INTRODUCTION

Improving nitrogen (N) use efficiency in crop production is important for obvious economic and environmental reasons. Nitrogen fertilization of corn usually provides the greatest return on investment of any crop input; therefore, farmers and their agricultural advisors must insure adequate N is available for the crop to maximize yields and economic returns. Soil contains N in organic (soil organic matter and microorganisms) and inorganic (ammonium and nitrate) forms. Nitrate is mobile in the soil and can be lost due to leaching and denitrification both of which have environmental consequences. Minimizing N loss and maximizing crop productivity is critical for increasing nitrogen use efficiency (NUE) in corn.

Crop rotation, N source, N rate, time of N application and the use of N stabilizers are all factors considered when making N recommendations. Generally, N application timing and N rate are the most scrutinized of these management decisions. The ideal time to apply fertilizer N would be just prior to the crops demand for N. Corn uses only 10% of its total N need prior to the V5 growth stage (V5 usually early June in Minnesota). From V5 to R2 the rate of N uptake peaks (Abendroth et al. 2011). At R3, the rate of uptake diminishes but uptake continues through R5. The uptake pattern of corn suggests the ideal time to apply N in corn is early June. However, June is the wettest month in most Minnesota counties and waiting until early June to sidedress all fertilizer N for corn is risky for both farmers and their fertilizer dealers. Therefore, some or all fertilizer N is applied prior to planting when farmers have more time and soil conditions allow, especially on medium and fine textured soils. The desire to increase yields and NUE while minimizing N losses has resulted in a dramatic increase in sidedress applications of N in Minnesota in recent years. For some of the same reasons farmers are also interested in “fine tuning” their N rates.

Minnesota and several other Midwest states use the MRTN approach for making N recommendations (Sawyer et al., 2006). Hundreds of site-years of N rate research plots, where Economic Optimum Nitrogen Rate (EONR) was determined, were included in this recommendation algorithm. The MRTN database has shown optimum N rates are not influenced by yield level and the MRTN approach assumes rates are relatively stable across time and landscape positions within a field. The MRTN rate recommendations are affected or adjusted based on crop rotation, price of N and corn and by soil type (parent material and/or productivity rating) in some states. Research has shown and soil scientists generally agree EONR can vary across landscape and time. However, predicting this variability, which is primarily driven by weather, and incorporating it into N recommendations has been difficult.

The majority of plant available nitrogen comes from two sources, N mineralized from soil organic matter and N additions (commercial fertilizer and manures). Mineralization of N and N losses from leaching and denitrification vary as a result of soil and climatic factors (primarily excessive rainfall), which cannot be predicted. The length of time between N application and N uptake in corn drives these losses. Adjusting N rates in-season with sidedress applications has been proposed as a method to improve N recommendations and N use efficiency (NUE).

The pre-sidedress nitrogen test (PSNT) was first proposed by Magdoff et al. (1984) as a 0-1 ft soil nitrate test taken just prior to sidedress, when corn was about 12-inches tall. The premise of the PSNT was waiting until sidedress time to sample would integrate early spring N mineralization from organic matter and spring weather conditions that drive both the amount of N available for the plant and the loss of N from the soil (Magdoff, 1991). This research showed the PSNT improved N recommendations in the northeast USA and eastern Midwest. The PSNT was adopted by some growers who regularly applied some or all fertilizer N at sidedress.
Fox et al. (1989) found the PSNT was effective at establishing a critical level for when no additional fertilizer N was needed, but it could not be accurately calibrated to base or adjust sidedress N recommendations. In Iowa, Blackmer et al. (1989) found the PSNT had great potential for improving N management in the Corn Belt, however they concluded as did Fox et al., the PSNT was best at predicting when no additional fertilizer N was needed.

In Minnesota, Schmitt and Randall (1994) compared the PSNT to a preplant nitrate test (PPNT) taken to a 0-2 ft depth. They found the PPNT was a sound, accurate and more practical soil N test for Minnesota growers, who were less likely to sidedress N. They developed an algorithm that predicted a soil N credit based on the PPNT result. The best results were obtained and the algorithm was developed from N responsive continuous corn experiments. They proposed a soil N credit, based on the PPNT, would be subtracted from a conventional N rate recommendation (based on yield goal at that time). The Minnesota PPNT should not be used on coarse textured soils and has the greatest potential for success for corn grown after corn and corn grown following a dry growing season (Schmitt and Randall, 1994).

Currently in Minnesota, there is interest in using sidedress N applications to “fine-tune” current N recommendations, primarily for yield enhancement. The objectives of this research project are 1) to demonstrate and evaluate soil-based (PSNT) methods for making in-season N rate adjustments (recommendations); 2) to evaluate the method’s ability to integrate climate and landscape based variability at the field scale; 3) to compare this PSNT approach for making N recommendations to a conventional preplant application by measuring grain yield, N removal, residual soil nitrate and economic return; and 4) to determine if the PSNT approach will improve N management for corn in Minnesota.

METHODS

Two research sites were established in southern Minnesota in 2014. Both were corn following soybean. A randomized complete block design of field length strips with a minimum of four replications was used at each location. The width of strips depended on available application equipment; whereas, the length of strips depended on field size and plot layout. Three fertilizer N treatments were applied with commercial application equipment by Central Valley Coop (CVC). Two treatments included a preplant fixed N rate plus a sidedress rate to be applied around V6. For treatment number 1 (fixed 75/25), a fixed rate of N (105 lb N/ac) was applied preplant with the intention of applying a fixed sidedress rate of 35 lb N/ac. For treatment number 2 (variable 65/35), a fixed rate of N (100 lb N/ac) was applied preplant with the intention of applying a variable sidedress rate averaging 40 lb N/ac. This variable rate would be based on PSNT soil samples collected from these plots. The third treatment was a fixed preplant only (U of M), MRTN based rate of 120 lb N/ac.

Soil samples [12-15 (0.75-inch diameter) cores to a 6-inch depth] were taken prior to planting on 2.5 ac grids to characterize the research site within the field. These samples were kept cool and moist before being delivered to Solum (Climate Corp.) in Ames, IA where they were analyzed for P, K, Zn (Mehlich III extractant), pH, soil organic matter, and CEC. At the V1-2 and V4-6 growth stages of corn, PSNT soil samples [8-10 (0.75-inch diameter) cores] were taken from each plot location (2-4 locations per strip-plot) at 0-1 and 1-2 ft depths. These samples were kept cool and moist before being delivered to CVC’s lab where they were analyzed for nitrate using the No-Wait Nitrate testing tool (Solum Inc., Mountain View, CA and Ames, IA). After being thoroughly mixed and analyzed for nitrate (No-Wait test) the samples were returned to the U of M SROC, dried at 125 degree F, ground and analyzed by a commercial lab for nitrate and ammonium nitrogen. After harvest, soil samples [2-3 (1.75-inch diameter) cores] were taken from each plot location (2-3 locations per strip-plot) at 0-2 and 2-4 ft depths. These samples were dried at 125 degree F, ground and analyzed by a commercial lab for nitrate and ammonium nitrogen.

Grain yield data were collected using the farmer cooperators combine via yield monitor and weigh wagon. The producer’s combine yield monitors were calibrated prior to harvest. A single grain sample was collected from each strip and analyzed for protein via NIR. Yield monitor data were processed using GK Technologies Ag Data
Manager software. Partial Factor Productivity (PFP) was calculated by dividing grain yield by the N applied and is reported as bushels per pound of N.

During the growing season remote sensing data (Crop Circle and aerial imagery) were collected at various stages to assist in evaluating the N response of corn to N treatments. The imagery was also used to identify problem areas (primarily plant stand and excess water issues) within the fields. The date each experimental procedure was completed at each location are presented in Table 1.

RESULTS AND DISCUSSION

Weather data

Weather data for each location are presented in Tables 3a (BP14), 3b (NF14) and Figures 1a and 1b. In-situ weather stations were installed at each location after planting to minimize the inconvenience for the farmer cooperator, which was especially important in a late spring like 2014. Prior to installation, precipitation data were obtained from the local observer network (State Climatology website) and temperature data were taken from Waseca if no local data were available. All climatic data were summarized at 8 am for the previous 24-hour period.

Late April and early May were cool and wet at both locations. Frequent rainfall events did not allow time for field operations or planting in south-central Minnesota during this period of 2014. Nearly two inches of precipitation was recorded at BP14 (Table 3a) in the first two weeks of May; whereas, NF14 (Table 3b) had 3.68 inches during the same period. Near the end of May, drier and warmer weather allowed for planting to be performed at both sites. Excessive rainfall occurred during a period from June 14 – 20, 6.6 and 5.7 inches were recorded at BP14 and NF14, respectively. Soils were saturated for several days as evidenced by the spike in soil moisture (Figure 1a and 1b), especially at BP14. These conditions were ideal for denitrification and leaching losses of fertilizer N applied in May. July was cool and drier than normal as was the first three weeks of August at both locations. Soil moisture declined steadily from mid July through the third week of August when much needed precipitation brought some relief to moisture stressed corn plants. Cool temperatures persisted throughout much of the growing season resulting in considerable less than normal growing degree unit accumulation (GDU). GDU’s from planting to first frost totaled only 2112 and 2101 at BP14 and NF14, respectively. These totals are about 400 less than normal and resulted in corn that had not fully matured prior to an early frost on September 13. Less than ideal growing conditions – wet spring, late planting, excessively wet June, cool and dry summer and early freeze – resulted in poor corn yields in these studies and throughout south-central Minnesota in 2014.

Soil test values and soil characteristics

Grid soil samples (0-6 inch depth) were taken to characterize the variability within the experimental area. At BP14 the dominant soil series was a Maxcreek silty clay loam and to a lesser extent Merton silt loam (Table 2.). Soil organic matter (SOM) ranged from 2.7 – 10.5% and averaged 5.5%. Cation exchange capacity (CEC) and pH also varied considerably at this location from 13 – 43 meq/100 g for CEC and 5.6 – 7.7 for pH. Nitrate concentration averaged across sampling areas was only 0.7 ppm. These very low surface soil NO₃-N values were likely the result of a winter rye cover crop seeded after soybean in 2013. Soil test P and K (Mehlich III extractant) averaged 54 ppm (range of 21 – 99) and 151 ppm (range of 99 – 218), respectively. About 30% of grid samples tested < 130 ppm K which may have resulted in some potential K deficiency; however, fertilizer K was applied in the fall of 2013. At NF14 the dominant soil series was a Hayden loam and to a lesser extent Dundas silt loam and Le Sueur loam. Soil organic matter (SOM) ranged from 1.7 – 4.2% and averaged 2.9%. CEC and pH also varied from 11 – 25 meq/100 g and 5.9 – 7.6, respectively. Nitrate concentration at NF14 averaged 3.6 ppm which is less than normal for corn following soybean. Soil test P and K averaged 48 ppm (range of 22 – 69) and 151 ppm (range of 178 – 335), respectively.

Soil Nitrate (PSNT)
Soil samples for nitrate-N (PSNT) were taken from 0-1 and 1-2 ft depths at V2 and V6 from multiple locations in each strip-plot. These samples were analyzed for NO₃-N by the No-Wait Nitrate Test and for NO₃-N and NH₄-N after being dried and ground. Only No-Wait Nitrate Test data are presented in this report as the data from the dried samples showed extraordinarily low values which were determined to be erroneous by the authors. Following field collection of the moist samples they were stored in a cooler at 40 degree F. in freezer bags (sealed plastic). After being analyzed by CVC using the No-Wait Test procedure they were stored at room temperature for several days prior to being returned to the SROC. It’s likely that bacteria in the soil denitrified most of the inorganic nitrogen in these samples in the warm, moist and anaerobic condition created by the plastic bags, prior to SROC staff drying the samples. The sample handling protocol will be changed in 2015 to eliminate this error.

Soil nitrate data from research locations (BP14 and NF14) are presented in Tables 4a and 4b. At BP14, NO₃-N was affected by the main effects of sampling time, N treatment (preplant N rates), and the interaction between sampling time and N treatment. When averaged across sampling times (V2 and V6), NO₃-N was greater with the fixed and U of M treatments compared with the variable treatment. The U of M treatment received 120 lb N/ac preplant compared with 105-lb and 100-lb for the fixed and variable treatments, respectively. Greater NO₃-N was found at V2 compared with V6 sampling, when averaged across the main effect of N treatment. These data suggest considerable N loss due to leaching and/or denitrification likely occurred during the exceptionally wet period in mid June. Some N was taken up by corn plants during this period (V2 to V6) but plant uptake alone would not explain the differences in NO₃-N observed in these soil data. A significant interaction between N treatment and sampling date showed at V2 the variable treatment had significantly less NO₃-N compared with the fixed and U of M treatments; whereas, at V6 no significant differences among treatments were observed. This interaction showed that after the excessive wet period in mid June all N treatments had similar NO₃-N left in the soil profile regardless of the preplant N rate. Moreover it suggests N losses were slightly greater with higher rates of preplant applied N. A comparison of sampling depths (0-1 ft vs 0-2 ft) showed numerically less NO₃-N in the 0-2 ft depth (0-2 was an average of 0-1 and 1-2 ft depths) compared with the 0-1 ft depth, especially at the V2 sampling time. Generally, significant differences in soil NO₃-N as a result of treatment main effects (sampling depth and preplant N rates) were similar between the two sampling depths.

At the NF14 location, NO₃-N was affected by the main effects of sampling time and N treatments (Table 4b). When averaged across sampling times (V2 and V6), NO₃-N was greatest with U of M treatment, intermediate with fixed and least with variable. These results correspond exactly with the preplant N rates applied. About twice as much NO₃-N was measured in soil samples at V2 compared with V6 sampling, when averaged across the main effect of N treatment. Similar to the BP14 location, these data suggest considerable N loss due to leaching and/or denitrification likely occurred during the exceptionally wet period in mid June. A significant interaction between N treatment and sampling date was not found at this location. A comparison of sampling depths (0-1 ft vs. 0-2 ft) showed numerically less NO₃-N in the 0-2 ft depth compared with the 0-1 ft depth and differences in soil NO₃-N as a result of treatment main effects (sampling depth and preplant N rates) were similar between the two sampling depths.

**Corn production parameters**

Corn grain yield and other production parameters for BP14 are presented in Table 5a. The farmer cooperator planted three different corn hybrids within the research plot area; therefore, each production parameter was carefully examined to insure hybrid differences did not mask treatment differences. Fortunately, two of the original five replications (blocks) were planted to a single hybrid. Two reps were split among two hybrids and one (rep 5) contained three hybrids. Data from rep 5 were removed and not used in this analysis. Hybrids did affect results of three parameters: grain moisture (hybrids differed in maturity), grain test weight and NDVI at V8 (Crop Circle). Because of the influence of hybrid, these parameters are not included in Table 5a. Fortunately, hybrids had only minimal effect on yield, partly because of the large effect of N treatments.

Corn grain yields from weigh wagon measurements were: greatest with the variable sidedress treatment (160 bu/ac) that received 120 lb N/ac (average) at sidedress and 100 lb N/ac preplant (Table 5a), intermediate with
the fixed sidedress treatment (150 bu/ac) that received 46 lb N/ac at sidedress and 105 lb N/ac preplant and least with the U of M (MRTN based) treatment (136 bu/ac) that did not receive any sidedress N only preplant applied N at 120 lb N/acre. These sidedress N rates were much greater than originally planned because the V6 (PSNT) soil data showed very little nitrate remaining in the soil profile in late June. Nitrate concentrations at the V6 sampling (0-1 ft and 0-2 ft depths) were < 6.0 ppm (Table 4a). Schmitt et al. (2002) gave no N credit when PPNT (0-2 ft depth) soil samples were < 6.0 ppm (Appendix Table I). Therefore, no N credit was given for the preplant applied N in the variable sidedress treatment and the sidedress rate was increased considerably from a proposed 40 lb N/ac up to 120 lb N/ac. The fixed sidedress rate was also increased but only from 35 to 46 lb N/ac. Average strip-plot yields from the combine yield monitor generally agreed closely with weigh wagon yields except for the variable sidedress treatment. Yield monitor yields for the variable treatment were 10 bu/ac greater (170 bu/ac) than weigh wagon yields (160 bu/ac). The authors have no explanation for this difference.

Grain N concentration and plant population were not significantly affected by N treatments at BP14 (Table 5a). N removal in corn grain was greater with treatments that received sidedress N (fixed and variable) than with the treatment without sidedress N (U of M). Partial Factor Productivity was greatest with the U of M treatment (1.13 bu/lb), intermediate with the fixed treatment (1.00 bu/lb) that received a modest sidedress N rate of 46 lb/ac and least with the variable treatment (0.73 bu/ac) that received the highest sidedress N rate (120 lb/ac). These PFP values are considerably less than normal and suggest poor NUE at this location.

After careful examination of the sidedress maps [prescription (Appendix B2), as applied (B3) and prescription / as applied overlay (B4)] from the NF14 site, we concluded the applicator was centered on the edges of each plot instead of in the middle of each plot. Therefore, many plots received only half of the correct rate and the other half was incorrect. This application error created treatment overlap in the middle of each plot where the weigh wagon yields and grain samples were collected. We have decided not to include the weigh wagon yields, grain N concentration, N uptake and NUE parameters in this report for the NF14 site.

Average strip-plot yields from the combine yield monitor for NF14 are presented in Figure 2. Due to the application error not every strip was usable (application overlap) and some strips received the incorrect N rate for their respective treatment. Figure 2 shows the relationship between grain yield and total N rate (preplant + sidedress) for combine yield strips where N rates were consistent across the strip (no overlap of rates). Three points (circled) clearly fall outside the other clustered data; therefore, we excluded these values prior to calculating the average yield (written in text near cluster) of each rate/yield cluster. The individual strip yield data are graphed with letters instead of symbols to note the original treatment (UM= U of M preplant only rate, F=Fixed sidedress rate and V=Variable sidedress rate). Strip yields averaged 139, 166 and 177 bu/ac for total N rates that averaged 120, 148 and 218 lb N/ac, respectively. The 120 lb rate was applied preplant; whereas, the other rates were split with 100 or 105 lb N/ac applied preplant and the rest at sidedress.

To calculate the economics of the in-season PSNT based N applications used in this study a few assumptions and costs are required. CVC quoted the following costs for the 2014 season: PSNT soil sampling on 4.5 ac grids/zones = $6.50/ac; sidedress application of urea with a high clearance applicator = $9.00 for fixed rate or $9.50 for variable rate; urea with Agrotain = $0.50/lb N; and corn at $4.00/bu. Using these values for fixed costs at BP14 and treatment average yields, the fixed sidedress treatment increased yields 14 bu/ac compared with the U of M preplant treatment or a gross return of $56/ac. The total N rate for this treatment was 151 lb N/ac or 31-lb ($15.50) greater. Therefore, if we assume a gross return of $56 minus $15.50 for additional fertilizer minus $9.00 for fixed rate application, this treatment returned $31.50 more than the U of M preplant only application. The variable treatment increased yields 24 bu/ac (weigh wagon data) compared with the U of M treatment. A gross return of $96 minus 100-lb of additional fertilizer ($50) minus $6.50 for sampling minus $9.50 for variable rate sidedress application, this treatment returned $30 more than the U of M treatment. These economic calculations show two key points from this study in 2014: 1) the value of applying sidedress (supplemental) N when spring precipitation is considerably greater than normal and 2) the cost benefit relationship of applying high rates of supplemental N. Moreover, the reduced rate fixed sidedress treatment returned a similar or slightly greater profit than the variable rate treatment primarily because of the cost of fertilizer N. At NF14, these economic calculations showed nearly identical results (calculations not shown).
The poor performance of preplant applied N in 2014, as shown by poor yields in the U of M treatment and PSNT (V6) values similar to background levels in all treatments, is not surprising considering the excessive June rainfall (7.8 and 8.7 inches at BP14 and NF14 sites, respectively). Saturated soil conditions in June obviously resulted in substantial loss of the preplant N. The U of M supplemental N worksheet would have recommended a sidedress application to the U of M treatment at both sites, but we decided to follow the research protocol and not apply supplemental N to the U of M treatment.

Residual soil nitrate (post harvest soil nitrate)

Residual soil N levels [nitrate, ammonium (NH₄-N) and total inorganic-N (TIN) = nitrate + ammonium] from soil samples taken after harvest were very low at both locations in 2014 (Table 6a, NF14 site not shown due to sidedress application error). These low levels suggest soil N from mineralization and fertilizer N were utilized by the corn crop. At BP14, NO₃-N was affected by the main effects of sampling depth, N treatment (N rates), and the interaction between sampling depth and N treatment. When averaged across sampling depths (0-2 and 2-4 ft), NO₃-N was greatest with the variable treatment, intermediate with the fixed treatment and least with the U of M treatment. Greater NO₃-N, NH₄-N and TIN were found at 0-2 depth than 2-4 ft depth, when averaged across the main effect of N treatment.

This growing season proved to be challenging for nitrogen management and research coordination. An extraordinarily wet spring, with delayed field operations and rushed decision making, combined with errors in coordination and communication among all parties resulted in poor research data in 2014. These errors will most certainly be corrected in 2015.
REFERENCES


Table 1. Experimental procedures and their completion dates for 2014 locations.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>BP14</th>
<th>NF14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apply P, K, S and Zn as needed to optimize corn production.</td>
<td>Oct 2013,</td>
<td>Oct 2013,</td>
</tr>
<tr>
<td>Collect 0-6” grid (2.5 ac) soil samples</td>
<td>May 16</td>
<td>May 21</td>
</tr>
<tr>
<td>Apply preplant N treatments</td>
<td>May 25, UAN w/herbicide</td>
<td>May 26, urea</td>
</tr>
<tr>
<td>Incorporate preplant fertilizer with tillage</td>
<td>None, No-till</td>
<td>May 26, field cult.</td>
</tr>
<tr>
<td>Plant corn</td>
<td>May 21,</td>
<td>May 26, DKC 49-29RIB</td>
</tr>
<tr>
<td></td>
<td>Spectrum 4660, 4130 &amp; 5045</td>
<td></td>
</tr>
<tr>
<td>Install weather station</td>
<td>May 24</td>
<td>Jun 3</td>
</tr>
<tr>
<td>At V2, collect PSNT soil samples (0-1’ and 1-2’)</td>
<td>Jun 6, V2</td>
<td>Jun 10, V2</td>
</tr>
<tr>
<td>Take stand counts</td>
<td>Oct 14</td>
<td>Jun 10</td>
</tr>
<tr>
<td>At V4-6, collect PSNT soil samples (0-1’ and 1-2’)</td>
<td>Jun 25, V5-6</td>
<td>Jun 25, V6</td>
</tr>
<tr>
<td>At V6, apply sidedress N treatments</td>
<td>Jul 7, V8-10</td>
<td>Jul 2, V8</td>
</tr>
<tr>
<td>Collect imagery of plot area</td>
<td>Jul 3, Jul 10, Aug 7</td>
<td>Jul 3, Jul 9, Aug 7</td>
</tr>
<tr>
<td>Take plot notes (crop color, N deficiency)</td>
<td>Jul 3</td>
<td>Jul 3 and 31</td>
</tr>
<tr>
<td>Combine harvest corn grain, collect grain sample</td>
<td>Oct 28</td>
<td>Nov 6</td>
</tr>
<tr>
<td>Take post harvest soil nitrate samples (0-2’ and 2-4’)</td>
<td>Oct 30</td>
<td>Nov 6</td>
</tr>
</tbody>
</table>

Table 2. Soil properties from grid soil samples at each of the experimental locations.

<table>
<thead>
<tr>
<th>Year</th>
<th>Location, abbrev.</th>
<th>Soil series</th>
<th>SOM</th>
<th>CEC</th>
<th>pH</th>
<th>NO₃-N</th>
<th>Solum Mehlich III</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>%</td>
<td>meq/100</td>
<td></td>
<td>ppm</td>
<td>P</td>
</tr>
<tr>
<td>2014</td>
<td>Blooming Prairie, BP14</td>
<td>Maxcreek SiCL</td>
<td>5.5†</td>
<td>27</td>
<td>6.6</td>
<td>0.7</td>
<td>54</td>
</tr>
<tr>
<td>2014</td>
<td>Northfield, NF14</td>
<td>Hayden L</td>
<td>2.9</td>
<td>16</td>
<td>6.7</td>
<td>3.6</td>
<td>48</td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td>Dundas SiL</td>
<td>1.7-4.2</td>
<td>11-25</td>
<td>5.9-7.6</td>
<td>0.3-7.8</td>
<td>22-69</td>
</tr>
</tbody>
</table>

† Mean value.
‡ Range in values.
Table 3a. Weekly relative humidity, air temperature, GDU, precipitation, 6- and 18-inch soil volumetric water content and temperature at Blooming Prairie in 2014.

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>RH %</th>
<th>Mean °F</th>
<th>Min °F</th>
<th>Max °F</th>
<th>GDU</th>
<th>Precip.</th>
<th>6-inch Soil</th>
<th>18-inch Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50/86 inch</td>
<td>m³/m³</td>
<td>°F</td>
<td>m³/m³</td>
<td>°F</td>
<td>m³/m³</td>
<td>°F</td>
</tr>
<tr>
<td>5/7</td>
<td>--</td>
<td>47</td>
<td>39</td>
<td>56</td>
<td>28</td>
<td>0.48</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5/14</td>
<td>--</td>
<td>54</td>
<td>44</td>
<td>65</td>
<td>54</td>
<td>1.54</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5/21</td>
<td>--</td>
<td>51</td>
<td>41</td>
<td>62</td>
<td>43</td>
<td>0.15</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5/28</td>
<td>74</td>
<td>64</td>
<td>55</td>
<td>77</td>
<td>116</td>
<td>0.09</td>
<td>0.30</td>
<td>61</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/4</td>
<td>66</td>
<td>70</td>
<td>61</td>
<td>81</td>
<td>145</td>
<td>0.57</td>
<td>0.30</td>
<td>66</td>
</tr>
<tr>
<td>6/11</td>
<td>66</td>
<td>66</td>
<td>57</td>
<td>76</td>
<td>113</td>
<td>0.01</td>
<td>0.29</td>
<td>66</td>
</tr>
<tr>
<td>6/18</td>
<td>71</td>
<td>67</td>
<td>58</td>
<td>75</td>
<td>115</td>
<td>5.12</td>
<td>0.32</td>
<td>65</td>
</tr>
<tr>
<td>6/25</td>
<td>85</td>
<td>71</td>
<td>63</td>
<td>80</td>
<td>153</td>
<td>1.51</td>
<td>0.36</td>
<td>69</td>
</tr>
<tr>
<td>7/2</td>
<td>85</td>
<td>69</td>
<td>62</td>
<td>77</td>
<td>140</td>
<td>0.80</td>
<td>0.29</td>
<td>69</td>
</tr>
<tr>
<td>7/9</td>
<td>75</td>
<td>67</td>
<td>56</td>
<td>78</td>
<td>123</td>
<td>0.05</td>
<td>0.28</td>
<td>67</td>
</tr>
<tr>
<td>7/16</td>
<td>79</td>
<td>65</td>
<td>56</td>
<td>75</td>
<td>110</td>
<td>0.40</td>
<td>0.24</td>
<td>67</td>
</tr>
<tr>
<td>7/23</td>
<td>75</td>
<td>71</td>
<td>62</td>
<td>80</td>
<td>148</td>
<td>0.00</td>
<td>0.23</td>
<td>67</td>
</tr>
<tr>
<td>7/30</td>
<td>80</td>
<td>68</td>
<td>56</td>
<td>79</td>
<td>124</td>
<td>0.50</td>
<td>0.22</td>
<td>68</td>
</tr>
<tr>
<td>8/6</td>
<td>80</td>
<td>69</td>
<td>54</td>
<td>84</td>
<td>133</td>
<td>0.57</td>
<td>0.21</td>
<td>67</td>
</tr>
<tr>
<td>8/13</td>
<td>82</td>
<td>68</td>
<td>58</td>
<td>80</td>
<td>131</td>
<td>0.42</td>
<td>0.21</td>
<td>67</td>
</tr>
<tr>
<td>8/20</td>
<td>83</td>
<td>71</td>
<td>60</td>
<td>84</td>
<td>153</td>
<td>0.36</td>
<td>0.21</td>
<td>68</td>
</tr>
<tr>
<td>8/27</td>
<td>87</td>
<td>72</td>
<td>64</td>
<td>84</td>
<td>166</td>
<td>1.39</td>
<td>0.21</td>
<td>70</td>
</tr>
<tr>
<td>9/3</td>
<td>89</td>
<td>67</td>
<td>59</td>
<td>78</td>
<td>127</td>
<td>2.68</td>
<td>0.29</td>
<td>67</td>
</tr>
<tr>
<td>9/10</td>
<td>83</td>
<td>65</td>
<td>54</td>
<td>76</td>
<td>112</td>
<td>1.14</td>
<td>0.28</td>
<td>65</td>
</tr>
<tr>
<td>9/17</td>
<td>81</td>
<td>49</td>
<td>40</td>
<td>61</td>
<td>8</td>
<td>0.54</td>
<td>0.30</td>
<td>56</td>
</tr>
<tr>
<td>9/24</td>
<td>78</td>
<td>61</td>
<td>49</td>
<td>75</td>
<td>frost</td>
<td>1.31</td>
<td>0.31</td>
<td>58</td>
</tr>
<tr>
<td>10/1</td>
<td>78</td>
<td>62</td>
<td>51</td>
<td>74</td>
<td>0.29</td>
<td>0.30</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>10/8</td>
<td>81</td>
<td>46</td>
<td>37</td>
<td>55</td>
<td>0.41</td>
<td>0.31</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>10/15</td>
<td>76</td>
<td>46</td>
<td>34</td>
<td>57</td>
<td>0.51</td>
<td>0.30</td>
<td>48</td>
<td></td>
</tr>
</tbody>
</table>
Table 3b. Weekly relative humidity, air temperature, GDU, precipitation, 6- and 18-inch soil volumetric water content and temperature at Northfield location in 2014.

<table>
<thead>
<tr>
<th>Week Ending</th>
<th>Air Temperature</th>
<th>6-inch Soil</th>
<th>18-inch Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RH</td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>5/7</td>
<td>--</td>
<td>47</td>
<td>39</td>
</tr>
<tr>
<td>5/14</td>
<td>--</td>
<td>54</td>
<td>44</td>
</tr>
<tr>
<td>5/21</td>
<td>--</td>
<td>51</td>
<td>41</td>
</tr>
<tr>
<td>5/28</td>
<td>--</td>
<td>66</td>
<td>55</td>
</tr>
<tr>
<td>6/4</td>
<td>82</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>6/11</td>
<td>73</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>6/18</td>
<td>70</td>
<td>67</td>
<td>59</td>
</tr>
<tr>
<td>6/25</td>
<td>81</td>
<td>72</td>
<td>64</td>
</tr>
<tr>
<td>7/2</td>
<td>82</td>
<td>70</td>
<td>63</td>
</tr>
<tr>
<td>7/9</td>
<td>72</td>
<td>69</td>
<td>59</td>
</tr>
<tr>
<td>7/16</td>
<td>79</td>
<td>67</td>
<td>58</td>
</tr>
<tr>
<td>7/23</td>
<td>74</td>
<td>72</td>
<td>63</td>
</tr>
<tr>
<td>7/30</td>
<td>79</td>
<td>69</td>
<td>58</td>
</tr>
<tr>
<td>8/6</td>
<td>81</td>
<td>71</td>
<td>57</td>
</tr>
<tr>
<td>8/13</td>
<td>80</td>
<td>69</td>
<td>58</td>
</tr>
<tr>
<td>8/20</td>
<td>83</td>
<td>72</td>
<td>61</td>
</tr>
<tr>
<td>8/27</td>
<td>86</td>
<td>73</td>
<td>63</td>
</tr>
<tr>
<td>9/3</td>
<td>87</td>
<td>68</td>
<td>59</td>
</tr>
<tr>
<td>9/10</td>
<td>83</td>
<td>66</td>
<td>53</td>
</tr>
<tr>
<td>9/17</td>
<td>80</td>
<td>50</td>
<td>40</td>
</tr>
<tr>
<td>9/24</td>
<td>80</td>
<td>62</td>
<td>49</td>
</tr>
<tr>
<td>10/1</td>
<td>82</td>
<td>61</td>
<td>50</td>
</tr>
<tr>
<td>10/8</td>
<td>80</td>
<td>47</td>
<td>38</td>
</tr>
<tr>
<td>10/15</td>
<td>77</td>
<td>45</td>
<td>33</td>
</tr>
</tbody>
</table>
Table 4a. Soil nitrate-N (PSNT) as affected by sampling time and depth and preplant N rate at BP-14.

<table>
<thead>
<tr>
<th>Nitrogen Treatment</th>
<th>Sampling Time</th>
<th>Method</th>
<th>Rate</th>
<th>V2</th>
<th>V6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>lb/ac</td>
<td>ppm</td>
<td>ppm</td>
<td></td>
</tr>
<tr>
<td>Soil nitrate 0-1 ft depth</td>
<td></td>
<td>Fixed</td>
<td>105</td>
<td>10.2</td>
<td>4.1</td>
<td>7.2 a†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>6.7</td>
<td>3.7</td>
<td>5.2 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>11.1</td>
<td>4.7</td>
<td>7.9 a</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td>9.3</td>
<td>A</td>
<td>4.2 B</td>
</tr>
<tr>
<td>Soil nitrate 0-2 ft depth</td>
<td></td>
<td>Fixed</td>
<td>105</td>
<td>6.6</td>
<td>3.5</td>
<td>5.0 a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>3.7</td>
<td>3.8</td>
<td>3.7 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>7.2</td>
<td>4.1</td>
<td>5.6 a</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td>5.8</td>
<td>A</td>
<td>3.8 B</td>
</tr>
</tbody>
</table>

† Numbers within a column followed by the same lower case letter and numbers within a row followed by the same upper case letter are not significantly different at (P ≤ 0.10).

Table 4b. Soil nitrate-N (PSNT) as affected by sampling time and depth and preplant N rate at NF-14.

<table>
<thead>
<tr>
<th>Nitrogen Treatment</th>
<th>Sampling Time</th>
<th>Method</th>
<th>Rate</th>
<th>V2</th>
<th>V6</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>lb/ac</td>
<td>ppm</td>
<td>ppm</td>
<td></td>
</tr>
<tr>
<td>Soil nitrate 0-1 ft depth</td>
<td></td>
<td>Fixed</td>
<td>105</td>
<td>14.9</td>
<td>6.4</td>
<td>10.6 b†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>13.6</td>
<td>5.4</td>
<td>9.5 c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>16.9</td>
<td>7.8</td>
<td>12.4 a</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td>15.2</td>
<td>A</td>
<td>6.5 B</td>
</tr>
<tr>
<td>Soil nitrate 0-2 ft depth</td>
<td></td>
<td>Fixed</td>
<td>105</td>
<td>10.5</td>
<td>5.5</td>
<td>8.0 b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>10.0</td>
<td>4.3</td>
<td>7.1 c</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>11.6</td>
<td>6.6</td>
<td>9.1 a</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td></td>
<td></td>
<td>10.7</td>
<td>A</td>
<td>5.5 B</td>
</tr>
</tbody>
</table>

† Numbers within a column followed by the same lower case letter and numbers within a row followed by the same upper case letter are not significantly different at (P ≤ 0.10).
Table 5a. Corn grain moisture, test weight, yield, N concentration, N removal and Partial Factor Productivity, and plant population as affected by N treatments at BP14.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed</td>
<td>105 46</td>
<td>ND</td>
<td>ND</td>
<td>150 b</td>
<td>132 a</td>
<td>94 a 1.00 b</td>
<td>31.0 a</td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>100 120</td>
<td>ND</td>
<td>ND</td>
<td>160 a</td>
<td>170 a 103 a</td>
<td>0.73 c 31.9 a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UM‡</td>
<td>120 0</td>
<td>ND</td>
<td>ND</td>
<td>136 c 79 b</td>
<td>132 c 1.13 a</td>
<td>30.6 a</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Prob. > F: 0.002 <0.01 0.195 0.017 <0.001 0.130

Average LSD (0.10): 8 7 NS 11 0.05 NS

† ND = no data for this location. ‡ UM=Univ. of MN rate based on MRTN (N rate calculator).
Table 6a. Residual soil N after harvest as affected by sampling depth and N treatment (rate) at BP14.

<table>
<thead>
<tr>
<th>Nitrogen Treatment</th>
<th>Sampling Depth</th>
<th>Average</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Method</td>
<td>PP Rate</td>
<td>SD Rate</td>
<td>0-2 ft</td>
<td>2-4 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td>lb/ac</td>
<td>lb/ac</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil nitrate-N</td>
<td>Fixed</td>
<td>105</td>
<td>46</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>120</td>
<td>4.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>0</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>Soil ammonium-N</td>
<td>Fixed</td>
<td>105</td>
<td>46</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>120</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>0</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td>Soil nitrate + ammonium-N</td>
<td>Fixed</td>
<td>105</td>
<td>45</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Variable</td>
<td>100</td>
<td>100</td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>UM</td>
<td>120</td>
<td>0</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average</td>
<td></td>
<td></td>
<td>7.3</td>
</tr>
</tbody>
</table>

† Numbers within a column followed by the same lower case letter and numbers within a row followed by the same upper case letter are not significantly different at (P ≤ 0.10).
Figure 1a. Daily precipitation and soil volumetric water content at Blooming Prairie in 2014.

Figure 1b. Daily precipitation and soil volumetric water content at Northfield in 2014.
Figure 2. Corn grain yields as affected by the total N rate (preplant + sidedress) at NF14. Potential outliers are circled and not included in mean calculations. Abbreviations: UM= UM preplant only rate (120 lb N/ac), F=Fixed sidedress rate (105 lb N/ac preplant plus sidedress) and V=Variable sidedress rate (100 lb N/ac preplant = sidedress).
APPENDIX TABLES.

Table I. Residual N credit values based on the concentration of NO$_3$-N measured before planting in the spring from the top two feet of soil (adapted from Schmitt et al., 2002).

<table>
<thead>
<tr>
<th>Soil NO$_3$-N ppm</th>
<th>Residual N Credit lb N per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-6.0</td>
<td>0</td>
</tr>
<tr>
<td>6.1-9.0</td>
<td>35</td>
</tr>
<tr>
<td>9.1-12.0</td>
<td>65</td>
</tr>
<tr>
<td>12.1-15.0</td>
<td>95</td>
</tr>
<tr>
<td>15.1-18.0</td>
<td>125</td>
</tr>
<tr>
<td>&gt;18.1</td>
<td>155</td>
</tr>
</tbody>
</table>
Figure A1. Sidedress prescription map for BP14. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure A2. Sidedress N as applied application map for BP14. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure A3. Cleaned yield map for BP14.
Figure B1. Northfield (NF14) preplant treatment map. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure B2. Sidedress prescription map for NF14. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure B3. Sidedress N as applied application map for NF14. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure B4. Overlay map of sidedress N prescription and as applied for NF14. This map clearly shows improper alignment of sidedress application. Colors represent N treatments applied in pounds of urea (46-0-0) per acre.
Figure B5. Individual yield strips used in yield/N rate cluster calculations at NF14 site.