UREA AND UREA ADDITIVES AS FERTILIZER SOURCES FOR CORN PRODUCTION IN MINNESOTA (2019 GROWING SEASON)

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BRIEF OVERVIEW

Urea is increasingly an important nitrogen (N) source in Minnesota. Approximately 43% of our farmers use urea as their major N source. In the southwestern, south-central and west-central areas approximately 45% of the N is applied in the fall, 50% is applied in the spring, and 5% is applied at sidedress. While most of those that use urea as the major N source apply it in the spring, approximately 4% do the major application with urea in the fall and there are others that apply some of their N as urea in the fall as this application is part of the listed Best Management Practices. However, in recent years, due in part to wet spring conditions, fall urea applications have resulted in yield reduction.

The objectives of this study were to: 1) evaluate fall and spring applications of urea to determine their feasibility and calculate the economic optimum N rate for fall and spring applications when corn follows corn (CC), corn follows wheat (CWh) and corn follows soybean (CSb), 2) Investigate the role of placement (band vs. broadcast and incorporated) and of a nitrification inhibitor and polymer coating (ESN) to improve management of urea.

MATERIALS AND METHODS

The study was conducted at the following Research and Outreach Centers during the 2019 growing season: Northwest (Crookston), West Central (Morris), Southwest (Lamberton), and Southern (Waseca). Following is the soil information for each site. At Crookston experimental sites were established under a corn-soybean (CSb) (Gunclub silty clay loam, 0 to 2 percent slopes) and a corn-corn (CC) cropping system (Colvin-Perella silty clay loams, 0 to 1 percent slopes). Lamberton experimental sites were established under a CSb (Canisteo clay loam, 0 to 2 percent slopes, Amiret loam, 2 to 6 percent slopes, Glencoe clay loam, 0 to 1 percent slopes) and a CC cropping system (Amiret loam, 2 to 6 percent slopes, small portion of Normania loam,1 to 3 percent slopes). Morris experimental sites were established under a CSb (Aazdahl-Formdale-Balaton clay loams, 0 to 4 percent slopes) and for CC cropping system (Aazdahl-Formdale-Balaton clay loams, 0 to 4 percent slopes; McIntosh silt loam, 1 to 3 percent slopes;Tara silt loam, 1 to 3 percent slopes). Waseca had an experimental site under a CSb cropping system (Nicollet clay loam, 1 to 3 percent slopes, Canisteo-

Glencoe complex, 0 to 2 percent slopes, and a small portion of Webster clay loam, 0 to 2 percent slopes).

Treatments are presented in Table 1. The treatments included a full set of N rates for fall and spring pre-plant (PP) applications of broadcast and shallow incorporation of urea (BI) to allow us to determine N response and calculate the economic optimum N rate (EORN). Rates ranged from 0 to 240 lb N/acre in CC and since the yield response is expected to maximize at a lower rate for CSb and CWh the rate ranged from 0 to 200 lb N/ac. There is also a comparison of different sources, placements, and timings: the standard practice that consist of anhydrous ammonia (AA) with N-Serve in the fall and without N-Serve in the spring, ESN broadcast and incorporated by tillage (BI), and urea with or without the nitrification inhibitor Instinct HL (24 oz/ac) either as BI or banded application (SSB) all as spring and fall applications. The sub-surface banded fertilizer was applied below the crop row position (except for urea and urea+Instinct treatments at Waseca that were applied between the crop rows). For the comparison treatments, we used a sub-optimal rate (most responsive portion of the response curve) to be able to more easily detect differences due to treatment. Treatments 15 to 24 were applied at 120 lb N/ac in CC and at 80 lb N/ac in CSb except for AA that was always applied at 120 lb N/ac because a lower rate was not achievable with the available equipment. The treatments were organized in a randomized complete block design replicated four times.

Plant dry biomass and N uptake were measured at V6, V12 and R6 development stages. Canopy sensing was performed with the Crop Circle and normalized difference red-edge (NDRE) index were calculated for the V6 and V12 development stages. At harvest grain yield was calculated and grain N content measured. After harvest, soil samples from the 0-12, 12-24, and 24-36-inch depth increments were collected and analyzed for ammonium-N and nitrate-N and total inorganic N (TIN) was calculated. Statistical analysis was performed using the SAS software and program. Differences were established at P=0.05.

PRELIMINARY RESULTS AND DISCUSSION

Waseca was 11 inches above normal for the Apr-Oct period with only June having below normal precipitation (Table 2). In Lamberton, precipitation was 9.4 inches above the normal average from Apr-Oct. (Table 2). Similarly, Morris was 11.4 inches above the normal. Crookston was at or below the normal during April through July, but was wetter than normal in August, September, and October, which resulted in 4.6 inches above the normal for the Apr-Oct period. The growing season across all sites in Minnesota was challenging. Generally, wet and cool conditions delayed planting and the crop growth rate was relatively slow.

Grain yield and grain N removal

During the 2019 growing season all sites and crop rotations, except Crookston-CC rotation in the fall and Morris CSb in the spring, had significant grain yield response to N application rate, but the response varied with sites and time of application (Table 3). Spring applications produced significantly greater yield than fall applications only at Waseca (Table 3, 9). Averaged across all sites and rotations the spring application produced 146 bu/ac compared to 141 for the fall application. As mentioned earlier, 2019 was a challenging and overall disappointing growing season. The highest yield we obtained in this study was only 205 bu/ac. It is clear that factors besides N rate or time of application had a substantial impact in the grain yield responses we obtained. Grain N removal increased with N rate at all sites (Table 4). Spring applications produced significantly greater N removal than fall applications in Waseca CSb and Crookston CSb. (Table 4).

In Waseca, the CSb crop had a linear response to N (yield was not maximized) for the fall application and a quadratic-plateau response for the spring application (Table 5). For the fall, the yield at the highest N rate (200 lb N/ac) was 189 bu/a. For the spring application, the EONR was 161 lb N/ac and the yield at the EONR was 203 bu/a. Across years for CC fall applications required 45 lb N/ac more than the spring application to reach the EONR and the yield at the EONR was 12 bu/ac lower than the spring application (Table 5). Similarly, for CSb fall applications required 26 lb N/ac more than the spring application to reach the EONR and the yield at the EONR was 11 bu/ac lower than the spring application. The data for all the years of the study clearly show that fall urea in south central Minnesota should not be used because the potential for N loss is too great. This follows current University of Minnesota BMPs.

In Lamberton, the CC crop for fall and spring application had quadratic-plateau response to N. For the fall application the EONR was 195 lb N/ac and the yield at the EONR was 159 bu/a, and for spring application the EONR was 190 lb N/ac and the yield at the EONR was 140 bu/a (Table 6). For the CSb crop, a quadratic response to N was also observed for both fall and spring. For the fall application the EONR was 131 lb N/ac and the yield at the EONR was 186 bu/a, and for spring application the EONR was 132 lb N/ac and the yield at the EONR was 178bu/a (Table 6). Across years for CC while the EONR for fall application was very similar to the spring application, the yield at the EONR was on average 23 bu/ac more for the spring application relative to the fall application.

Similarly, for CSb the difference in EONR was only 3 lb N/ac lower with spring than fall application, but the yield at the EONR was 6 bu/ac greater with spring than fall application. This indicates that overall the spring application results in better nitrogen use efficiency than the fall application.

In Morris, the CC crop had a linear response to N (yield was not maximized) for fall application and a quadratic- plateau response for spring applications (Table 7). Grain yield was 190 bu/a for fall at the highest N rate (240 lb N/ac). For the spring application the EONR was176 lb N/ac and the yield at the EONR was 175 bu/a. The CSb crop had a quadratic- plateau response to N for fall and spring applications (Table 7). For the fall application the EONR was165 lb N/ac and the yield at the EONR was 170 bu/a. Grain yield for the spring application was 118 bu/a and the yield at the EONR was 162 bu/ac. Across years for CC the EONR with spring applications was 37 lb N/ac lower than for fall, and the spring application yielded 11 bu/ac above the fall application. Similarly, for CSb, across years the EONR was 36 lb N/ac lower than for fall applications, tough the grain yield at the EONR was similar (3 bu/ac lower for spring than fall application). Again, as observed for Lamberton, while the results are not as consistent as observed in Waseca, the southwest and west-central portion of Minnesota showed that fall applications are not as efficient as spring applications. Overall, fall applications required additional N to reach the EONR and the yield at the EONR was typically lower, or at best very similar, to the yields obtained with the spring applications.

In Crookston, the CC crop showed no significant response to N application both for fall and spring applications (Table 8). The CSb crop had quadratic response to N for spring application and no response to N for fall application (Table 8). For the spring application, the EONR was 189 lb N/ac and the yield at the EONR was 198 bu/ac. While there were several non-N response curves at Crookston (seven out of 12), the years where there was a response to N showed that fall applications required more N to achieve the EONR compared to the spring application to achieve a lower, or at best similar, yield at the EONR.

While studies were conducted in south-central Minnesota to provide a comparison, the major objective of this study was to evaluate whether fall urea application could still be considered an acceptable practice for wester Minnesota. The results from southcentral Minnesota consistently confirmed that fall application of urea is not acceptable for this region, which had been known and used as the guide for many years as a Nitrogen Best Management Practices (N-BMP) (Table 5, 9). For western Minnesota (Lamberton representing the southwest region, Morris representing the west-central region, and Crookston representing the northwest region) we observed less consistent results compared to southcentral Minnesota (Table 6-9). However, having 40 response curves over four distinct growing seasons across the western portion of the state allow us to describe on average what is most likely to happen when comparing fall to spring applications of urea. Averaged across all these 40 site-years and crop rotations (Table 6-8) the spring urea application needed 27 lb N/ac less nitrogen than the fall application to achieve the EONR and produced 9 bu/ac more yield than the fall application at the EONR. Based on these results and the need to improve nitrogen use efficiency for both economic and environmental reasons, fall urea application should not be considered a N-BMP for Minnesota. Though we feel confident on the results, at this point these conclusions can be considered preliminary. We will continue to examine the data in rigorous scientific ways, publish results in peer-reviewed journals, and adjust N-BMPs guidelines as needed.

The source of N showed difference in yield response only at Waseca for fall application, and Lamberton-CC and Crookston-CSb for spring applications (Table 10). Only these three situations will be discussed. At Waseca ESN and the treatments with sub-surface band (SSB) applications produced better yields than the urea broadcast and incorporated (BI) treatments, but there was no difference due to using the nitrification inhibitor (+I). At Lamberton, anhydrous ammonia (AA) outperformed both urea with inhibitor sub-surface band (U+I/SSB) and urea broadcast and incorporated (U/BI). Also, ESN was better than U+I/SSB. In Crookston ESN was better than broadcast and incorporated urea regardless of nitrification inhibitor usage (Table 10). In Morris, fall AA+I produced greater yield than urea BI (Table 11). In terms of Grain N removal, there were only a few situations where N source/placement made a difference (Table 12-13); only the significant differences will be discussed. Morris CC had greater yield with ESN than U+I/BI, U/BI, and U/SSB, also U+I/BI produced lower yields than the AA treatments (Table 12). In Crookston the CSb rotation had greater N removal with ESN than urea when both were BI.

The effect of urea placement across N inhibitors (with and without Instinct) for all the evaluated years shows that SSB of urea has the greatest potential to increase yields for fall applications (Table 14 and 16). That said, the benefit only occurred about half of the time (52% of the time), so the additional difficulty (time and expense) of applying urea as a SSB might not be justified. The data also shows that SSB applications cannot be used as a way to improve urea performance for fall applications. For those cases where SSB produced a benefit, the yield increase was 33 bu/ac compared to the BI application. For spring applications, the placement does not have a clear pattern.

The use of Instinct as a nitrification inhibitor regardless of placement (BI or SSB) is not justified for fall or spring applications (Table 15, 16). Using the inhibitor as a way to justify fall urea applications is not valid as it only improved yields 7% of the time.

Anhydrous Ammonia applied in the fall produced the greatest and most consistent grain yield benefit (Table 16). Compared to urea BI there was a 60% chance of improving yield. In those cases, the yield increase was 49 bu/ac on average. Compared to urea SSB in the fall the benefit of AA was still observed, but it was only for 30% of the time. This is likely, because as explained earlier, a SSB application in the fall tends to improve urea performance compared to urea BI. Compared to ESN, AA was better only 25% of the time during fall applications. For spring applications AA performed better than urea (regardless of urea application method) approximately 30% of the time. These results illustrate that urea in the fall and in wet springs has greater potential for N loss than anhydrous ammonia. Using ESN in the fall as a way to reduce concerns regarding N loss with urea is not justified. In the spring, the results were similar to those in the fall. However, from previous studies we have observed that in wet springs the use of ESN can be beneficial compared to urea. Additional analyses of the data in this study in conjunction with weather and soil information are needed and will be conducted in the future.

Summary

- Fall urea is problematic due to wet springs and warmer falls/winters. While this is a preliminary analysis, most likely current BMP's for wester Minnesota will need to be adjusted to reflect changes in weather and cropping conditions as reflected in this study.
- All variables equal, spring applications produced more grain than fall applications.
- Anhydrous ammonia is superior to urea, especially in the fall.
- Banding urea (SSB) or using ESN in the fall had limited advantage.
- The use of the nitrification inhibitor Instinct with urea did not increase yield.

This last section of the report provides additional information collected during the study. At this stage in the data analysis, these values constitute ancillary information that will be included along with previous years of data to evaluate in greater depth the results presented in the earlier sections. At this point the data has been evaluated statistically, but little attempt has been made to relate these results to results presented in the earlier sections.

Canopy sensing and Plant N uptake

Canopy sensing measurements both at V6 and V12 development stage were linearly correlated to grain yield, but the relationship was low for V6 (R^2=0.29) and V12 development stage (R^2=0.26) (Fig. 1). These results are in contrast to previous years where we normally observe that in general, the relationship improves, as the plant becomes a better integrator of growing season conditions up to the time of sensing. Regardless, the data highlight the fact that it may be difficult to use sensing technologies alone to improve N management. The data also highlights the fact that the 2019 season was very challenging. It is possible that by V12 deficiencies due to N supply had not fully developed. Also, as mentioned earlier, during 2019 other stressors might have had a greater role than N treatment on the crop responses we measured.

In general, plant N uptake increased with N rate at all locations except Lamberton CSb where there were no differences (Appendix-1, 2). At V6, generally N uptake increased with N rate to 80 or 120 lb N/ac rate, but for total N at R6 uptake continued to increase with additional fertilizer N rates.

Plant N uptake was greater under spring application than fall application at all stages in Waseca CSb; at V6 at Lamberton CSb, at R6 in Crookston CC, V12 and R6 at Crookston CSb, and at V6 in Morris CC (Appendix-1, 2). No differences were observed between fall and spring applications across N rates in Lamberton CC and Morris CSb (Appendix-1, 2).

The N source and placement treatments produced small and inconsistent differences in plant N uptake across the various locations and crop rotations and for the different development stages (Appendix-3, 4, 5). At Lamberton CC and Crookston CC had no difference in plant N uptake at any of the development stages (Appendix-3). However, in Morris CC total N uptake at R6 was greatest in the AA/I, followed by ESN/BI, and all the urea treatments had the lowest uptake (Appendix-3). Plant N uptake was significantly greater with spring application than fall application only at V12 in Morris CC (Appendix-3). Lamberton CSb and Morris CSb had no difference in plant N uptake at any of the development stages (Appendix-4). Waseca CSb had only differences in V12 (Appendix-4). Crookston

CSb had greater plant N uptake at R6 in the ESN than Urea treatments (Appendix-4). For the CSb rotations only at V6 in Morris, Urea had significantly greater yield than AA/I (Appendix-5).

Soil measurements

At Waseca in CSb, amounts of soil NH_{4+}-N for all the depths were similar for different N rate at V4 and Post-harvest (Appendix-6). Soil NO_{3-}-N increased with increasing N rates at V4 development stage at all depths (Appendix-6). The fact that there was substantially greater NO_{3-}-N in the top two feet of the soil correspond with the greater yields we observed for this location with spring compared to fall applications. Also, the fact that there were no differences in soil N at post-harvest despite mediocre grain yields; indicate that there was substantial potential for N loss. There were not significant differences on the soil NNH_{4+}-N and NO_{3-}-N content at any depth among source/placement treatment at V4 and post-harvest (Appendix-7) ,except that U/BI had significantly greater N-NO_{3-} content at12-24 and 24-36" for V4 development stage (Appendix-8).

At Lamberton in CC, soil NH_{4+}-N was similar among rates, however soil NO_{3-}-N increases with N rate at all depths (Appendix-9) at V4. At V4, fall applications had greater soil NO_{3-}-N than spring applications at the 12-24 inches depth, but soil NO_{3-}-N was similar for fall than spring application timing for the other depths (Appendix-9). At post-harvest sampling, no differences were detected among N rates or time of application at any depth (Appendix-9). There were not significant differences on the soil NH_{4+}-N and NO_{3-}-N content at any depth among source/placement treatment at V4 and post-harvest, except NH_{4+}-N content at 0-12" that was greater in the U+I/SSB and lower in the U/BI (Appendix-10).

At Lamberton in CSb, similar NH_{4+}-N concentrations were detected among N rates at V4 and Post-harvest sampling at all depths (Appendix-11). Soil NO_{3-}-N increased with increasing N rates both at V4 development stage at 0-12 and 12-24" and at all depths for post-harvest sampling (Appendix-11). When N source and placement treatments were evaluated, similar amount of soil NH_{4+}-N and NO_{3-}-N were observed among treatments (Appendix-12, 13).

At Morris in CC, concentration of soil NO_{3-}-N increased with N rate at V4 development stage at 0-12 and 12-24" soil depths (Appendix-14). At post-harvest, only the 24-36" depth showed differences among N rates but in general low concentrations were observed at the end of the growing season (Appendix-14). At V4, soil NO_{3-}-N concentration at 0-12" was greater under the AA/I and ESN/I treatment than the other sources (Appendix-15), and at 12-24" soil NO_{3-}-N were similar among ESN and SSB treatments but greater than BI treatments (Appendix-15). No differences among sources/placement were detected on soil NH_4^+-N and NO_3^--N concentrations at post-harvest (Appendix-15).

In Morris CSb, the concentration of soil NO_3^--N increase when N rates increased at all depths at V4, and 12-24 and 24-36" at post-harvest (Appendix-16). Soil NH_4^+-N and NO_3^--N content was not affected by N source and placement treatments at both sampling times (Appendix-17).

At Crookston CWt, soil NO_3^--N content increased significantly with N rates at 0-12" and 12-24" at V4 (Appendix-19), and at all depths at post-harvest sampling (Appendix-19). No differences were found among N source and placement treatments at V4 development stage and Post-harvest (Appendix -20).

At Crookston CSb, at V4 soil NO_3^--N content was significantly affected by N rates at 0-12" soil depth, and at 12-24" at post-harvest sampling (Appendix-21). Soil NH_4^+-N and NO_3^--N content was not affected by N source and placement treatments at both sampling times (Appendix-22).

Total inorganic N (TIN) (NH_4^+-N plus NO_3^--N) in the top 36 inches of the soil were highest at V4 at Waseca 228 lbs N/ac for the spring application. Soil TIN was also high at V4 at Crookston for CC for the spring application. For these two locations at V4 fall TIN was also high with 161 lb N/ac at Waseca and 169 lb N /ac at Crookston. These two sites also had the highest TIN at post-harvest for both fall and spring applications, ranging between 102 and 106 lb N/ac. These results might help explain why there was no grain yield response to N at Crookston for CC. The fact that Waseca had a grain yield response that was linear (for fall) and a relatively high EONR (164 lb N/ac) for spring indicate that N was either not the limiting factor or that substantial N loss occurred before the crop was able to utilize substantial N. The fact that substantial N was present at post-harvest may be a reflection of either unused N (other factors were more limiting to the crop) or substantial mineralization after the crop reached physiological maturity. It was also interesting to observe that in Crookston CSb the EONR was high, but the TIN at V4 and post-harvest was relatively high and did not change substantially between the two sampling times for either fall or spring (range 124 to 102 lb N/ac). Overall, there were very small differences between CC and CSb rotations at V4 or post-harvest. Averaged across N rate at V4 for fall applications TIN was 132 lb N/ac for CSb and 138 lb N/ac for CC while for spring applications TIN was 146 lb N/ac for CSb and 145 lb N/ac for CC. Averaged across N rate at post-harvest for fall applications TIN was 92 lb N/ac for CSb and 87 lb N/ac for CC while for spring applications TIN was 94 lb N/ac for CSb and 95 lb N/ac for CC. These results need to be further explored in relation to crop grain yield and N use. Similarly, additional analysis will be conducted with the data collected across all four years of the study.

Table 1. Treatment list.

Trt#	Product	Method	Time	Rate (lb N/ac)
1	check	check	Fall	0
2	Urea	Broadcast	Fall	40
3	Urea	Broadcast	Fall	80
4	Urea	Broadcast	Fall	120
5	Urea	Broadcast	Fall	160
6	Urea	Broadcast	Fall	200
7	Urea	Broadcast	Fall	240
8	check	check	Spring PP	0
9	Urea	Broadcast	Spring PP	40
10	Urea	Broadcast	Spring PP	80
11	Urea	Broadcast	Spring PP	120
12	Urea	Broadcast	Spring PP	160
13	Urea	Broadcast	Spring PP	200
14	Urea	Broadcast	Spring PP	240
15	AA+Nserve	Injected	Fall	120
16	Urea	Subsurface-band	Fall	120(80)*
17	Urea+Instinct	Broadcast	Fall	120(80)*
18	Urea+Instinct	Subsurface-band	Fall	120(80)*
19	ESN	Broadcast	Fall	120 (80)*
20	AA	Injected	Spring PP	120
21	Urea	Subsurface-band	Spring PP	120(80)*
22	Urea+Instinct	Broadcast	Spring PP	120(80)*
23	Urea+Instinct	Subsurface-band	Spring PP	120(80)*
24	ESN	Broadcast	Spring PP	120 (80)*

*Source/application comparison for the corn-soybean and corn-wheat rotation were compared at N rate of 80 lb N/ac, and for corn-corn rotation at N rate of 120 lb N/ac. All broadcast treatments were incorporated by tillage.

Table 2. Mean monthly cumulative precipitation for the 30-yr normal and the 2019 growing season for each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. cumm.
		Inch							
Waseca	30-yr avg.	3.21	3.93	4.69	4.42	4.75	3.67	2.67	27
	2019	4.25	6.33	3.32	6.43	5.34	6.69	5.94	38
Lamberton	30-yr avg.	2.78	3.55	4.15	3.73	3.2	3.22	2.15	22.8
	2019	5.91	4.80	2.35	6.86	2.22	6.02	4.00	32.2
Morris	30-yr avg.	2.27	3.00	4.00	3.66	3.05	2.32	1.84	20.1
	2019	2.23	4.06	5.47	4.54	5.53	6.64	3.02	31.5
Crookston	30-yr avg.	1.14	3.04	3.81	3.14	2.89	2.89	1.89	18.8
	2019	1.56	1.38	1.39	3.32	4.72	6.92	4.15	23.4

Table 3. Grain yield response to N application rates at different sites and crop rotations in 2019.

		Waseca - CSb	Lamberton - CC	Lamberton - CSb	Morris - CC	Morris - CSb	Crookston - CC	Crookston - CSb
		bu ac-1						
Fall	0-N	103.9 e	53.0 e	130.1 c	89.6 c	110.4 b	100.8	104.3 d
	40-N	122.3 d	103.5 d	155.2 b	129.9 bc	143.0 ab	110.6	122.6 c
	80-N	145.8 c	116.7 cd	168.0 ab	112.1 bc	152.0 a	123.4	133.8 c
	120-N	153.6 c	134.3 bc	190.4 a	124.4 bc	156.6 a	107.6	163.7 b
	160-N	173.5 b	152.7 ab	186.3 a	166.9 ab	169.2 a	118.6	173.8 ab
	200-N	189.0 a	165.0 a	180.0 a	150.8 ab	173.5 a	117.7	181.2 a
	240-N	-	156.8 ab	-	190.2 a	-	-	-
	***P* values**	<.0001	<.0001	0.001	0.0285	0.0177	0.1097	<.0001
Spring	0-N	101.2 d	61.8 c	126.7 b	67.6 c	125.3	105.9 c	105.0 d
	40-N	144.2 c	95.0 bc	141.9 b	105.5 bc	141.0	106.3 c	136.9 c
	80-N	176.9 b	103.9 abc	170.0 a	138.0 ab	150.6	113.6 abc	155.1 b
	120-N	188.7 ab	128.9 ab	178.9 a	166.3 a	173.8	122.3 ab	190.4 a
	160-N	203.9 a	133.1 ab	172.5 a	166.3 a	154.9	124.4 a	189.9 a
	200-N	205.1 a	139.6 ab	183.1 a	176.1 a	165.7	111.7 bc	199.2 a
	240-N	-	142.5 ab	-	178.5 a	-	-	-
	***P* values**	<.0001	0.0171	0.0003	0.0040	0.1541	0.0550	<.0001
	Fall	149.1 b	124.9	167.5	137.7	150.8	113.1	146.6
	Spring	170.0 a	115.0	162.2	142.6	151.9	114.0	162.8
	***P* values**	0.0489	0.3686	0.5067	0.7143	0.8949	0.7873	0.1090

Within a comparison group, numbers followed by the same letter are not significantly different.

Table 4. Grain N removal response to N application rates at different sites and crop rotations in 2019.

	Waseca - CSb	Lamberton - CC	Lamberton - CSb	Morris- CC	Morris - CSb	Crookston - CC	Crookston - CSb
	____________________	____________________	____________________	lb N ac-1	____________________	____________________	____________________
N rate (N)							
0-N	44.01 d	22.87 d	54.50 c	36.5 d	49.66 b	54.03 c	53.27 d
40-N	59.47 c	41.25 c	66.91 bc	57.6 cd	56.50 b	55.03 c	66.66 c
80-N	80.34 b	45.14 c	78.13 b	68.7 bc	60.05 b	64.53 ab	73.99 c
120-N	87.06 b	64.13 b	96.77 a	73.9 bc	77.91 a	61.52 bc	98.73 b
160-N	101.88 a	76.30 ab	97.98 a	86.7 ab	78.87 a	67.06 ab	100.16 b
200-N	107.45 a	76.22 ab	100.50 a	84.1 ab	87.53a	72.50 a	113.66 a
240-N	-	84.24 a	-	104.7 a	-	-	-
Time (T)							
Fall	68.61 b	62.26	83.71	73.3	68.2	60.54	79.08 b
Spring	91.46 a	54.93	81.22	73.1	68.64	64.35	89.74 a
				……………P values………………..			
N rate (N)	<.0001	<.0001	<.0001	<.0001	<.0001	0.0006	<.0001
Time (T)	<.0001	0.1331	0.5169	0.9730	0.9174	0.1213	0.0061
N x T	0.0004	0.8289	0.4462	0.5585	0.1657	0.8099	0.6010

Within a comparison group, numbers followed by the same letter are not significantly different.

Table 5. *Waseca, type of response to N, economic optimum N rate (EONR) calculated at a 0.1 N price: corn ratio, and grain yield at that EONR for different years and crop rotations [corn-corn (CC) and corn-soybean (CSb)]. Difference was calculated as the average across years-spring results minus -fall results.*

	Rotation	Time	Response to N	EONR (lb N ac^{-1})	EONR Yield (bu ac^{-1})
2016	CC	Fall	Linear	240	217
	CC	Spring	Quadratic plateau	202	234
	CSb	Fall	Quadratic plateau	188	241
	CSb	Spring	Quadratic plateau	184	251
2017	CC	Fall	Linear	240	222
	CC	Spring	Quadratic plateau	206	224
	CSb	Fall	Quadratic plateau	156	226
	CSb	Spring	Quadratic plateau	132	233
2018	CC	Fall	Linear	240	191
	CC	Spring	Quadratic plateau	178	208
	CSb	Fall	Linear	200	224
	CSb	Spring	Quadratic plateau	164	235
2019	CSb	Fall	Linear	200	189
	CSb	Spring	Quadratic plateau	161	203
Difference	CC			-45	12
	CSb			-26	11

Table 6. *Lamberton, type of response to N, economic optimum N rate (EONR) calculated at a 0.1 N price: corn ratio, and grain yield at that EONR for different years and crop rotations [corn-corn (CC) and corn-soybean (CSb)]. Difference was calculated as the average across years-spring results minus -fall results.*

Lamberton	Rotation	Time	Response to N	EONR (lb N ac^{-1})	EONR Yield (bu ac^{-1})
2016	CC	Fall	Linear	240	150
	CC	Spring	Linear	240	197
	CSb	Fall	Linear	200	214
	CSb	Spring	Quadratic plateau	154	199
2017	CC	Fall	Linear	240	201
	CC	Spring	Linear	240	202
	CSb	Fall	Quadratic plateau	170	183
	CSb	Spring	Quadratic plateau*	200	207
2018	CC	Fall	Linear	240	122
	CC	Spring	Linear	240	183
	CSb	Fall	Linear	200	187
	CSb	Spring	Linear	200	207
2019	CC	Fall	Quadratic plateau	195	159
	CC	Spring	Quadratic plateau	190	140
	CSb	Fall	Quadratic plateau	127	184
	CSb	Spring	Quadratic plateau	132	178
Difference	CC			-1	23
	CSb			-3	6

Table 7. *Morris, type of response to N, economic optimum N rate (EONR) calculated at a 0.1 N price: corn ratio, and grain yield at that EONR for different years and crop rotations [corn-corn (CC) and corn-soybean (CSb)]. Difference was calculated as the average across years-spring results minus -fall results.*

Morris	Rotation	Time	Response to N	EONR (lb N ac-1)	EONR Yield (bu ac-1)
2016	CSb	Fall	Quadratic plateau	193	204
	CSb	Spring	Quadratic plateau	168	206
2017	CC	Fall	Linear	240	140
	CC	Spring	Linear	240	182
2018	CC	Fall	Linear	240	157
	CC	Spring	Quadratic plateau	192	164
	CSb	Fall	No N response	0/200	196/163
	CSb	Spring	No N response	0/200	161/193
2019	CC	Fall	Linear	240	190
	CC	Spring	Quadratic plateau	176	175
	CSb	Fall	Quadratic plateau	165	170
	CSb	Spring	Quadratic plateau*	118	162
Difference	CC			-37	11
	CSb			-36	-3

*The ANOVA analysis showed no significant effect to N rate (Table 3). The regression analysis was marginal (Pr>F 0.0594 and R2 0.0594). Visually the response fit a quadratic plateau model.

Table 8. *Crookston, type of response to N, economic optimum N rate (EONR) calculated at a 0.1 N price: corn ratio, and grain yield at that EONR for different years and crop rotations [corn-corn (CC), corn-soybean (CSb), and corn-wheat (CWh)]. Difference was calculated as the average across years-spring results minus -fall results.*

Crookston	Rotation	Time	Response to N	EONR (lb N ac-1)	EONR Yield (bu ac-1)
2017	CWh	Fall	Quadratic plateau	182	157
	CWh	Spring	Quadratic plateau	111	155
	CSb	Fall	No N response	0/200	149/148
	CSb	Spring	No N response	0/200	176/170
2018	CWh	Fall	No N response	0/200	119/135
	CWh	Spring	Quadratic	86	133
	CSb	Fall	No N response	0/200	149/149
	CSb	Spring	No N response	0/200	138/161
2019	CC	Fall	No N response	0/200	101/118
	CC	Spring	No N response	0/200	106/112
	CSb	Fall	Linear	200	182
	CSb	Spring	Quadratic plateau	189	198
Difference	CWh (1yr)			-71	-2
	CSb (1yr)			-11	16

Table 9. *Grain yield response to Fall vs. Spring applications of Urea for 2016 to 2019 growing season at each experimental site. Grain yield comparison is average across all N-rates.*

		Waseca		Lamberton		Morris		Crookston		
		CC	CSb	CC	CSb	CC	CSb	CWh	CSb	CC
		bu ac^{-1}								
2016	Fall	156 b	207 b	116 b	165	-	178	-	-	-
	Spring	183 a	218 a	136 a	170	-	180	-	-	-
2017	Fall	151 b	199 b	154	159 b	98 b	-	133 b	161	-
	Spring	173 a	210 a	151	168 a	123 a	-	141 a	171	-
2018	Fall	144 b	168 b	90 b	141	121	162 b	127	150	-
	Spring	171 a	198 a	120 a	156	132	177 a	120	144	-
2019	Fall	-	149 b	125	168	138	151	-	147	113
	Spring	-	170 a	115	162	143	152	-	163	114

Within a comparison group, numbers followed by the same letter are not significantly different.

Table 10. Grain yield response to N sources at different sites and crop rotations in 2019.

		Waseca - CSb	Lamberton - CC	Lamberton - CSb	Morris - CC	Morris - CSb	Crookston - CC	Crookston - CSb
		bu ac-1						
Fall	AA+ Nserve/I	-	145.8	-	164.5	-	-	-
	ESN/BI	163.1 a	134.9	165.8	183.0	158.7	115.5	133.7
	U+I/BI	142.9 b	127.8	147.7	103.8	147.6	111.3	131.1
	U+I/SSB	174.6 a	134.8	161.7	148.9	144.5	-	-
	U/BI	145.8 b	134.3	164.8	124.4	152.0	123.4	133.8
	U/SSB	176.8 a	148.9	180.5	158.3	146.2	-	-
	***P* values**	0.0001	0.7805	0.1779	0.227	0.9374	0.3954	0.9144
Spring	AA/I	-	154.7 a	-	199.3	-	-	-
	ESN/BI	153.5	146.5 ab	168.8	178.2	161.7	111.4	173.7a
	U+I/BI	165.1	137.6 abc	172.9	152.6	183.4	115.4	151.1 b
	U+I/SSB	156.2	125.0 c	160.4	163.5	159.5	-	-
	U/BI	176.9	128.9 bc	170.0	166.3	150.6	113.6	155.1 b
	U/SSB	162.6	138.7 abc	167.3	158.7	155.3	-	-
	***P* values**	0.1024	0.1000	0.8214	0.1437	0.4917	0.8570	0.0050
	Fall	160.6	138.2	164.0	147.2 b	149.8	116.7	132.9 b
	Spring	162.9	138.6	167.9	169.8 a	162.1	113.5	160.0 a
	***P* values**	0.6500	0.9248	0.4738	0.0509	0.1348	0.4482	<.0001

Within a comparison group, numbers followed by the same letter are not significantly different.

Table 11. Grain yield response to anhydrous ammonia with (AA+Nserve) and without (AA) nitrogen inhibitor N-serve, and Urea application at the rate of 120 lb N/a for the corn-soybean rotation at Lamberton, Waseca, and Morris sites in 2019.

		Waseca - CSb	**Lamberton - CSb**	**Morris - CSb**
		___bu ac-1___		
Fall	AA+ Nserve/I	-*	178.7	189.9 A
	U/BI	-	190.4	156.6 B
	***P* values**		0.2631	0.082
Spring	AA/I	195.8*	179.0	161.2
	U/BI	188.7	178.9	173.8
	AA+Nserve	187.5*	-	-
	***P* values**	0.5873	0.9502	0.5029
	Fall	-	184.5	173.3
	Spring	-	178.9	167.5
	***P* values**	-	0.4170	0.6539

*The AA applications were done in the fall due to frozen soils. Those treatment plots were used to compare the regular spring treatment (AA) to AA with inhibitor applied in the spring. *Within a comparison group, numbers followed by the same letter are not significantly different.*

Table 12. Grain N removal response to N sources rates at different sites and crop rotations in 2019.

	Waseca - CSb	Lamberton - CC	Lamberton - CSb	Morris - CC	Morris - CSb	Crookston - CC	Crookston - CSb
				lb N ac^{-1}			
AA/I*	-	72.7	-	94.48 ab	-	-	-
ESN/BI	75.1	63.3	81.6	95.09 a	72.9	58.8	87.21 a
U+I/BI	71.3	55.3	80.5	65.45 c	74.8	61.1	78.36 ab
U+I/SSB	74.3	57.8	82.3	87.41 ab	67.9	-	-
U/BI	80.3	64.1	77.8	73.91 bc	60.0	64.5	73.99 b
U/SSB	80.3	70.4	89.3	74.09 bc	67.0	-	-
Time (T)							
Fall	74.5	64.5	80.1	76.46	67.6	61.3	69.37 b
Spring	78.0	63.1	84.5	87.02	69.5	61.7	90.33 a
			………………P values……………				
Source (S)	0.1466	0.144	0.4795	0.1009	0.3633	0.2778	0.044
Time (T)	0.1811	0.7510	0.2824	0.1445	0.7034	0.8859	<.0001
S x T	0.0002	0.2823	0.4425	0.5293	0.4855	0.3747	0.0880

*AA/I is averaged across fall (AA+ Nserve/I) and spring (AA/I) treatments. *Within a comparison group, numbers followed by the same letter are not significantly different.*

Table 13. Grain N removal response to anhydrous ammonia with (AA+Nserve) and without (AA) nitrogen inhibitor N-serve, and Urea application at the rate of 120 lb N/a for the corn-soybean rotation at Lamberton, Waseca, and Morris sites in 2019.

	Waseca - CSb†	**Lamberton - CSb**	**Morris - CSb**
		lb N ac^{-1}	
AA/I	109.32	94.4*	83.3*
U/BI	106.88	96.8	77.9
AA+ Nserve/I	107.63	-	-
Time (T)			
Fall	-	97.4	81.0
Spring	-	93.8	80.2
Source (S)	0.9729	0.7282	0.1390
Time (T)	-	0.5995	0.8227
S x T	-	0.1467	0.0013

*AA/I is averaged across fall (AA+ Nserve/I) and spring (AA/I) treatments.

Table 14. *Grain yield response to placement of Urea broadcasted and incorporated (BI) vs. subsurface banded (SSB) for 2016 to 2019 growing season at each experimental site. Grain yield comparison is average across urea (U) and Urea+Instinct (U+I) treatments.*

			Waseca		Lamberton		Morris	
Year	**Time**	**Placement**	**CC**	**CSb**	**CC**	**CSb**	**CC**	**CSb**
			bu ac^{-1}					
2016	Fall	BI	167 b**	208	115 b*	157 b*	-	183
		SSB	196 a	214	139 a	182 a	-	177
	Spring	BI	210 a*	224 a*	147	178	-	184
		SSB	197 b	215 b	172	184	-	183
2017	Fall	BI	163	197	165 b**	155 b*	94 b*	-
		SSB	166	198	182 a	182 a	139 a	-
	Spring	BI	193 b*	222	161	172	126	-
		SSB	233 a	223	168	182	126	-
2018	Fall	BI	143 b*	146 b*	75 b*	119 b*	125	161
		SSB	160 a	190 a	100 a	143 a	129	172
	Spring	BI	190 a*	198 a*	108 b*	150 b**	143	170
		SSB	162 b	171 b	160 a	169 a	139	174
2019	Fall	BI	-	144 b*	131.5	156.3	114.1	149.8
		SSB	-	176 a	141.8	171.1	153.6	145.3
	Spring	BI	-	171 a*	133.3	171.4	159.5	167.1
		SSB	-	159 b	131.8	163.8	161.1	157.4

** P< 0.05; ** P < 0.10. Within a comparison group, numbers followed by the same letter are not significantly different.*

Table 15. *Grain yield response to applications of urea (U) and Urea+Instinct (U+I) for 2016 to 2019 growing season at each experimental site. Grain yield comparison is average Urea broadcasted and incorporated (BI) vs. subsurface banded (SSB) treatments.*

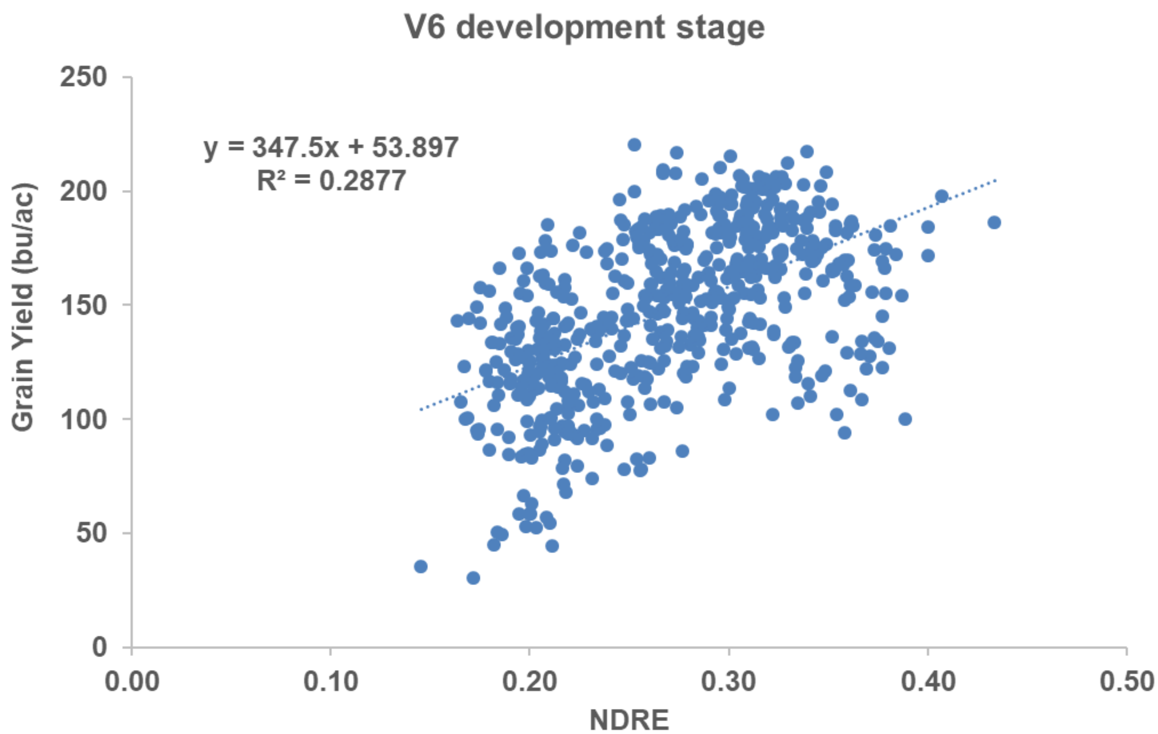
			Waseca		Lamberton		Morris		Crookston	
Year	**Time**	**Inhibitor**	**CC**	**CSb**	**CC**	**CSb**	**CC**	**CSb**	**CC**	**CSb**
			bu ac^{-1}							
2016	Fall	U	177	209	125	162	-	177	-	-
		U+I	185	213	129	177	-	182	-	-
	Spring	U	205	221	153	179	-	184	-	-
		U+I	202	218	165	184	-	183	-	-
2017	Fall	U	153 b	199	176	173	114	-	132	148
		U+I	176 a	197	171	163	118	-	134	168
	Spring	U	217	221	172 a	180	132	-	150	158
		U+I	209	224	157 b	173	120	-	148	169
2018	Fall	U	174	172	89	133	131	167	134	155 b
		U+I	161	167	85	128	123	166	132	162 a
	Spring	U	187 a	182	131	162	144	172	128	144
		U+I	164 b	180	137	157	137	172	138	167
2019	Fall	U		161	142	176	141	149	123	134
		U+I		159	132	155	126	146	111	131
	Spring	U		170	134	169	163	153	114	155
		U+I		161	131	167	158	172	115	151

Within a comparison group, numbers followed by the same letter are not significantly different.

Table 16. *Occurrence of Grain yield response and yield difference of different N-source combinations across sites for 2016 to 2019 growing season for fall and Spring applications.*

Comparison	Time	Occurrence	Percent %	Yield Diff bu ac^{-1}
AA > Urea BI	Fall	18/30	60	49
(across w & w/o inhibitor)	Spring	10/31; 1/31*	32; 3	45; -29
AA > Urea SSB	Fall	6/20	30	58
(across w & w/o inhibitor)	Spring	6/20; 2/20*	30; 10	32; -49
ESN > Urea BI	Fall	5/22	23	37
	Spring	6/22	27	30
ESN > AA	Fall	0/8; 2/8*	0; 25*	; -39
	Spring	2/8	25	29
SSB > BI	Fall	11/21,	52	33
(across w & w/o inhibitor)	Spring	3/21; 5/21*	14; 24*	38; -18
U+I > U	Fall	2/27	7	15
(across placement)	Spring	2/27*	7	-19

* Indicates reverse response



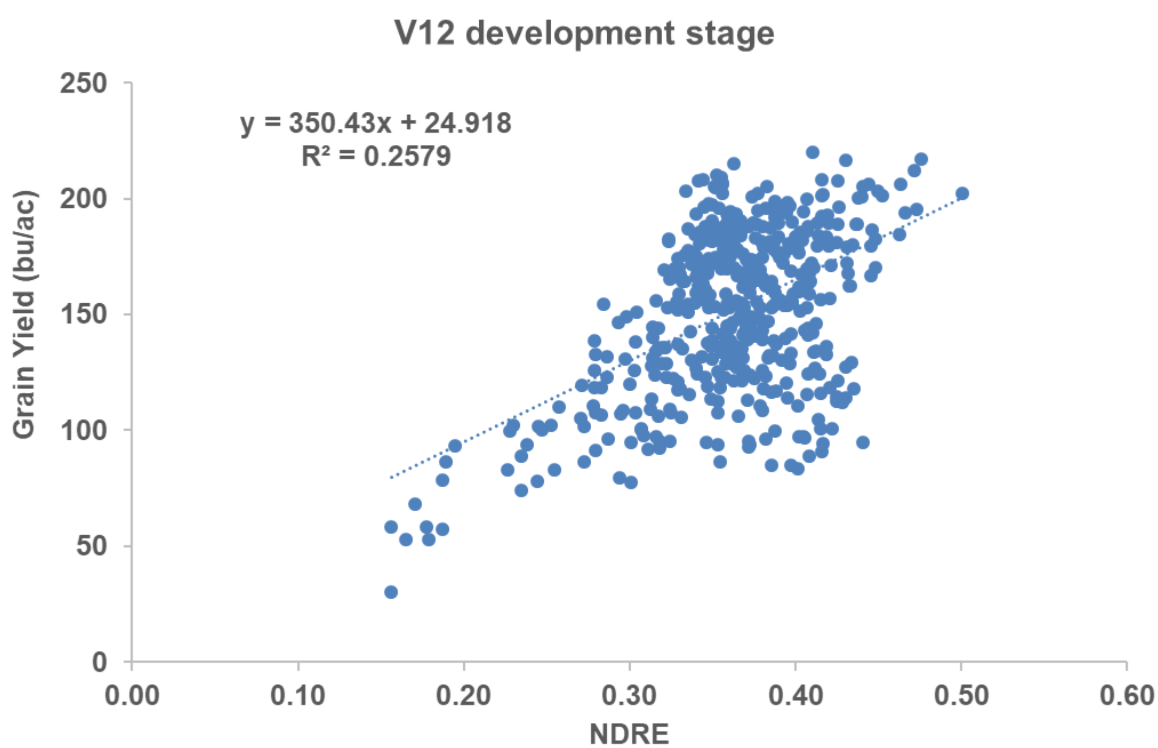


Figure 1. Relationship of grain yield and crop Circle normalized difference red-edge (NDRE) index calculated for the V6 and V12 development stages averaged across all variables in the study for 2019 growing season.

Appendix- 1. Plant N uptake at V6, V12, and R6 (Total N) development stages in response to N application rates at different sites for continuous crop rotation during the 2019 growing season.

	Lamberton - CC			Morris – CC			Crookston - CC		
	V6	**V12**	**R6‡**	**V6**	**V12**	**R6‡**	**V6**	**V12**	**R6‡**
					lb N ac^{-1}				
N rate (N)									
0-N	5.38 b	26.09 c	35.14 d	4.27 c	23.14 e	53.99 d	7.41 c	24.39 d	70.85 c
40-N	7.57 a	44.23 b	64.51 c	7.27 bc	39.44 de	77.15 cd	8.19 c	34.61 c	71.61 c
80-N	7.95 a	55.48 ab	64.25 c	9.55 ab	43.93 cd	93.74 bc	10.19 b	44.49 b	83.45 b
120-N	7.35 a	60.26 a	91.92 b	9.44 ab	62.01 bc	98.64 bc	11.09 ab	47.14 ab	80.51 bc
160-N	7.30 a	64.21 a	112.76 ab	12.03 a	65.16 ab	120.83 ab	10.76 ab	50.84 ab	90.17 ab
200-N	6.77 a	59.96 ab	110.10 b	10.62 a	76.92 ab	116.26 ab	11.75 a	52.38 a	96.26 a
240-N	6.65 ab	62.14 a	136.39 a	11.56 a	83.55 a	143.51 a	-	-	-
Time (T)									
Fall	7.0	54.4	91.2	8.44 b	52.36	98.77	5.66	40.5	79.12 b
Spring	7.0	52.0	84.6	10.06 a	60.26	102.4	10.14	44.11	85.16 a
					………………P values……………				
N rate (N)	0.0108	0.0002	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Time (T)	0.8309	0.5642	0.316	0.0538	0.1174	0.6456	0.1596	0.0763	0.0366
N x T	0.0493	0.6842	0.7596	0.4981	0.2784	0.6299	0.3677	0.6533	0.8855

‡Total N uptake at R6 is the sum of grain N and stover N. *Within a comparison group, numbers followed by the same letter are not significantly different.*

Appendix-2. Plant N uptake at V6, V12, and R6 (TotalN) development stages in response to N application rates at different sites for corn-soybean crop rotations during the 2019 growing season.

	Waseca - CSb			**Lamberton - CSb**			**Morris – CSb**			**Crookston - CSb**		
	V6	**V12**	**R6‡**	**V6**	**V12**	**R6‡**	**V6**	**V12**	**R6‡**	**V6**	**V12**	**R6‡**
	lb N ac-1											
N rate (N)												
0-N	6.88 d	33.91 d	63.24 d	14.25	57.37 d	75.15 d	8.39 c	34.82 d	62.18 d	9.24 c	22.98 d	61.27 d
40-N	12.10 c	57.81 c	85.91 c	15.11	73.49 c	93.24 c	14.62 b	52.74 c	72.50 cd	12.73 b	37.66 c	78.09 c
80-N	14.21	68.98 c	109.61	17.54	78.23 bc	113.07 b	14.12 b	66.51 b	81.03 c	15.07 a	51.44 b	89.68 c
120-N	13.58	89.70 b	118.68	16.00	94.55 a	129.59 a	17.76 a	72.23 b	101.53 b	15.45 a	59.25 ab	115.00 b
160-N	19.39 a	104.23	142.50	17.58	79.74 abc	128.72 ab	18.88 a	85.15 a	114.37	16.20 a	58.12 ab	121.26 b
200-N	16.09 b	106.43	149.20	17.22	90.31 ab	138.06 a	16.87 a	86.46 a	124.85 a	16.08 a	66.84 a	137.88 a
Time (T)												
Fall	11.31 b	63.96 b	95.75 b	17.82 a	81.89	114.75	14.62	66.77	91.52	13.72	44.51 b	93.77 b
Spring	16.10 a	88.73 a	127.30	14.41 b	76.00	111.19	15.60	65.86	93.97	14.54	54.25 a	107.3 a
	……………..P values……………											
N rate (N)	<.0001	<.0001	<.0001	0.2455	0.0005	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Time (T)	<.0001	<.0001	<.0001	0.0005	0.2028	0.438	0.1323	0.7517	0.5775	0.1032	0.0006	0.0021
N x T	0.0185	0.0010	0.0006	0.9968	0.5718	0.3449	0.6828	0.0370	0.2082	0.0963	0.3067	0.404

‡Total N uptake at R6 is the sum of grain N and stover N. *Within a comparison group, numbers followed by the same letter are not significantly different.*

Appendix-3. Plant N uptake at V6 and R6 development stages in response to management practices at different sites for continuous corn rotations during the 2019 growing season.

	Lamberton - CC			Morris – CC			Crookston - CC		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
	lb N ac^{-1}								
Management†(M)									
AA/I†	8.4	66.3	105.9	10.59	67.11	134.06 a	-	-	-
ESN/BI	6.9	64.5	89.2	11.62	81.66	130.10 a	10.1	41.9	77.7
U+I/BI	7.7	61.3	82.0	9.16	56.69	94.31 ab	9.6	47.7	77.7
U+I/SSB	8.1	61.4	83.8	12.06	71.22	116.28 b	-	-	-
U/BI	7.4	60.3	91.9	9.44	62.01	98.64 b	10.2	44.5	83.4
U/SSB	8.1	65.3	100.1	10.85	64.12	101.69 b	-	-	-
Time (T)									
Fall	7.8	64.9	94.1	9.78	58.92 b	106.08	9.8	43.6	79.0
Spring	7.7	61.4	89.8	11.46	75.29 a	118.94	10.1	45.8	80.2
	……………….P values……………								
Management (M)	0.3116	0.9419	0.1262	0.3023	0.2640	0.0552	0.5596	0.4316	0.3282
Time (T)	0.7266	0.4075	0.4587	0.0542	0.0117	0.1555	0.5030	0.5513	0.7292
M x T	0.9736	0.8117	0.273	0.1110	0.5039	0.5897	0.0749	0.6375	0.3994

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.
‡Total N uptake at R6 is the sum of grain N and stover N.
Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-4. Plant N uptake at V6 and R6 development stages in response to management practices at different sites for corn-soybean rotations during the 2019 growing season.

	Waseca - CSb			Lamberton - CSb			Morris – CSb			Crookston - CSb		
	V6	**V12**	**R6‡**	**V6**	**V12**	**R6‡**	**V6**	**V12**	**R6‡**	**V6**	**V12**	**R6‡**
							lb N ac-1					
Management†(M)												
ESN/BI	13.1	77.82 ab	106.1	16.9	88.1	109.1	17.3	73.3	94.7	15.6	52.3	101.87 a
U+I/BI	11.8	65.12 b	100.9	16.7	79.6	111.5	15.2	72.3	96.6	15.1	48.5	92.50 ab
U+I/SSB	12.5	82.26 a	101.9	14.9	79.7	110.2	13.9	67.2	86.7	-	-	-
U/BI	14.2	68.98 ab	109.6	17.5	76.3	112.8	14.1	66.5	81.0	15.1	51.4	89.68 b
U/SSB	11.7	83.14 a	108.5	17.0	90.6	122.5	15.0	56.9	86.3	-	-	-
Time (T)												
Fall	12.4	76.3	104.0	17.3	83.4	112.3	13.70 b	63.74	85.4	15.02	44.40 b	83.66 b
Spring	13.0	74.6	106.7	15.9	82.3	114.1	16.52 a	70.71	92.7	15.44	57.11 a	105.7 a
							P values					
Management (M)	0.5076	0.0538	0.2999	0.4009	0.0722	0.5354	0.3220	0.1258	0.2677	0.7060	0.7125	0.0501
Time (T)	0.5375	0.6982	0.3861	0.1082	0.7465	0.7466	0.0135	0.1038	0.1484	0.4589	0.0044	<0.0001
M x T	0.0344	0.0012	<.0001	0.0224	0.7277	0.5731	0.9557	0.1190	0.3628	0.7951	0.9568	0.0433

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.
‡Total N uptake at R6 is the sum of grain N and stover N.
Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-5. Plant N uptake at V6 and R6 development stages in response to management practices at different sites for corn-soybean rotations during the 2019 growing season.

	Waseca - CSb			Lamberton - CSb			Morris – CSb		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
	lb N ac^{-1}								
Management†(M)									
AA/I†	17.5	86.31	146.74	14.3	91.6	131.1	13.5 b	74.4	109.8
U/BI	16.49	110.32	144.4	16.0	94.6	129.6	17.8 a	72.2	101.5
AA+Nserve	16.62	92.59	146.91	-	-	-			
Time (T)									
Fall	-	-	-	15.9	94.0	135.6	16.1	77.7	107.3
Spring	-	-	-	14.4	92.2	125.1	15.1	69.0	104.1
	………………P values……………								
Management (M)	0.9539	0.3138	0.9746	0.2357	0.5792	0.7714	0.0028	0.7086	0.0993
Time (T)	-	-	-	0.3184	0.7314	0.0659	0.3570	0.1568	0.4889
M x T	-	-	-	0.1916	0.2370	0.3399	0.7872	0.1014	0.0033

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.
‡Total N uptake at R6 is the sum of grain N and stover N.

Appendix-6. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under corn-soybean rotation in Waseca during 2019 growing season.

Soil Extractable N (lb/ac) at Waseca-CSb												
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	37.0	19.5 c	17.6	15.3 d	15.6	15.5 d	29.5	15.3	14.4	9.5	15.9	17.8
40-N	37.9	31.3 bc	15.0	27.8 c	13.5	23.0 c	30.4	15.5	15.5	11.3	17.1	14.3
80-N	37.4	42.5 b	16.3	35.8 c	14.3	24.8 bc	31.0	14.3	19.1	9.5	19.0	14.0
120-N	40.4	68.3 a	19.0	50.0 d	17.5	32.0 ab	32.4	14.0	15.5	9.0	16.5	12.5
160-N	38.5	85.5a	13.3	55.8 ab	14.5	32.5 a	30.1	14.0	17.3	8.3	17.4	12.8
200-N	36.9	85.3 a	18.5	59.8 a	19.9	37.8 a	31.4	15.3	15.3	9.8	17.6	17.8
Time (T)												
Fall	38.5	33.8 b	15.9	31.9 b	14.8	25.7	30.9	14.3	15.9	9.0	16.8	14.8
Spring	37.5	77.0 a	17.3	49.5 a	16.9	29.5	30.7	15.1	16.5	10.1	17.8	14.8
	………………P values……………						………………P values……………					
N rate (N)	0.8587	<.0001	0.1228	<.0001	0.1137	<.0001	0.9134	0.9195	0.011	0.7094	0.3739	0.1512
Time (T)	0.5361	<.0001	0.3015	<.0001	0.1484	0.078	0.9142	0.4886	0.4398	0.3124	0.2349	1.00000
N x T	0.5057	0.0009	0.1923	0.0007	0.0914	0.6813	0.8049	0.6632	0.2157	0.9816	0.2053	0.0606

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-7. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Waseca during 2019 growing season.

	Soil Extractable N (lb/ac) at Waseca-CSb											
	V4						**Post-Harvest**					
	0-12”		**12-24”**		**24-36”**		**0-12”**		**12-24”**		**24-36”**	
	NH_4-N	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**
Management†(M)												
ESN/BI	38.4	38.3	17.8	24.8	17.6	22.5	32.4	17.5	15.8	10.5	16.4	13.3
U+I/BI	34.8	37.3	14.6	30.0	14.3	23.3	30.9	14.0	15.6	11.8	17.1	18.5
U+I/SSB	47.1	31.3	16.3	28.3	18.9	30.8	32.6	14.3	17.1	10.5	17.6	14.3
U/BI	37.4	42.5	16.3	35.8	14.3	24.8	31.0	14.3	19.1	9.5	19.0	14.0
U/SSB	42.3	36.3	15.6	25.0	15.9	22.8	30.6	12.5	16.3	10.3	17.3	22.3
Time (T)												
Fall	35.9	28.1 b	15.3	26.4	16.2	26.2	31.2	15.3	16.6	10.0	17.6	17.8
Spring	44.1	46.1 a	17.0	31.1	16.2	23.4	31.9	13.7	17.0	11.0	17.4	15.1
	………………P values……………						………………P values……………					
Management(M)	0.2970	0.6186	0.5027	0.0849	0.0793	0.6983	0.5241	0.2727	0.1604	0.9605	0.1533	0.5891
Time (T)	0.0406	0.0003	0.1335	0.0884	0.9670	0.5041	0.4513	0.2637	0.6441	0.5951	0.8164	0.5117
M x T	0.1448	0.2074	0.8138	0.1444	0.0938	0.4859	0.049	0.6477	0.0354	0.7983	0.256	0.586

Appendix-8. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Waseca during 2019 growing season.

	Soil Extractable N (lb/ac) at Waseca CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management† (M)												
AA/I†	58.0	87.0	19.25	39.0 b	21.5	24 b	31.5	16.5	15.5	10	16.5	11
AA+Nserve/I	119.8	90.0	15	35.5 b	15.0	23.5 b	30	12.5	15.75	7.5	15	9.5
U/BI	41.8	98.0	19.5	61.5 a	18.8	36 a	30.75	15.5	14.75	9.5	17	11.5
	………………P values…………..						………………P values…………..					
Management(M)	0.0823	0.9376	0.0795	0.0064	0.3701	0.0448	0.8167	0.4158	0.8531	0.5833	0.1566	0.5874

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: 120 lb N/ac Urea/broadcast; *Within a comparison group, numbers followed by the same letter are not significantly different.*

Appendix-9. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under continuous corn rotation in Lamberton during 2019 growing season.

Soil Extractable N (lb/ac) at Lamberton CC												
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	30.5	7.8 d	10.4	6.3 c	6.8	7.8 c	28.5	6.3	16.9	3.3	13.8	2.5
40-N	27.5	17.0 cd	9.5	12.0 c	8.0	11.3 bc	27.8	5.8	18.9	3.5	16.3	2.5
80-N	30.5	18.8 cd	11.4	12.3 bc	10.3	11.8 bc	29.1	7.0	16.4	3.5	14.4	3.3
120-N	31.0	31.8 bc	12.1	21.0 ab	7.6	15.8 abc	27.5	6.5	18.8	3.5	16.9	3.3
160-N	31.5	46.5 ab	10.8	24.3 a	9.3	21.3 a	32.5	11.8	19.1	5.3	14.8	5.5
200-N	30.3	41.5 ab	11.9	24.5 a	7.6	19.8 ab	29.5	7.0	18.1	4.0	16.0	3.5
240-N	34.6	54.3 a	10.6	23.9 a	9.5	18.8 ab	32.4	16.5	17.2	9.4	14.7	11.1
Time (T)												
Fall	**30.1**	**32.8**	**11.2**	**20.1 a**	**8.1**	**16.1**	**28.7**	**7.1**	**17.9**	**4.3**	**15.0**	**3.7**
Spring	**31.6**	**29.4**	**10.8**	**15.4 b**	**8.8**	**14.3**	**30.5**	**10.3**	**17.9**	**5.0**	**15.5**	**5.3**
	………………P values……………						………………P values……………					
N rate (N)	0.7453	0.0003	0.8402	0.0003	0.3201	0.03	0.5537	0.3649	0.5505	0.2646	0.2696	0.3363
Time (T)	0.454	0.5336	0.7062	0.061	0.4704	0.456	0.2929	0.2473	0.983	0.596	0.5707	0.4517
N x T	0.5799	0.846	0.9752	0.2379	0.5673	0.9991	0.5509	0.701	0.2518	0.866	0.0261	0.8862

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-10. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under continuous corn rotation in Lamberton during 2019 growing season.

	Soil Extractable N (lb/ac) at Lamberton CC											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management† (M)												
AA/I†	30.9	17.5	11.1	12.3	8.3	8.8	30.5 ab	8.3	16.8	4.0	14.5	3.3
ESN/BI	32.4	38.0	12.0	16.8	7.3	12.5	30.1 ab	8.0	17.8	4.3	15.0	2.8
U+I/BI	35.7	27.8	12.0	16.2	8.8	13.4	29.3 bc	8.6	17.3	3.2	15.4	2.5
U+I/SSB	61.1	25.0	9.9	17.5	9.3	13.3	32.4 a	8.0	16.3	3.5	13.5	2.5
U/BI	31.0	31.8	12.1	21.0	7.6	15.8	27.5 c	6.5	18.8	3.5	16.9	3.3
U/SSB	28.5	24.0	9.3	19.8	7.0	13.8	28.8 bc	7.8	19.0	3.3	16.4	2.3
Time (T)												
Fall	30.93	28.18	11.13	21.3 a	8.07	14.00	30.00	8.53	17.70	3.83	15.26	2.80
Spring	42.25	25.50	11.04	13.2 b	8.00	11.75	29.54	7.17	17.58	3.42	15.29	2.75
	………………P values……………						………………P values……………					
Management(M)	0.4311	0.2501	0.2197	0.4082	0.6024	0.1352	0.0115	0.7015	0.5027	0.5974	0.3769	0.2894
Time (T)	0.2713	0.5933	0.9734	0.0025	0.9357	0.1125	0.5707	0.0805	0.9249	0.3422	0.9812	0.9742
M x T	0.4648	0.1513	0.2402	0.3119	0.6377	0.7213	0.0003	0.0347	0.4242	0.4392	0.5816	0.0697

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.
Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-11. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under corn-soybean rotation in Lamberton during 2019 growing season.

Soil Extractable N (lb/ac) at Lamberton-CSb												
	V4						Post-Harvest					
	0-12"		12-24"		24-36"		0-12"		12-24"		24-36"	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	25.5	5.8 c	11.4	6.5 d	4.3	6.5	32.4	9.0 c	16.8	6.3 d	14.4	4.3 c
40-N	29.8	6.8 c	10.4	12.8 cd	6.0	11.5	29.4	10.3 bc	13.9	6.8 cd	13.1	5.0 bc
80-N	29.6	16.3 bc	15.9	23.4 bc	6.3	17.5	33.0	11.1 abc	17.0	7.6 bcd	14.4	5.9 bc
120-N	32.3	24.0 b	11.8	23.5 bc	7.3	17.5	32.9	12.0 ab	16.0	8.0 bc	13.4	6.5 b
160-N	29.7	32.5 b	11.4	39.3 ab	8.0	20.5	31.2	12.4 ab	15.8	9.3 ab	16.4	9.6 a
200-N	30.8	62.0 a	13.0	54.8 a	7.0	22.0	30.8	13.8 a	16.1	10.8 a	14.3	10.8 a
Time (T)												
Fall	32.6	23.6	13.8	26.0	8.9 a	17.8	31.5	12.1	15.7	8.3	13.3	7.4
Spring	26.8	25.3	10.8	27.1	4.0 b	14.0	31.8	10.8	16.2	8.0	15.2	6.6
	………………P values……………						………………P values……………					
N rate (N)	0.8194	<.0001	0.6285	<.0001	0.944	0.1263	0.604	0.0398	0.1829	0.0001	0.5496	<.0001
Time (T)	0.1199	0.7035	0.1578	0.874	0.0483	0.2603	0.7191	0.1171	0.5347	0.5796	0.0561	0.1945
N x T	0.7144	0.8413	0.983	0.9426	0.0409	0.9417	0.81	0.0657	0.9444	0.0079	0.9455	<.0001

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-12. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Lamberton during 2019 growing season.

	Soil Extractable N (lb/ac) at Lamberton CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management†(M)												
ESN/BI	29.3	19.0	10.3	20.0	6.8	19.5	33.4	11.5	14.5	7.8	13.6	5.8
U+I/BI	24.3	16.0	11.3	21.0	5.8	13.5	32.1	10.3	16.3	7.8	14.6	5.0
U+I/SSB	35.6	37.0	10.8	22.3	4.5	18.0	28.9	11.0	15.4	7.3	12.5	4.8
U/BI	29.6	16.0	15.9	23.4	6.3	17.5	32.9	11.1	17.1	7.7	14.4	6.3
U/SSB	30.6	13.0	9.8	18.0	5.3	14.0	33.3	12.8	16.3	7.5	13.9	5.8
Time (T)												
Fall	28.6	16.4	12.8	19.8	6.6	18.4	32.3	10.6	16.5	7.2	14.6	4.5 b
Spring	31.1	24.0	10.2	21.9	4.8	14.6	31.9	12.0	15.3	8.0	13.1	6.4 a
	………………P values……………						………………P values……………					
Management(M)	0.2239	0.0945	0.2137	0.7825	0.9206	0.6755	0.1446	0.304	0.3429	0.9703	0.7442	0.7426
Time (T)	0.5087	0.2151	0.1265	0.4952	0.3040	0.2430	0.8351	0.0813	0.151	0.1381	0.1829	0.007
M x T	0.0574	0.1722	0.8501	0.6354	0.7833	0.8448	0.6079	0.1312	0.3435	0.052	0.0343	0.1039

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.
Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-13. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Lamberton during 2019 growing season.

	Soil Extractable N (lb/ac) at Lamberton CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management†(M)												
AA/I†	63.1	56.8	10.8	36.0	6.5	13.5	32.9	12.3	16.1	8.8	14.6	8.3
U/BI	32.3	24.0	11.8	23.5	7.3	17.5	32.9	12.0	16.0	8.0	13.4	6.5
Time (T)												
Fall	65.5	42.8	11.5	28.5	8.8	14.5	34.1	12.3	16.9	8.3	14.1	7.8
Spring	29.9	38.0	11.0	31.0	5.0	16.5	31.6	12.0	15.3	8.5	13.9	7.0
	………………P values……………						………………P values……………					
Management(M)	0.3529	0.1265	0.7817	0.2429	0.8767	0.2641	1.0000	0.8793	0.9296	0.6357	0.2975	0.2596
Time (T)	0.2876	0.8158	0.8996	0.8101	0.4547	0.5518	0.2147	0.8793	0.2676	0.8738	0.8299	0.6213
M x T	0.5099	0.8158	0.4934	0.7369	0.354	0.7619	0.3744	0.6506	0.2676	0.1754	0.3994	0.4146

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: 120 lb N/ac Urea/broadcast;

Appendix-14. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under continuous corn rotation in Morris during 2019 growing season.

Soil Extractable N (lb/ac) at Morris-CC												
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	27.0 b	10.75 b	8.9	14 d	5.8	12.8	21.9	8.0	11.3	3.8	11.3	6.0 b
40-N	30.6 b	12.0 b	10.5	16.5 d	7.8	14.0	19.5	7.0	11.4	4.3	9.8	4.5 b
80-N	26.6 b	15.25 b	8.5	25.5 bcd	8.6	22.0	21.3	8.0	10.0	5.3	10.9	5.4 b
120-N	32.0 ab	20.75 b	10.0	22.5 cd	8.0	16.5	21.8	8.0	11.5	4.5	11.4	5.8 b
160-N	38.0 a	32.25 b	14.1	40.5 b	8.1	27.5	20.4	11.5	12.6	7.3	11.0	12.0 a
200-N	28.4 b	28.75 b	12.5	35.25 bc	9.0	18.5	18.8	8.3	12.4	6.0	10.4	7.8 ab
240-N	31.3 b	77.75 a	10.9	60.5 a	6.5	28.5	21.9	9.8	10.1	8.8	9.8	9.0 ab
Time (T)												
Fall	30.6	25.4	11.4	30.4	7.9	19.6	20.5	7.9	11.1	5.6	10.3	7.3
Spring	30.5	31.1	10.1	30.9	7.4	20.3	21.0	9.4	11.6	5.8	10.9	7.1
	………………P values……………						………………P values……………					
N rate (N)	0.0155	0.0001	0.3148	<.0001	0.4748	0.1567	0.6561	0.2877	0.4512	0.1454	0.4082	0.0499
Time (T)	0.9497	0.4281	0.3626	0.9060	0.5823	0.8621	0.6412	0.1244	0.5172	0.8377	0.2462	0.6470
N x T	0.8741	0.9788	0.4257	0.2162	0.3544	0.5258	0.7658	0.0485	0.1628	0.2272	0.8227	0.8942

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-15. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under continuous corn rotation in Morris during 2019 growing season.

Soil Extractable N (lb/ac) at Morris-CC												
	V4						**Post-Harvest**					
	0-12”		**12-24”**		**24-36”**		**0-12”**		**12-24”**		**24-36”**	
	NH_4-N	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**
Management† (M)												
AA/I†	34.1	48.5 a	11.4	24.3 b	9.0	16.8	22.0	10.3	9.3	5.0	9.1	6.5
ESN/BI	32.8	45.0 a	14.9	38.8 a	9.8	28.5	19.5	9.3	11.1	7.3	11.1	10.0
U+I/BI	28.4	21.25 b	10.6	21.8 b	8.6	13.5	22.3	9.3	10.6	3.8	10.1	5.3
U+I/SSB	33.0	21.0 b	12.1	29.5 ab	7.8	21.5	23.9	10.5	12.5	7.0	12.1	7.0
U/BI	32.0	20.8 b	10.0	22.5 b	8.0	16.5	21.8	8.0	11.5	4.5	11.4	5.8
U/SSB	31.9	20.8 b	9.8	30.8 ab	9.1	19.0	22.1	8.5	12.5	3.5	11.1	4.3
Time (T)												
Fall	**32.5**	**24.0 b**	**11.9**	**26.8**	**8.5**	**19.2**	**22.71**	**10.0 a**	**11.42**	**6.3 a**	**10.75**	**7.7 a**
Spring	**31.5**	**35.1 a**	**11.0**	**29.0**	**9.0**	**19.4**	**21.13**	**8.6 b**	**11.08**	**4.1 b**	**10.91**	**5.0 b**
	……………..P values………….						……………..P values………….					
Management(M)	0.8654	0.0104	0.158	0.0681	0.9267	0.2519	0.3388	0.4537	0.1377	0.2137	0.2033	0.5268
Time (T)	0.6948	0.0651	0.4418	0.5384	0.6723	0.9455	0.1428	0.0874	0.6594	0.051	0.8361	0.0925
M x T	0.4081	0.376	0.3142	0.4658	0.883	0.3224	0.3888	0.2583	0.7949	0.3291	0.8166	0.2727

†AA/Inj: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/Bdcst: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/Bdcst: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-16. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under corn-soybean rotation in Morris during 2019 growing season.

	Soil Extractable N (lb/ac) at Morris-CSb											
	V4						Post-Harvest					
	0-12"		12-24"		24-36"		0-12"		12-24"		24-36"	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	28.6	9.8 b	10.4	10.5 d	9.9	11.8 c	20.5	11.0	10.6	5.5 d	10.3	5.3 b
40-N	28.9	13.5 b	10.8	19.3 cd	10.1	12. 8 c	21.9	12.0	11.1	6.5 cd	11.0	6.3 b
80-N	26.8	16.0 b	13.4	31.8 bc	12.5	21.5 bc	23.0	13.5	12.1	7.3 cd	12.6	6.5 b
120-N	22.3	26.5 b	13.1	28.8 bcd	10.0	16.3 c	22.4	13.5	11.6	8.0 bc	10.6	5.8 b
160-N	21.8	50.8 a	8.9	48.0 b	9.1	32.3 ab	22.4	15.5	11.6	11.0 a	10.9	13.8 a
200-N	22.9	47.3 a	11.8	79.0 a	10.0	40.5 a	23.3	13.0	12.8	9.8 ab	12.9	10.8 a
Time (T)												
Fall	**24.7**	**28.0**	**11.0**	**39.8**	**11.2**	**25.3**	**22.0**	**12.6**	**11.0**	**8.4**	**11.0**	**8.8**
Spring	**25.7**	**26.6**	**11.7**	**32.7**	**9.3**	**19.8**	**22.5**	**13.6**	**12.3**	**7.6**	**11.7**	**7.3**
	………………P values……………						………………P values……………					
N rate (N)	0.3021	0.0002	0.5907	<.0001	0.7442	<.0001	0.7748	0.2183	0.759	0.0002	0.1227	<.0001
Time (T)	0.6895	0.805	0.6838	0.2374	0.1514	0.1151	0.6879	0.335	0.1109	0.2123	0.3141	0.1381
N x T	0.0386	0.4387	0.7984	0.4252	0.6851	0.0802	0.9293	0.2719	0.2931	0.9677	0.6755	0.4087

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-17. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Morris during 2019 growing season.

	Soil Extractable N (lb/ac) at Morris-CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management†(M)												
ESN/BI	26.1	27.0	14.5	33.8	11.0	18.0	21.3	13.0	11.9	7.3	11.9	6.8
U+I/BI	24.1	19.5	11.5	25.8	10.9	22.0	21.6	13.0	12.8	8.8	11.5	7.0
U+I/SSB	21.9	28.5	11.1	27.8	11.1	16.5	22.0	14.3	12.0	8.3	12.5	6.5
U/BI	26.8	16.0	13.4	31.8	12.5	21.5	23.0	13.5	12.1	7.3	12.6	6.5
U/SSB	25.6	19.8	12.9	23.0	12.3	16.8	20.6	11.0	13.8	7.8	13.1	8.3
Time (T)												
Fall	**23.6**	**14.7 b**	**12.0**	**24.8**	**11.0**	**17.9**	**21.2**	**12.8**	**12.75**	**8**	**12.35**	**7.5**
Spring	**26.2**	**29.6 a**	**13.4**	**32.0**	**12.1**	**20.0**	**22.2**	**13.1**	**12.25**	**7.7**	**12.3**	**6.5**
	………………P values……………						………………P values……………					
Management(M)	0.7055	0.259	0.5567	0.5515	0.9142	0.1952	0.8426	0.5847	0.5538	0.8054	0.8599	0.6172
Time (T)	0.2815	0.0009	0.3138	0.1168	0.4374	0.264	0.4621	0.8147	0.5322	0.7468	0.9608	0.2186
M x T	0.9141	0.3049	0.7632	0.7515	0.2201	0.109	0.8835	0.9302	0.0451	0.8859	0.7183	0.4719

†AA/Inj: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/Bdcst: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/Bdcst: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-18. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Morris during 2019 growing season.

	Soil Extractable N (lb/ac) at Morris CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management† (M)												
AA/I†	49.4	71 a	12.0	56.3 a	7.9	19.3	21.8	14.3	10.8	9.7	28.5	10.3
U/BI	22.3	26.5 b	13.1	28.8 b	10.0	16.3	22.4	13.5	11.6	8.0	10.6	5.8
Time (T)												
Fall	38.0	53.5	11.0	38.5	9.1	14.8	22.3	13.5	9.4 b	9.3	23.0	8.5
Spring	33.6	44.0	14.1	46.5	8.8	20.8	22.0	14.3	13.8 a	8.0	12.0	6.7
	………………P values……………						………………P values……………					
Management(M)	0.2054	0.0105	0.7834	0.042	0.2532	0.5333	0.3929	0.6424	0.3941	0.2058	0.3099	0.0942
Time (T)	0.8327	0.53	0.4517	0.5081	0.8342	0.2238	0.4531	0.6424	0.0211	0.2058	0.3376	0.3195
M x T	0.6866	0.9203	0.6056	0.1889	0.9443	0.9166	0.8284	0.0398	0.0866	0.7912	0.2446	0.2186

†AA/I: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/BI: 120 lb N/ac Urea/broadcast;

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-19. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under continuous corn rotation in Crookston during 2019 growing season.

	Soil Extractable N (lb/ac) at Crookston CC											
	V4						**Post-Harvest**					
	0-12”		**12-24”**		**24-36”**		**0-12”**		**12-24”**		**24-36”**	
	NH_4-N	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**	**NH_4-N**	**NO_3-N**
N rate (N)												
0-N	31.9	38.0 e	8.9	17.5 b	6.8	19.3	30.3	27.3 b	16.6	9.0 b	15.1	6.0 b
40-N	37.1	47.8 e	8.8	16.0 b	6.3	13.0	34.0	30.5 b	19.0	10.5 b	18.5	5.8 b
80-N	35.6	72.8 d	8.9	27.3 a	9.4	32.0	30.4	34.0 ab	17.8	10.8 b	15.5	9.5 b
120-N	38.1	97.3 c	10.9	16.8 b	8.8	12.0	31.6	30.5 b	15.6	10.8 b	18.6	7.0 b
160-N	31.9	168.5 a	9.3	28.5 a	8.6	14.0	35.0	35.5 ab	17.4	25.5 a	16.0	20.8 a
200-N	23.6	124.8 b	10.8	23.0 ab	9.5	21.0	33.5	41.5 a	19.1	24.5 a	18.9	22.0 a
Time (T)												
Fall	35.8	77.9 b	10.1	19.7	8.4	17.3	32.3	32.1	17.8	12.1 b	16.0	10.3
Spring	30.3	105.1 a	9.0	23.3	8.0	19.8	32.6	34.3	17.4	18.3 a	18.2	13.3
	………………P values……………						………………P values……………					
N rate (N)	0.542	<.0.0001	0.5431	0.0224	0.1278	0.0846	0.1692	0.0407	0.4710	0.0005	0.4473	0.0002
Time (T)	0.2573	<0.0001	0.248	0.1672	0.6159	0.5677	0.8437	0.3763	0.7729	0.0224	0.1487	0.2142
N x T	0.6385	0.0003	0.0725	0.0010	0.0418	0.0081	0.9381	0.4574	0.4865	0.0935	0.8821	0.6429

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-20. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under continuous corn rotation in Crookston during 2019 growing season.

	Soil Extractable N (lb/ac) at Crookston-CC											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management†(M)												
ESN/BI	30.3	80.0	9.6	16.3	6.5	18.5	33.3	31.5	16.9	12.0	17.3	8.3
U+I/BI	34.1	85.8	10.0	19.5	8.3	19.0	32.6	28.5	16.9	11.3	16.6	14.0
U/BI	35.6	72.8	8.9	27.3	9.4	32.0	30.4	34.0	17.8	10.8	15.5	9.5
Time (T)												
Fall	29.0	75.8	8.7	16.5	7.9	16.7	32.8	31.7	16.5	11.8	15.7	10.3
Spring	37.7	83.2	10.3	25.5	8.2	29.7	31.3	31.0	17.8	10.8	17.3	10.8
	………………P values……………						………………P values……………					
Management(M)	0.8749	0.782	0.6761	0.155	0.0997	0.3574	0.1724	0.186	0.8627	0.8823	0.7162	0.6272
Time (T)	0.3362	0.633	0.1311	0.0626	0.8094	0.142	0.2453	0.7774	0.3913	0.6317	0.3806	0.9222
M x T	0.1236	0.3062	0.2808	0.0087	0.2618	0.1356	0.0889	0.8662	0.54	0.1906	0.4181	0.2623

†AA/Inj: Anhydrous ammonium+Nserve in the Fall, and anhydrous ammonium in the Spring application both injected; U/Bdcst: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/Bdcst: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.

Appendix-21. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N rates, application time, and soil depths under corn-soybean rotation in Crookston during 2019 growing season.

Soil Extractable N (lb/ac) at Crookston CSb												
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
N rate (N)												
0-N	17.1	19.5 c	12.6	9.5	12.4	6.8	30.9	19.3	21.3	6.5 ab	23.4	3.0
40-N	17.3	26.3 bc	13.5	9.5	13.6	10.3	34.0	16.3	22.6	4.3 c	23.4	2.8
80-N	16.6	40.0 bc	12.8	9.3	11.5	6.3	34.3	18.0	20.9	5.3 bc	24.6	3.8
120-N	18.5	46.5 b	12.3	8.8	10.6	5.0	33.1	17.0	20.1	4.8 bc	21.8	3.8
160-N	17.4	90.8 a	13.1	13.5	12.6	7.0	32.0	16.3	21.6	4.3 c	24.4	3.5
200-N	18.3	105.3 a	11.9	10.8	11.1	7.3	33.8	16.8	21.5	7.3 a	22.8	5.3
Time (T)												
Fall	17.9	45.1 b	13.2	10.0	11.9	6.1	32.5	17.6	21.2	4.8 b	23.0	3.2
Spring	17.2	64.3 a	12.2	10.4	12.1	8.1	33.5	16.9	21.5	6.0 a	23.8	4.2
	………………P values……………						………………P values……………					
N rate (N)	0.7968	<.0001	0.8191	0.154	0.2637	0.3243	0.1865	0.5447	0.5883	0.0154	0.5214	0.4192
Time (T)	0.4111	0.0043	0.1586	0.7028	0.7887	0.1311	0.2469	0.5328	0.6724	0.0316	0.4276	0.1659
N x T	0.0825	0.0144	0.1081	0.2064	0.5106	0.2886	0.5782	0.6522	0.2086	0.0532	0.4791	0.3949

Within a comparison group, numbers followed by the same letter are not significantly different.

Appendix-22. Soil extractable N as ammonium (NH_4-N) and nitrate (NO_3-N) at V4 development stage, and Post-Harvest sampling time for different N management, application time, and soil depths under corn-soybean rotation in Crookston during 2019 growing season.

	Soil Extractable N (lb/ac) at Crookston-CSb											
	V4						Post-Harvest					
	0-12”		12-24”		24-36”		0-12”		12-24”		24-36”	
	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
Management† (M)												
ESN/BI	16.4	44.3	13.1	9.0	11.4	6.3	34.1	15.0	22.3	4.3	25.1	2.8
U+I/BI	17.8	38.8	11.6	7.0	11.1	5.0	32.4	17.0	21.1	4.3	23.1	3.3
U/BI	16.6	40.0	12.8	9.3	11.5	6.3	34.3	18.0	20.9	5.3	24.6	3.8
Time (T)												
Fall	16.6	37.3	12.9	8.2	10.5	5.5	33.3	15.8	21.4	4.2	23.2	3.0
Spring	17.3	44.7	12.1	8.7	12.2	6.2	33.8	17.5	21.4	5.0	25.4	3.5
	………………P values……………						………………P values……………					
Management(M)	0.5993	0.6276	0.3479	0.1136	0.9524	0.3732	0.3385	0.0839	0.6821	0.2762	0.5157	0.1488
Time (T)	0.5746	0.1475	0.3405	0.5885	0.1154	0.4249	0.6620	0.1262	1.0000	0.1593	0.1402	0.2216
M x T	0.9075	0.7265	0.7449	0.2932	0.4014	0.5910	0.7346	0.1708	0.5027	0.7097	0.1757	1.0000

† U/Bi: Urea/broadcast; U/SSB: Urea/subsurface band; U+I/BI: Urea+Instinct/broadcast; U+I/SSB: Urea+Instinct/subsurface band.