

Table 30. Four-yr average N uptake in the grain, stover, and total DM; apparent fertilizer N recovery in the total DM and grain; and NUE as influenced by rate and time of N application for second-year corn in a C-C-S rotation/drainage study at Waseca, 2007-2010.

N Rate			Nitrogen Uptake			Apparent N Recovery		
Preplant	SD	Total	Grain	Stover	Total DM	Total	Grain	NUE
- - - - - lb N/A - - - - -			- - - - - lb N/A - - - - -			- - - - % - - - -		bu/lb N
Stats for RCB across years (all treatments)								
Year								
2007			99.1	33.2	132.3	56	43	0.58
2008			98.4	31.9	130.3	70	54	0.73
2009			79.6	22.6	102.2	54	44	0.68
2010			73.3	20.1	93.4	41	33	0.64
P>F:			0.002	<0.001	<0.001			
LSD (0.05):			10.1	3.8	11.3			
Treatment								
0	0	0	32.6	10.7	43.3	--	--	--
80	0	80	73.8	19.6	93.4	63	51	0.87
120	0	120	89.5	24.4	113.9	59	47	0.74
60	80 (V3)	140	101.9	26.6	128.5	61	50	0.76
160	0	160	98.2	30.3	128.5	53	41	0.62
200	0	200	106.3	37.7	143.9	50	37	0.51
240	0	240	111.0	39.3	150.3	45	33	0.46
Statistical Analysis								
P>F:			<0.001	<0.001	<0.001			
LSD (0.05):			6.5	4.0	8.0			
CV (%):			9.1	18.6	8.6			
Interactions (P>F)								
Yr x treatment			0.002	0.001	0.001			
Contrast (P>F)								
Preplant vs Split			0.252	0.070	0.998			

Table 31. Four-yr average NDVI measurements taken by Crop Circle and GreenSeeker instruments and relative chlorophyll content as influenced by N rate and time of N application for second-yr corn in a C-C-S rotation/drainage study at Waseca, 2007-2010.

N Rate			Crop Circle	GreenSeeker	Relative
Preplant	SD	Total	V9	V8	chlorophyll
-------- lb N/A --------			---------- NDVI ----------		%
Stats for RCB across years (all treatments)					
Year					
2007			0.653	0.524	92.5
2008			0.611	0.730	91.1
2009			0.662	0.709	84.3
2010			0.669	0.755	83.2
P<F:			<0.001	<0.001	<0.001
LSD (0.05):			0.013	0.024	2.6
Treatment					
0	0	0	0.527	0.538	61.4
80	0	80	0.664	0.702	83.6
120	0	120	0.667	0.701	90.9
60	80 (V3)	140	0.676	0.713	95.5
160	0	160	0.664	0.692	93.8
200	0	200	0.667	0.697	93.4
240	0	240	0.676	0.713	95.7
Statistical Analysis					
P<F:			<0.001	<0.001	<0.001
LSD (0.05):			0.013	0.027	2.8
CV (%):			2.5	4.9	3.9
Interaction (P>F)					
Yr x treatment			<0.001	<0.001	<0.001
Contrast (P>F)					
Preplant vs. Split			0.068	0.124	0.210

Table 32. Four-yr average economic return to fertilizer N as affected by N rates and method of N application for first-year and second-year corn at Waseca, 2007-10.

N Rate/Method				Fert. N and Corn Grain Price Scenario[2/]		
Preplant	SD	Total	ΔYield[1/]	A	B	C
-------- lb N/ A ----------			bu/A	---------- $/A ----------		
First-Year Corn						
0	0	0	0	--	--	--
60	0	60	46.3	161.	174.	266.
90	0	90	67.7	235.	257.	392.
60	40 (V3)	100	68.8	226.	246.	383.
120	0	120	73.1	244.	267.	414.
150	0	150	75.6	242.	265.	416.
180	0	180	72.7	219.	239.	384.
Second-Year Corn						
0	0	0	0	--	--	--
80	0	80	69.9	248.	279.	418.
120	0	120	88.5	306.	344.	521.
60	80 (V3)	140	105.8	358.	392.	604.
160	0	160	98.7	331.	372.	570.
200	0	200	102.2	329.	370.	574.
240	0	240	110.3	345.	388.	609.

[1/] ΔYield = N treatment yield – zero-N control yield.

[2/] Scenario =

A: N = $0.40/lb (extra application = $9.50/A) and corn = $4.00/bu.

B: Urea = $0.45/lb (application = $7.50/A) and corn = $4.00/bu.
UAN = $0.50/lb (application = $9.50/A).

C: Nitrogen = same as in B and corn = $6.50/bu.

Table 33. Annual tile water discharge from the C-C-S and continuous corn plots for each of the N treatments in 2007-2010.

N Rate/Time			Year				4-Yr
Preplant	SD	Total	2007	2008	2009	2010	Total
------ lb N/A ------			---------------------- inches (SE)[1/] ----------------------				
			First-Year Corn				
0	0	0	14.5 (4.0)	2.5 (1.2)	1.4 (0.8)	22.3 (4.5)	40.7
60	40	100	11.0 (1.8)	1.5 (0.4)	0.1 (0.1)	18.3 (3.6)	30.9
120	0	120	13.8 (2.4)	2.0 (0.4)	0.6 (0.4)	21.6 (4.7)	38.0
	Avg.		13.1	2.0	0.7	20.7	36.5
			Second-Year Corn				
0	0	0	12.4 (3.2)	5.0 (1.7)	1.0 (0.7)	17.5 (1.8)	35.9
60	80	140	13.7 (2.4)	3.0 (1.6)	0.4 (0.1)	21.6 (1.7)	38.7
160	0	160	10.5 (2.1)	5.5 (1.4)	0.8 (0.4)	26.8 (2.7)	43.6
	Avg.		12.2	4.5	0.7	22.0	39.4
			Soybeans				
0	0	0	10.1 (2.4)	4.0 (1.9)	1.3 (0.6)	16.9 (3.5)	32.3
0	0	0	9.5 (1.1)	3.3 (1.4)	0.6 (0.3)	22.1 (2.4)	35.5
0	0	0	9.2 (1.2)	2.8 (1.4)	1.4 (0.5)	21.5 (2.5)	34.9
	Avg.		9.6	3.4	1.0	20.2	34.2
			Continuous Corn				
160	0	160	11.5 (6.5)	3.4 (3.1)	1.2 (1.1)	17.0 (6.1)	33.1

[1/] Standard error of the mean (SE).

Table 34. Annual flow-weighted NO_3-N concentrations from the C-C-S and continuous corn plots as affected by rate and time of N application, 2007-2010.

N Rate/Time			Year				4-Yr
Preplant	SD	Total	2007	2008	2009	2010	Average
------ lb N/A ------			------------------ mg NO_3-N/L (SE)[1/] ------------------				
			First-Year Corn				
0	0	0	5.3 (1.1)	11.6 (2.0)	4.1 (0.4)	4.0 (0.7)	6.2
60	40	100	8.3 (1.2)	11.5 (1.7)	--	8.2 (0.6)	9.3
120	0	120	7.8 (0.6)	11.2 (1.7)	6.1 (2.1)	6.4 (0.4)	7.9
			Second-Year Corn				
0	0	0	5.6 (0.8)	7.0 (0.8)	3.0 (1.6)	3.0 (0.4)	4.6
60	80	140	11.0 (0.5)	11.0 (0.6)	3.9 (1.3)	5.1 (0.1)	7.8
160	0	160	12.5 (2.4)	12.2 (1.1)	5.5 (1.4)	5.6 (0.3)	9.0
			Soybeans				
0	0	0	4.8 (1.2)	6.8 (0.8)	6.9 (1.0)	3.8 (0.7)	5.6
0	0	0	6.3 (0.9)	12.3 (1.9)	9.9 (0.5)	4.1 (1.0)	8.2
0	0	0	6.5 (1.1)	11.7 (0.5)	12.6 (0.3)	4.8 (0.8)	8.9
			Continuous Corn				
160	0	160	8.2 (2.5)	11.0 (3.2)	6.6 (3.7)	6.2 (0.9)	8.0

[1/] Standard error of the mean (SE).

Table 35. Annual NO_3-N losses from the C-C-S rotation and continuous corn as affected by rate and time of N application, 2007-2010.

N Rate/Time			Year				4-Yr
Preplant	SD	Total	2007	2008	2009	2010	Total
------ lb N/A ------			------------------ lb NO_3 N/A (SE)[1/] ------------------				
			First-Year Corn				
0	0	0	19.2 (8.3)	5.7 (2.2)	1.4 (0.8)	21.3 (8.1)	47.6
60	40	100	20.5 (3.8)	3.7 (0.8)	0.4 (0.4)	33.1 (4.8)	57.7
120	0	120	24.2 (3.9)	4.8 (0.3)	1.1 (1.1)	31.7 (7.3)	61.8
			Second-Year Corn				
0	0	0	15.1 (3.2)	8.6 (3.7)	1.2 (1.0)	11.6 (0.8)	36.5
60	80	140	33.9 (5.4)	7.7 (4.4)	0.4 (0.2)	25.1 (2.3)	67.1
160	0	160	27.9 (2.8)	14.6 (2.7)	1.2 (0.7)	34.3 (4.4)	78.0
			Soybeans				
0	0	0	11.9 (5.3)	5.6 (2.3)	1.8 (1.2)	14.3 (4.0)	33.6
0	0	0	13.1 (1.1)	9.1 (4.4)	1.2 (0.6)	19.7 (3.5)	43.1
0	0	0	13.3 (2.6)	7.8 (4.2)	3.8 (1.3)	22.6 (1.6)	47.5
			Continuous Corn				
160	0	160	27.7 (21.1)	8.9 (8.4)	2.6 (2.5)	26.1 (12.8)	65.3

[1/] Standard error of the mean (SE).

Table 36. Four-yr NO_3-N loss to tile drainage normalized for drain flow for each N treatment within each crop as affected by crop and rate/time of N, 2007-10.

N Rate/Time			4-Yr Avg. ΔCorn[1/]	4-Yr Total		NO_3-N lost/in	Increase over Control		Ratio of ΔYield (bu/A):
PP	SD	Total	Yield	NO_3-N lost	Drainage	of drainage	ΔNO_3-N lost [2/]	Percent	ΔNO_3-N (lb/in)
----- lb N/A -----			bu/A	lb/A	inches	lb/in	lb/in	%	[3/]
				First-Year Corn					
0	0	0	0	47.6	40.7	1.17	0	--	--
60	40	100	68.8	57.7	30.9	1.87	0.70	60	98
120	0	120	73.1	61.8	38.0	1.63	0.46	39	159
				Second-Year Corn					
0	0	0	0	36.5	35.9	1.02	0	--	--
60	80	140	105.8	67.1	38.7	1.73	0.71	70	149
160	0	0	98.7	78.0	43.6	1.79	0.77	75	128
				Soybeans					
0	0	0	0	33.6	32.3	1.04	0	--	
0	0	0	0	43.1	35.5	1.21	0.17	16	
0	0	0	0	47.5	34.9	1.36	0.32	31	
				Corn-Corn-Soybean Rotation					
Control						1.08	0	--	--
85% split						1.60	0.52	49	124
100% preplant						1.59	0.51	48	144

1/ Δ Yield = N treatment yield – zero-N control yield.

2/ Δ NO_3-N = N treatment NO_3-N lost – zero-N control NO_3-N lost/inch of "flow-normalized" drainage.

3/ Lower ratios within a crop/cropping system indicate less corn yield per lb of nitrate lost in the tile drainage = less desirable.

Table 37. Four-yr NO_3-N loss to tile drainage normalized for drain flow across the three N treatments within each crop as affected by crop and rate/time of N, 2007-10.

N Rate/Time			4-Yr Avg. ΔCorn	4-Yr Total		NO_3-N lost/in	Increase over Control		Ratio of ΔYield (bu/A):
PP	SD	Total	Yield[1/]	NO_3-N lost	Drainage	of drainage	ΔNO_3-N lost [2/]	Percent	ΔNO_3-N (lb/in)
- - - - - lb N/A - - - - -			bu/A	lb/A	Inches	lb/in	lb/in	%	[3/]
					First-Year Corn				
0	0	0	0	47.6	40.7	1.30	0	--	--
60	40	100	68.8	57.7	30.9	1.58	0.28	22	246
120	0	120	73.1	61.8	38.0	1.69	0.39	30	187
					36.5				
					Second-Year Corn				
0	0	0	0	36.5	35.9	0.93	0	--	--
60	80	140	105.8	67.1	38.7	1.70	0.77	83	137
160	0	0	98.7	78.0	43.6	1.98	1.05	113	94
					39.4				
					Soybeans				
0	0	0	0	33.6	32.3	0.98	0	--	
0	0	0	0	43.1	35.5	1.26	0.28	29	
0	0	0	0	47.5	34.9	1.39	0.41	42	
					34.2				
					Corn-Corn-Soybean Rotation				
Control						1.07	0	--	--
85% split						1.60	0.44	45	192
100% preplant						1.69	0.62	62	140

[1/] Δ Yield = N treatment yield – zero-N control yield.

[2/] Δ NO_3-N = N treatment NO_3-N lost – zero-N control NO_3-N lost/inch of "flow-normalized" drainage.

[3/] Lower ratios within a crop/cropping system indicate less corn yield per lb of nitrate lost in the tile drainage = less desirable.

Table 38. Four-yr NO_3-N loss to tile drainage normalized for drain flow across the three N treatments and three crops (27 plots = 36.7") as affected by crop and rate/time of N, 2007-10.

N Rate/Time			4-Yr Avg. ΔCorn Yield[1/]	4-Yr Total		NO_3-N lost/in of drainage	Increase over Control		Ratio of ΔYield (bu/A): ΔNO_3-N (lb/in)
PP	SD	Total		NO_3-N lost	Drainage		ΔNO_3-N lost [2/]	Percent	
----- lb N/A -----			bu/A	lb/A	Inches	lb/in	lb/in	%	[3/]
First-Year Corn									
0	0	0	0	47.6	40.7	1.30	0	--	--
60	40	100	68.8	57.7	30.9	1.57	0.27	21	255
120	0	120	73.1	61.8	38.0	1.68	0.38	29	192
Second-Year Corn									
0	0	0	0	36.5	35.9	0.99	0	--	--
60	80	140	105.8	67.1	38.7	1.83	0.84	85	126
160	0	0	98.7	78.0	43.6	2.12	1.13	114	87
Soybeans									
0	0	0	0	33.6	32.3	0.92	0	--	
0	0	0	0	43.1	35.5	1.17	0.25	27	
0	0	0	0	47.5	34.9	1.29	0.37	40	
Corn-Corn-Soybean Rotation									
Control						1.07	0	--	--
85% split						1.52	0.45	44	190
100% preplant						1.70	0.63	61	140

[1/] Δ Yield = N treatment yield – zero-N control yield.

[2/] Δ NO_3-N = N treatment NO_3-N lost – zero-N control NO_3-N lost/inch of "flow-normalized" drainage (36.7").

[3/] Lower ratios within a crop/cropping system indicate less corn yield per lb of nitrate lost in the tile drainage = less desirable.

APPROVED electronic - attached

BY: Bruce Montgomery
Project Manager Date: 4-4-11