UREA AND UREA ADDITIVES AS FERTILIZER SOURCES FOR CORN PRODUCTION IN MINNESOTA (2018 GROWING SEASON. Preliminary Report)

Fabián Fernández, Daniel Kaiser, Jeffrey Vetsch

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 in some regions of Minnesota. 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 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 2018 growing season: Northwest (Crookston), West Central (Morris), Southwest (Lamberton), and Southern (Waseca). At Crookston 2 experimental sites were established under w**heat-corn (CWh) (**Wheatville very fine sandy loam, clayey till substratum, 0 to 2 percent slopes) and **corn-soybean (CSb) rotation** (Gunclub silty clay loam, 0 to 2 percent slopes). All other locations had a CC and CSb rotation. In Lamberton the **CSb** rotation was located on a Normania loam (1 to 3 percent slopes) and small section of Amiret loam (2 to 6 percent slopes), and the **CC** rotation was on an Amiret loam (2 to 6 percent slopes), Webster clay loam (0 to 2 percent slopes), and a small portion with Normania loam (1 to 3 percent slopes). In Morris the **CSb** rotation was on a Byrne silt loam (1 to 6 percent slopes) and a Tara silt loam (1 to 3 percent slopes), and the **CC** rotation was established on a Forman-Aastad complex soil (1 to 4 percent slopes) and a very small portion of Aastad clay loam (1 to 3 percent slopes). In Waseca, the **CSb** rotation was on a 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) and the **CC** rotation was (Clarion loam, 2 to 6 percent slopes), Nicollet clay loam (1 to 3 percent slopes), and a very 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 0 to 200 lb N/ac for CSb and CWh where the yield response is expected to maximize at a lower rate than CC. There is also a comparison of different sources, placements, and timings: the standard practice that consist of anhydrous ammonia (AA) with N-Serve (32 oz/ac) 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 and CWh 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 and 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.

RESULTS AND DISCUSSION

In Lamberton precipitation was 233 mm (9.2 in) above normal for Ap-Oct. (Table 2). In Morris June and July were wetter with 98 mm (3.9 in) above normal. In Waseca, except for July and August, all other months were wetter than 30 yr normal and the growing season total being 256 mm (10 in) above normal. At Crookston most of the growing season was drier than normal except for June that was wetter than normal (Table 2).

Air mean temperature was in general cooler in April and warmer in May compared with the 30yr average (Table 2).

Response to Nitrogen Rate

With exception of Crookston CWh and CSb rotations and Morris CSb rotation where there were no responses to N, all others had a significant positive response to N rate application in grain yield and grain N removal (Table 3, 4, Fig. 1). The type of response, however, varied from linear to quadratic-plateau by sites and time of application. Spring applications produced greater yield and N removal than fall applications in 4 of 8 sites/rotation (Table 3,4). Across the sites with differences, spring applications produced 26 bu/ac more yield than fall applications.

In Lamberton, the CC crop for fall application had a linear response to N (yield was not maximized) where yield was122 bu/ac for fall at the highest N rate (240 lb N/ac) (Fig. 1a). Spring application for CC crop had a linear response and the yield was 183 bu/ac at the highest N rate (240 lb/N/ac) (Fig. 1a). Overall, grain yield and grain N removal were greater for the spring than fall application. The spring application yielded 30 bu/ac more than fall (Table 3, 4 Fig. 3). In Lamberton the CSb crop had also a linear response to N for the fall and spring (Fig. 1b), where yield was 187 and 207 bu/a at the highest N rate (200 lb N/ac) for fall and spring application, respectively (Fig. 1b). Overall, grain yield and grain N removal were not significant different for the fall and spring application (Table 3, 4) when averaged across all N rates (Table 3,4, Fig. 3). The fact that there was a linear response to N rate for both fall and spring applications illustrate that there was substantial N loss potential due to excessive rain during the growing season (Table 2).

In Waseca, the CC crop had a quadratic response to N for the fall application and a quadratic-plateau response for the spring application (Fig. 1c). For the spring application the EONR was 178 lb N/ac and the yield at the EONR was 208 bu/a. For the fall the yield at the highest N rate (240 lb N/ac) was 191 bu/a. Overall, the spring application yielded 27 bu/a more than the fall application (Table 3, Fig. 3). In Waseca the CSb crop had a linear and quadratic-plateau response to N for fall and spring applications, respectively (Fig. 1d). For the fall the yield at the highest N rate (200 lb N/ac) was 224 bu/a. For the spring application the EONR was 164 lb N/ac and the yield at the EONR was 235 bu/a. Averaged across N rates the spring application yielded 30 bu/ac more than the fall application (Table 3, Fig. 3). These data follow a similar pattern as observed in 2016 and 2017 (2016/17 report) and indicate that current University of Minnesota BMPs continue to be accurate for south central Minnesota where fall urea should not be used because the potential for N loss is too great.

In Crookston, the CWh crop had a quadratic response to N for spring application and no response to N for fall application (Fig. 2a). For the spring application the EONR was 192 lb N/ac and the yield at the EONR was 164 bu/a. The CSb crop showed no significant response to N application both at fall and spring application (Fig. 2b, Table 3). Averaged across N rates the spring application yielded similar to the fall application for both crops (Table 3, Fig. 3). The lack of response to N, especially for CSb has been consistent for the two years of the study. While one of the key aspects of this study is to evaluate the differences between fall and spring applications, these results are important, especially for the northwest where the university currently does not have a substantial amount of corn response data to N. Based on these data, corn grown after soybean may need very little if any N to optimize yields. This may be related to lower yield potential, ample N supply from soil and previous crop residue, or a combination of factors that needs to be evaluated further.

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 application (Fig. 2c). Grain yield was 157 bu/a for fall at the highest N rate (240 lb N/ac) (Fig. 2c). For the spring application the EONR was 86 lb N/ac and the yield at the EONR was 133 bu/a (Fig. 2c). There was not a significant difference between fall and spring application when averaged across all N rates (Table 3, Fig. 3). The CSb crop showed no response to N for either fall or spring applications (Fig. 2d, Table 3), however, grain yield was 15 bu/ac greater for the spring than fall application average across all N rates (Table 3, Fig. 3). The contrasting differences between rotations highlight the need to continue to evaluate management scenarios across years to better understand the likelihood of N response and what should be considered a BMP.

Overall across N rates and application time, CSb rotation showed a significant greater yield than CC and CWh rotation at all sites (Fig. 4). Overall CSb need 34 lb/ac less N and follows what we have observed based on the N rate calculator for MN. Currently, at an N price to corn price ratio of 0.1, CC needs 34 lb N/ac more than CSb http://cnrc.agron.iastate.edu/nRate.aspx.

Response to Nitrogen Source and Placement

The source of N and method of application also showed difference in yield response at all locations except for Crookston for both crops and Morris for CSb (Table 5). At Lamberton, anhydrous ammonia (AA) had greater grain yield than the other N sources/placements in both crops for fall application (Table 5). For spring application AA had similar grain yield than ESN but greater than the other N sources/placement (Table 5). It is important to remember, however, that AA in CSb was applied at 120 lb N/ac whereas the other treatments were applied at 80 lb N/ac. This must be taken into account when interpreting the results in Fig. 5 and Tables 5 and 6; a direct comparison of AA can be done in the CC crop only because all sources were applied at the same rate of 120 lb N/ac. Although not statistically significant except at CC spring application, the subsurface band applications of urea (with and without Instinct) showed a trend for greater yield relative to broadcast and incorporated urea in the CC and CSb rotations (Table 5).

Anhydrous ammonia (AA) had similar grain yield than ESN at both crops at Waseca. At Waseca under CC and CSb the lowest yield was observed in the Urea+Instinct/BI treatment in the fall (Table 5). The subsurface band applications of urea (with and without Instinct) showed a significant greater yield relative to broadcast and incorporated urea in the CC and CSb rotations in the fall application (Table 5), however grain yield were lower in the subsurface band applications than broadcast and incorporated urea for spring application (Table 5).

At Morris CC anhydrous ammonia (AA) had greater grain yield than the other N sources/placements for fall application (Table 5). In the spring application AA/I had similar yield than ESN/BI and U/BI but greater than U/SSB and U+I/BI treatments (Table 5).

Overall spring application yielded more than fall applications except at Crookston (Table 5). In general terms, the response of grain N removal to N source and placement treatments followed a similar trend to those observed for grain yield (Table 6).

Across all locations and crop rotations the AA/I treatment had similar grain yield than ESN/BI but greater than the rest of the treatments (Fig. 5). Urea subsurface band treatment had similar grain yield than the urea broadcast and incorporated treatment. For 2018 growing season, Urea+Instinct applied in a subsurface band had greater grain yield relative to the Urea+Instinct broadcast and incorporated treatment (Fig. 5). However, this treatment (Urea+Instinct applied in a subsurface band) was not different than the urea treatments withoug the inhibiotor. As with the response to N rate, in general the fall application resulted in lower yields regardless of N source (Table 5). Overall, when evaluating across the three years of the study, we observe that regardless of the N source or placement, there is no clear advantage to indicate a particular N source or placement would help producers improve their odds to making a fall application of urea more efficient. The only comparison that shows consistent advantage (only looking at treatments with the same rate) is anhydrous ammonia+Nserve relative to other sources or placements. This indicates, that if a fall application is to be considered, the best source is anhydrous ammonia with a nitrification inhibitor.

Plant N uptake and canopy sensing

In general plant N uptake increased with N rate at all locations except Morris CSb where there were no differences (Table 7 and 8). 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 CC and CSb; at V12 and Total N uptake at R6 at Lamberton CC, and at Total N uptake at R6 in Morris CC and Lamberton CSb (Table 7 and 8). No differences were observed between fall and spring applications across N rates in Crookston CWh and CSb and Morris CSb (Table 7 and 8).

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 (Table 9 and 10). At Lamberton CC had no difference in plant N uptake at V6 and V12 (Table 9). However, at total N uptake at R6 was greatest in the AA/I, followed by ESN/BI, and all the urea treatments had the lowest uptake (Table 9). Subsurface band application had greater total N uptake at R6 than broadcasted application for Urea and Urea+Instinct (Table 9). Waseca

CC showed only differences at V6, ESN an U/BI showed the greatest N uptake than other treatments (Table 9). Morris CC had differences in N uptake at all stages (Table 9).

Crookston CC and CSb, and Morris CSb had no differences in plant N uptake at any stage (Table 9 and 10). Lamberton CSb had differences in N uptake at V12 and R6 where AA tend to be greater than the rest of the treatments (Table 10). Waseca only showed differences at the end of the growing season, at R6 AA and ESN had greater total N uptake than the rest of the urea and urea+instinct treatments (Table 10).

Canopy sensing measurements both at V6 and V12 development stage were linearly correlated to grain yield but the relationship was stronger at V12 (R_2=0.56) than at V6 development stage (R_2=0.26) (Fig. 6). In general, the relationship improved 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. By the time the correlation becomes stronger it would be difficult to supply N unless high-clearance equipment is available. Insufficient N until V12 can also result in reduced yield potential that likely cannot be regained with a late N application.

Soil Measurements Preliminary Analysis

At Lamberton in CC, soil N-NH_{4+} was similar among rates, however soil N-NO_{3-} increases with N rate at all depths (Table 11) at V4. At V4 Spring applications had greater soil N-NO_{3-} than fall applications at the surface depth (0-12"), but soil N-NO_{3-} was similar for Fall than Spring application timing for the deeper depths (Table 11). At post-harvest sampling no differences were detected among N rates or time of application at any depth (Table 11). There were not significant differences on the soil N-NH_{4+} and N-NO_{3-} content at any depth among source/placement treatment at V4 and post-harvest except N-$NO3_{-}$ content at 24-36" that was greater in the AA/I than rest of the treatments(Table 12).

At Lamberton in CSb, similar N-NH_{4+} concentrations were detected among N rates at V4 and Post-harvest sampling at all depths (Table 13). Soil N-NO_{3-} increased with increasing N rates both at V4 development stage at all depths, and at 24-36" at Post-harvest sampling (Table 13). When N source and placement treatments were evaluated, concentration of N-NH_{4+} at 0-12" in V4 was significant greater under AA/I and U+I/SSB than rest of the treatments (Table 14). As mentioned before, it is important to point out that AA/I was applied at 120 lb N/ac whereas all other treatments were applied at 80 lb N/ac. At post-harvest N-NH4+ at 0-12" was similar for U/BI and ESN/BI but greater than the rest of the treatments (Table 14).

At Waseca in CC, concentration of soil N-NH_{4+} and N-NO_{3-} where similar for different N rate (Table 15) at V4 and Post-harvest, except at the concentration of soil N-NH4+ at 12-24" post-harvest that showed some differences among N rates (Table 15). There were not significant differences on the soil N-NH4+ and N-$NO3_{-}$ content at any depth among source/placement treatment at V4 and post-harvest (Table 16).

At Waseca in CSb, concentration of soil N-$NH4_{+}$ and N-NO_{3-} at 0-12", and N-$NO3_{-}$ at 12-24" and 24-36" increased with N rate at V4 development stage (Table 17). Similar soil N concentrations were observed among N rates at post-harvest (Table 17). No differences were found among N source and placement treatments at V4 development stage and Post-harvest (Table 18).

At Crookston CWh, soil N-NO_{3^-} content increased significantly with N rates at 0-12" and 12-24" in V4 (Table 19), and at 24-36" at post-harvest sampling (Table 19). No differences were found among N source and placement treatments at V4 development stage and Post-harvest (Table 20).

At Crookston CSb, at V4 soil N-NO_{3^-} content was significantly affected by N rates at 0-12" and 12-24" depths (Table 21). No differences on soil N-NH_{4^+} and N-NO_{3^-} content among N rates were observed at Post-harvest sampling except for the 12-24" depth for N-NO_{3^-} where the soil N-NO_{3^-} content increased with N rates increased (Table 21). Soil N-NH_{4^+} and N-NO_{3^-} content was not affected by N source and placement treatments at both sampling times (Table 22). It was surprising that there was little N present in the soil (0N treatment), but we observed no yield response to N in Crookston (Table 3, Fig. 20) . A possible explanation to this lack of yield response to N may be that the soil mineralized substantial amounts of N during the growing season, and that was sufficient to supply crop needs. This is illustrated by the fact that post-harvest soil N in the 12-24" depth increased with increasing N rate at this location (for both CWh and CSb, as well as for CSb in Morris where there were no grain yield responses to N).

At Morris in CC, concentration of soil N-NO_{3^-} increased with N rate (Table 15) at V4 development stage at all depths (Table 23). At Post-harvest, only the 24-36" depth showed differences among N rates (Table 23) but in general low concentrations were observed at the end of the growing season. At V4 only soil N-NO_{3^-} concentration at 0-12" was greater under the ESN/I treatment than the other sources (Table 24). No differences among sources/placement were detected on soil N-NH_{4^+} and N-NO_{3^-} concentrations at post-harvest (Table 24).

In Morris CSb, no differences among N rates were found on the concentration of soil N-$NH4_{+}$ and N-NO_{3^-} except at 12-24" at post-harvest where there was a significant increase on soil N-NO_{3^-} with N rates increased (Table 25). The lack of yield response to N may be related to large amounts of N present in the soil profile early in the season (19.5 ppm N-NO_{3^-} for the check at V4 on the top 12 inches of the soil). Soil N-$NH4_{+}$ and N-$NO3_{-}$ contents were not affected by N source and placement treatments at both sampling times (Table 26).

In summary, N-NH_{4^+} was low regardless of N rate indicating that N transforms rapidly to N-NO_{3^-}. Early in the growing season (V4 development stage) N-NO_{3^-} increased with N rate. At Post-harvest, however, there was very little residual N regardless of N rate. The N source and placement treatments show small and inconsistent differences at the V4 development stage.

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 air temperature and mean monthly cumulative precipitation for the 30-yr normal and the 2018 growing season and each experimental site.

		Precipitation (mm)							
Location	Year	April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. cumm.
Waseca	30-yr avg.	82	100	119	113	121	93	68	695
	2018	89	134	147	111	122	268	80	951
Morris	30-yr avg.	59	72	102	99	85	74	64	555
	2018	17	54	217	168	81	47	69	653
Crookston	30-yr avg.	30	74	97	76	84	62	53	476
	2018	4	44	199	37	42	59	77	462
Lamberton	30-yr avg.	76	87	105	99	102	77	51	597
	2018	45	115	182	157	92	167	71	830

		Mean air Temperature (˚C)							
		April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. avg.
Waseca	30-yr avg.	7.8	14.6	20.1	22.0	20.8	16.1	8.8	15.7
	2018	0.6	18.4	21.6	21.7	20.7	17.8	6.4	15.3
Morris	30-yr avg.	6.6	13.8	19.1	21.3	20.1	15.0	7.5	14.8
	2018	-0.5	17.1	19.6	15.8	20.2	14.8	3.9	13.0
Crookston	30-yr avg.	5.6	12.9	18.2	20.6	19.7	14.0	6.3	13.9
	2018	0.7	16.3	20.1	20.4	19.5	13.2	3.7	13.4
Lamberton	30-yr avg.	7.5	14.4	20.3	22.5	20.6	16.1	9.2	15.8
	2018	0.0	18.1	21.9	22.2	21.1	17.5	6.1	15.3

Table 3. Grain yield response to N application timing and rates of urea broadcast and incorporated by tillage at different sites and crop rotations [corn-corn (CC), corn-soybean (CSb) and corn-wheat (CWh)].

		Grain Yield (bu/a)							
	N rate (lb/ac)	Lamberton - CC	Lamberton - CSb	Waseca - CC	Waseca - CSb	Crookston -CWh	Crookston -CSb	Morris - CC	Morris - CSb
Fall	0-N	63 b	92 d	84 d	20 d	119	149	81 d	197
	40-N	72 b	122 c	103 cd	148 c	126	143	80 d	145
	80-N	80 b	123 c	132 bc	152 c	133	153	106 c	164
	120-N	76 b	157 b	156 ab	159 c	119	143	130 b	147
	160-N	106 a	182 ab	168 ab	202 b	129	161	132 b	157
	200-N	113 a	187 a	175 a	224 a	135	149	156 a	163
	240-N	122 a	-	191 a	-	-	-	158 a	-
	***P* values**	0.0002	<.0001	<.0001	<.0001	0.7566	0.6492	<.0001	0.1982
Spring	0-N	60 e	107 c	93 c	117 d	105 b	138	71 c	161
	40-N	80 de	97 c	112 c	159 c	118 ab	131	99 bc	184
	80-N	93 cd	153 b	178 b	191 b	129 a	144	112 b	173
	120-N	116 bc	184 a	198 ab	231 a	138 a	146	155 a	165
	160-N	136 b	188 a	199 a	241 a	128 a	145	161 a	187
	200-N	169 a	207 a	206 a	228 a	102 b	162	173 a	193
	240-N	183 a	-	214 a	-	-	-	155 a	-
	***P* values**	<.0001	<.0001	<.0001	<.0001	0.0087	0.5151	<.0001	0.2546
	Fall	90 b	141	144 b	168 b	127	150	121	162 b
	Spring	120 a	156	171 a	198 a	120	144	132	177 a
	***P* values**	0.0064	0.2327	0.0345	0.0267	0.1894	0.3107	0.2509	0.0491

Table 4. Grain N removal response to N application timing and rates of urea broadcast and incorporated by tillage at different sites and crop rotations [corn-corn (CC), corn-soybean (CSb) and corn-wheat (CWh)].

		Grain N removal (lbs N/a)							
	N rate (lb/ac)	Lamberton - CC	Lamberton - CSb	Waseca - CC	Waseca - CSb	Crookston -CWh	Crookston -CSb	Morris - CC	Morris - CSb
Fall	0-N	26 b	42 c	40 c	54 c	63	80 c	35 c	106
	40-N	32 b	52 c	49 c	72 b	67	82 bc	34 c	85
	80-N	35 b	53 bc	57 bc	69 bc	72	91 abc	44 c	95
	120-N	33 b	69 b	76 ab	71 bc	63	86 bc	60 b	82
	160-N	45 a	96 a	83 a	103 a	68	94 ab	60 b	89
	200-N	49 a	100 a	86 a	117 a	76	101 a	73 a	96
	240-N	54 a	-	99 a	-	-	-	78 a	-
	***P* values**	<.0001	<.0001	0.0010	<.0001	0.4586	0.0899	<.0001	0.3075
Spring	0-N	28 d	44 d	41 c	55 c	48 c	78	29 c	91
	40-N	34 d	41 d	51 c	72 c	64 ab	78	48 b	105
	80-N	40 cd	70 c	93 b	92 b	67 ab	85	47 b	97
	120-N	54 bc	93 b	102 b	120 a	76 a	91	75 a	97
	160-N	62 b	92 b	109 ab	132 a	71 a	85	84 a	110
	200-N	80 a	115 a	112 ab	125 a	58 bc	97	92 a	108
	240-N	90 a	-	128 a	-	-	-	79 a	-
	***P* values**	<.0001	<.0001	<.0001	<.0001	0.0035	0.3227	<.0001	0.5421
	Fall	39 b	66	70 b	83 b	68	89	55 b	92 b
	Spring	55 a	76	91 a	101 a	64	85	65 a	101 a
	***P* values**	0.0025	0.2397	0.0128	0.0337	0.1834	0.3533	0.0945	0.0472

Table 5. Grain yield response to N application timing and N source and placement at different sites and crop rotations [corn-corn (CC), corn-soybean (CSb) and corn-wheat (CWh)].in fall and spring at different sites and crop rotations.

		Grain Yield (bu/a)							
		Lamberton - CC	Lamberton - CSb	Waseca - CC	Waseca - CSb	Crookston -CWh	Crookston -CSb	Morris - CC	Morris - CSb
Fall	AA/I	-	-	147 b	-	-	-	-	-
	AA+ Nserve/I	157 a	192 a*	166 ab	186 a*	-	-	168 a	181*
	ESN/BI	106 b	142 bc	171 ab	186 a	127	159	141 b	164
	U/BI	76 b	130 bc	156 ab	154 b	133	153	130 b	164
	U/SSB	104 b	150 b	193 a	187 a	-	-	133 b	169
	U+I/BI	75 b	120 c	130 b	142 b	133	163	121 b	158
	U+I/SSB	96 b	146 bc	191 a	193 a	-	-	126 b	174
	***P* values**	0.0006	0.0016	0.0429	0.0065	0.7256	0.3769	0.0124	0.8337
Spring	AA/I	182 a	201 a*	169 c	224 a*	-	-	162 a	174*
	ESN/BI	145 ab	181 ab	196 ab	210 ab	124	153	163 a	186
	U/BI	116 bc	159 bc	198 a	191 bc	129	144	155 a	173
	U/SSB	147 ab	147 c	177 bc	169 cd	-	-	134 b	171
	U+I/BI	101 c	146 c	181 abc	203 ab	138	167	131 b	167
	U+I/SSB	174 a	168 bc	147 d	157 d	-	-	144 ab	177
	***P* values**	0.0066	0.0703	0.0010	0.0006	0.2361	0.2081	0.0090	0.7453
	Fall	102 b	147 b	165 b	175 b	130	158	136 b	168
	Spring	148 a	170 a	178 a	193 a	130	154	148 a	175
	***P* values**	<.0001	0.0075	0.1016	0.0297	0.8861	0.5829	0.0448	0.2638

*Anhydrous ammonia rate was 120 lb N/ac while the other treatments received only 80 lb N/ac in the CSb rotation.

Table 6. Grain N removal response to N application timing and N source and placement at different sites and crop rotations [corn-corn (CC), corn-soybean (CSb) and corn-wheat (CWh)].in fall and spring at different sites and crop rotations.

		Grain N removal (lbs N/a)							
		Lamberton - CC	Lamberton - CSb	Waseca - CC	Waseca - CSb	Crookston -CWh	Crookston -CSb	Morris - CC	Morris - CSb
Fall	AA/I	-	-	69 c	-	-	-	-	-
	AA+ Nserve/I	72 a	99 a	83 bc	91 a	-	-	81 a	102
	ESN/BI	46 b	71 b	84 abc	91 a	67	101	64 b	96
	U+I/BI	34 bc	54 c	62 c	62 b	67	99	57 b	88
	U+I/SSB	40bc	62 bc	100 ab	93 a	-	-	53 b	103
	U/BI	33 c	50 c	76 bc	69 b	72	91	60 b	95
	U/SSB	45 bc	66 bc	109 a	91 a	-	-	62 b	97
	***P* values**	0.0002	0.0002	0.0150	0.0098	0.4922	0.3331	0.0224	0.7832
Spring	AA/I	94 a	106 a	87	116 a	-	-	77 a	104
	ESN/BI	83 ab	94 a	98	112 a	62	96	83 a	108
	U+I/BI	46 d	65 c	90	103 ab	68	103	56 c	100
	U+I/SSB	85 ab	79 b	74	69 d	-	-	73 ab	102
	U/BI	54 c	70 bc	102	92 bc	67	85	75 ab	97
	U/SSB	70 bc	80 b	100	75 cd	-	-	64 bc	91
	***P* values**	0.0023	<.0001	0.1314	0.0005	0.5121	0.2312	0.0056	0.589
	Fall	45 b	68 b	83	83 b	69	97	63 b	97
	Spring	72 a	82 a	92	95 a	66	95	71 a	100
	***P* values**	<.0001	0.0126	0.1222	0.0439	0.3338	0.6090	0.0242	0.3644

Table 7. Plant N uptake (Total N) at V6, V12, and R6 development stages response to N application timing and rates of urea broadcast and incorporated by tillage at different sites for corn-corn (CC) and corn-wheat (CWh) rotations.

	Plant N uptake (lb N/a)											
	Lamberton - CC			Waseca - CC			Crookston - CWh			Morris – CC		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
N rate (N)												
0-N	2 c	16 f	43 d	3 d	20 e	65 d	4 c	24 e	65 b	11 d	34 c	54 e
40-N	6 a	20 ef	51 d	9 cd	31 de	77 d	6 b	31 bc	76 a	14 cd	41 bc	63 de
80-N	5 ab	26 de	55 cd	16 bc	43 cd	110 c	9 a	37 ab	81 b	18 bc	49 b	71 d
120-N	4 b	31 cd	64 c	26 a	59 b	135 b	9 a	44 a	81 b	22 ab	72 a	101 c
160-N	5 ab	36 bc	78 b	18 b	52 bc	141 b	9 a	41 a	82 a	24 a	77 a	107 bc
200-N	5 ab	48 a	93 a	23 ab	64 ab	146 b	10 a	43 a	80 a	25 a	83 a	124 a
240-N	5 ab	43 ab	102 a	29 a	76 a	171 a	-	-	-	21 ab	74 a	119 ab
Time (T)												
Fall	4	27 b	59 b	14 b	40 b	105 b	8	36	80	19	19	84 b
Spring	4	36 a	80 a	22 a	58 a	136 a	8	38	75	20	20	99 a
	……………………*P* values………………………											
N rate (N)	0.0058	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.0155	<.0001	<.0001	<.0001
Time (T)	0.4041	0.0007	<.0001	0.0003	<.0001	<.0001	0.7184	0.3725	0.1261	0.7126	<.0001	0.0013
N x T	0.5182	0.1564	0.0022	0.1080	0.3336	0.3172	0.0464	0.0835	0.0226	0.7680	0.0456	0.0592

‡Total N uptake at R6 is the sum of grain N and stover N.

Table 8. Plant N uptake (Total N) at V6, V12, and R6 development stages response to N application timing and rates of urea broadcast and incorporated by tillage at different sites for a corn-soybean (CSb) rotation.

	Plant N uptake (lb N/a)											
	Lamberton - CSb			Waseca - CSb			Crookston - CSb			Morris – CSb		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
N rate (N)												
0-N	7	34 c	67 d	11 c	24 d	75 d	8 c	44 b	93 c	17	72	148
40-N	6	38 bc	71 d	17 b	40 c	98 c	11 bc	48 b	97 bc	16	72	148
80-N	8	48 b	96 c	16 b	45 bc	108 c	14 a	65 a	106 b	17	73	144
120-N	7	62 a	120 b	16 b	52 b	1320 b	12 ab	62 a	107 ab	19	74	142
160-N	7	65 a	139 a	21 a	71 a	162 a	13 ab	62 a	109 ab	18	76	151
200-N	7	62 a	154 a	21 a	68 a	167 a	13 ab	68 a	119 a	16	75	155
Time (T)												
Fall	7	48	1036 b	16 b	41 b	109 b	12	57	106	17	73	142
Spring	7	55	112 a	18 a	59 a	137 a	12	59	104	18	75	154
	……………………*P* values………………………											
N rate (N)	0.3834	<.0001	<.0001	<.0001	<.0001	<.0001	0.0039	0.0005	0.0034	0.8972	0.9059	0.8208
Time (T)	0.4906	0.0829	0.0477	0.0223	<.0001	<.0001	0.8321	0.5939	0.4593	0.4526	0.5768	0.0614
N x T	0.2317	0.2388	0.0107	0.1652	0.0297	0.0025	0.8691	0.1940	0.8073	0.6913	0.1905	0.0969

‡Total N uptake at R6 is the sum of grain N and stover N.

Table 9. Plant N uptake at V6 and R6 development stages response to N source and placement and N application timing at different sites for corn-corn (CC) and corn-wheat (CWh) rotations.

	Plant N uptake (lb N/a)											
	Lamberton - CC			Waseca - CC			Crookston - CWh			Morris – CC		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
Management†(M)												
AA/I†	5	43	115 a	13 b	59	131	-	-	-	19 bc	76 ab	119 a
ESN/BI	5	44	91 b	26 a	64	130	8	67	77	25 a	81 a	109 ab
U+I/BI	4	29	59 c	16 b	50	111	8	35	80	25 a	59 d	86 c
U+I/SSB	3	38	90 b	19 ab	64	135	-	-	-	17 c	70 bc	98 bc
U/BI	4	31	64 c	26 a	59	135	9	37	81	22 ab	72 abc	101 b
U/SSB	4	38	84 b	11 b	57	149	-	-	-	16 c	64 cd	95 bc
Time (T)												
Fall	4	31 b	66 b	19	59	127	8	33 b	81	20	64 b	96 b
Spring	4	42 a	101 a	19	59	136	9	40 a	78	21	76 a	106 a
	……………………*P* values…………………….											
Management (M)	0.0988	0.1119	<.0001	0.0033	0.3608	0.1059	0.2497	0.8321	0.7131	0.0019	0.0020	0.0017
Time (T)	0.8675	0.0038	<.0001	0.9233	0.9510	0.2127	0.1043	0.0129	0.4866	0.5847	0.0003	0.0015
M x T	0.8263	0.4877	0.1562	0.0073	0.0003	0.0687	0.1344	0.1531	0.5658	0.5249	0.5802	0.0742

†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.

Table 10. Plant N uptake at V6 and R6 development stages response to N source and placement and N application timing at different sites for a corn-soybean (CSb) rotation.

	Plant N uptake (lb N/a)											
	Lamberton - CSb			Waseca - CSb			Crookston - CSb			Morris – CSb		
	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡	V6	V12	R6‡
Management†(M)												
AA/I†	6	69 a	149 a	14	54	144 a	-	-	-	18	79	160
ESN/BI	7	63 ab	118 b	17	54	141 a	14	59	116	18	78	150
U+I/BI	6	50 bc	88 c	15	48	115 b	15	66	118	19	77	145
U+I/SSB	7	55 bc	107 bc	14	46	117 b	-	-	-	18	80	157
U/BI	8	48 c	96 c	16	45	108 b	14	65	106	17	73	144
U/SSB	7	53 bc	107 bc	15	48	113 b	-	-	-	17	78	143
Time (T)												
Fall	7	51 b	101 b	14	50 b	116 b	14	63	115	17 b	76	148
Spring	6	62 a	121 a	16	53 a	130 a	15	64	112	19 a	79	152
	……………………*P* values………………………											
Management (M)	0.3004	0.0193	<.0001	0.2897	0.4777	0.0005	0.6502	0.3167	0.1277	0.9062	0.9345	0.4305
Time (T)	0.1222	0.0079	0.0012	0.0723	0.0212	0.0078	0.4939	0.6539	0.4889	0.0472	0.3362	0.5303
M x T	0.5272	0.8202	0.8721	0.0605	0.0007	<.0001	0.2789	0.2026	0.6120	0.7661	0.8198	0.7500

†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.

Table 11. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Lamberton in continuous corn (CC).

	Soil Extractable N (ppm) 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	5.8	3.8 c	1.9	2.1 d	1.3 b	1.3 b	7.1	2.1	2.8	0.63	2.5	0.56
40-N	6.7	5.4 c	1.7	2.9 cd	1.4 b	1.7 b	7.7	1.9	3.1	0.63	3.2	0.50
80-N	5.9	7.0 bc	1.9	3.6 cd	2.0 a	1.6 b	7.7	1.8	2.6	0.56	2.9	0.50
120-N	6.3	8.6 bc	1.6	5.1 bc	1.4 b	3.3 a	7.9	2.0	3.2	0.75	2.8	0.50
160-N	5.9	12.6 b	1.9	7.4 ab	1.6 b	3.4 a	6.7	1.8	2.9	0.63	3.3	0.6
200-N	6.8	20.3 a	1.5	7.9 a	1.4 b	3.8 a	7.3	1.5	2.8	0.63	2.8	0.50
240-N	6.9	20.4 a	1.4	7.4 ab	1.4 b	4.1 a	7.8	1.9	2.8	0.75	2.6	0.56
Time (T)												
Fall	6.2	7.6 b	1.7	4.7	1.6	2.7	7.6	1.9	2.9	0.59	2.7	0.50
Spring	6.5	14.7 a	1.7	5.7	1.4	2.8	7.3	1.8	2.8	0.71	3.0	0.55
	……………………………………………*P* values ………………………………………………………											
N rate (N)	0.0984	<.0001	0.2506	<.0001	0.0318	<.0001	0.0681	0.4993	0.4797	0.6832	0.7031	0.6679
Time (T)	0.2546	<.0001	0.5160	0.1585	0.1378	0.7188	0.2268	0.8144	0.4407	0.0652	0.3341	0.0885
N x T	0.2359	0.0328	0.0321	0.7491	0.2960	0.7088	0.2023	0.3625	0.1453	0.3277	0.9418	0.6679

Table 12. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Lamberton in continuous corn (CC).

	Soil Extractable N (ppm) 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†	8.2	8.6	1.9	6.1	1.8	2.4	7.9	1.6	3.1	0.69	2.7	0.81 a
ESN/BI	7.3	11.7	2.2	4.5	1.9	2.3	7.6	1.9	3.1	0.63	2.5	0.44 b
U+I/BI	6.2	8.9	1.6	4.1	1.4	1.8	7.2	1.6	2.8	0.63	2.6	0.50 b
U+I/SSB	9.0	11.5	1.7	3.9	1.3	1.9	7.6	1.5	3.3	0.56	3.3	0.50 b
U/BI	6.3	8.6	1.6	5.1	1.4	3.3	7.9	2.0	3.2	0.75	2.8	0.50 b
U/SSB	10.0	13.7	2.2	4.5	1.7	2.4	8.1	1.8	3.2	0.63	3.0	0.50 b
Time (T)												
Fall	7.3	9.1	1.8	4.9	1.6	2.4	7.7	1.9	3.1	0.65	2.8	0.50
Spring	11.4	11.9	2.0	4.5	1.6	2.3	7.7	1.6	3.1	0.65	2.8	0.58
	……………………………………………*P* values						………………………………………………					
Management(M)	0.2759	0.5225	0.1263	0.1544	0.1441	0.0833	0.4309	0.4884	0.5612	0.8053	0.1146	0.0286
Time (T)	0.3187	0.1479	0.1627	0.4307	1.0000	0.6324	0.9375	0.1225	0.8261	1.0000	0.7533	0.2079
M x T	0.2861	0.7256	0.1706	0.3410	0.9822	0.6429	0.1336	0.1031	0.0209	0.7636	0.0982	0.4880

†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.

Table 13 Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Lamberton in corn-soybean (CSb).

	Soil Extractable N (ppm) 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	7.7	16.1 b	2.3	3.1 c	2.0	2.4 b	11.1	1.2	4.4	0.62	3.2	0.63 bc
40-N	8.4	8.6 b	2.3	4.1 bc	1.8	2.8 b	11.1	1.0	4.0	0.75	3.4	0.50 c
80-N	7.9	10.9 b	2.1	5.3 ab	2.2	2.6 b	12.0	1.5	4.2	0.87	4.3	0.67 abc
120-N	9.5	12.4 b	2.5	5.3 ab	1.8	3.1 ab	11.8	1.3	4.1	0.88	3.1	0.88 ab
160-N	9.7	21.3 a	1.9	7.0 a	1.6	3.8 a	11.8	1.5	4.7	0.80	3.6	0.69 abc
200-N	9.8	21.7 a	2.5	6.0 a	2.0	3.7 a	11.7	1.4	4.3	1.0	3.5	0.93 a
Time (T)												
Fall	8.5	11.5	2.1	5.2	1.7 b	3.2	11.7	1.2	4.5	0.79	3.6	0.66
Spring	9.1	15.5	2.4	5.1	2.1 a	2.9	11.5	1.4	4.1	0.85	3.4	0.77
	……………………………………………*P* values ……………………………………………………											
N rate (N)	0.1077	0.0003	0.8573	0.0020	0.6873	0.0461	0.7241	0.4408	0.8924	0.1991	0.0929	0.0427
Time (T)	0.2990	0.0678	0.4214	0.9149	0.0374	0.3734	0.6853	0.1841	0.2823	0.4595	0.6132	0.2079
N x T	0.2231	0.5036	0.5410	0.5888	0.2346	0.6871	0.3749	0.1962	0.2542	0.0038	0.0489	0.0023

Table 14. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Lamberton in corn-soybean (CSb).

	Soil Extractable N (ppm) 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†	16.9 a	16.1	1.9	5.6	1.4	3.1	9.8 b	1.3	3.8	0.88	3.1 b	0.75
ESN/BI	9.7 bc	12.8	2.5	5.3	1.8	3.3	10.8 ab	1.3	4.1	0.75	3.1 b	0.56
U+I/BI	8.1 c	11.9	2.0	4.5	1.5	2.8	9.4 b	1.4	3.2	0.50	2.9 b	0.50
U+I/SSB	14.0 ab	11.2	2.4	4.6	2.0	2.5	10.1 b	1.2	3.7	0.58	3.2 b	0.50
U/BI	7.6 c	10.8	2.1	5.3	2.2	2.6	12.0 a	1.5	4.2	0.88	4.2 a	0.67
U/SSB	8.4 c	12.2	2.1	5.8	1.9	3.4	10.5 b	1.5	3.5	0.69	3.2 b	0.50
Time (T)												
Fall	10.2	12.3	1.8 b	5.8 a	1.7	3.2 a	10.3	1.4	3.7	0.76	3.2	0.60
Spring	11.3	12.7	2.5 a	4.6 b	1.9	2.7 b	10.6	1.3	3.8	0.67	3.4	0.56
	……………………………………..……………*P* values ……………………..…………………………………….											
Management(M)	0.0061	0.2477	0.4216	0.1173	0.3670	0.2410	0.0182	0.7990	0.6262	0.0768	0.0383	0.0580
Time (T)	0.4845	0.7703	0.0030	0.0007	0.2237	0.0393	0.4005	0.3895	0.8841	0.2902	0.2799	0.5343
M x T	0.0480	0.6363	0.1167	0.0547	0.4520	0.4171	0.1856	0.3763	0.5852	0.9313	0.1688	0.1247

†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.

Table 15. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Waseca in continuous corn (CC).

	Soil Extractable N (ppm) at Waseca-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	8.1	13.5	3.0	8.4	3.1	5.1	5.5	2.7	3.6 abc	1.3	3.8	1.5
40-N	7.3	21.8	3.4	11.6	3.4	6.3	5.9	2.3	4.3 a	1.4	4.3	1.3
80-N	7.7	13.3	2.9	9.4	2.3	6.9	5.9	2.9	3.9 ab	1.8	4.4	2.1
120-N	7.9	23.1	3.1	9.9	3.5	5.3	6.6	3.2	4.2 a	1.6	4.2	1.3
160-N	8.2	21.4	3.3	13.8	3.1	7.5	6.6	2.8	3.1 c	1.7	3.6	1.6
200-N	7.3	15.8	3.1	9.9	3.4	5.5	6.2	2.8	3.8 abc	1.8	4.2	2.1
240-N	8.7	24.0	3.1	10.6	3.3	5.8	6.2	3.0	3.3 bc	2.1	3.7	3.2
Time (T)												
Fall	7.9	18.2	3.3	11.2	3.5	6.4	6.2	2.7	3.9	1.4 b	4.4	1.7
Spring	7.9	19.8	3.0	9.8	3.1	5.7	6.1	2.9	3.6	1.9 a	3.6	2.0
	……………………………………..……………*P* values ………………………..……………………………………											
N rate (N)	0.6790	0.5343	0.9748	0.7693	0.9861	0.4130	0.4095	0.5626	0.0423	0.4221	0.8232	0.1793
Time (T)	0.9854	0.6801	0.3441	0.4357	0.2147	0.3115	0.8105	0.2556	0.0843	0.0133	0.0212	0.4391
N x T	0.3297	0.6187	0.9565	0.9892	0.4254	0.7093	0.1474	0.2988	0.2688	0.9834	0.2598	0.4429

Table 16. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Waseca in continuous corn (CC).

	Soil Extractable N (ppm) at Waseca-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†	8.3	20.9	3.2	12.3	3.4	6.3	5.7	2.7	3.7	1.4	3.8	1.4
ESN/BI	8.7	18.8	2.8	9.4	3.1	5.7	6.3	3.0	3.1	1.7	3.4	1.6
U+I/BI	8.2	16.9	3.4	10.4	3.2	5.8	6.7	2.9	3.8	1.6	3.8	1.8
U+I/SSB	8.5	17.9	3.1	9.1	2.7	4.8	5.8	2.7	3.2	1.5	3.4	1.4
U/BI	7.9	23.1	3.1	9.9	3.5	5.3	6.6	3.2	4.2	1.6	4.2	1.3
U/SSB	8.2	17.1	2.9	12.4	3.0	7.3	6.3	2.9	3.3	1.8	3.5	1.5
Time (T)												
Fall	8.7	21.5	3.2	11.3	3.2	6.0	6.5	3.0	3.6	1.8	3.7	1.5
Spring	8.2	16.8	2.9	9.8	3.1	5.7	6.0	2.8	3.5	1.5	3.7	1.5
	……………………………………..…………..*P* values ………………….………………………………											
Management(M)	0.7683	0.9379	0.8207	0.8082	0.4112	0.5251	0.5020	0.8997	0.0317	0.8090	0.5705	0.3720
Time (T)	0.4862	0.2433	0.2996	0.3918	0.6252	0.7471	0.2219	0.4601	0.7223	0.1223	1.000	0.6755
M x T	0.1459	0.8436	0.9239	0.8361	0.4382	0.7110	0.8910	0.3051	0.1788	0.5036	0.4657	0.8340

†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.

Table 17. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Waseca in corn-soybean (CSb).

	Soil Extractable N (ppm) 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	5.4 ab	7.1 d	1.81	3.7 c	2.5	2.6 c	7.0	3.3	2.4	2.3	3.1	3.4
40-N	4.6 b	13.1 cd	1.84	3.9 ab	2.0	4.6 ab	6.3	3.6	2.7	4.4	3.1	4.9
80-N	6.0 a	18.2 c	1.84	6.0 b	2.2	3.9 b	6.8	3.4	2.8	2.4	3.1	3.6
120-N	6.3 a	26.5 b	1.86	8.1 a	2.2	5.6 a	7.8	3.9	2.8	3.8	2.9	3.8
160-N	6.3 a	31.1 b	1.78	7.7 ab	2.3	4.4 a	6.8	4.4	2.3	3.2	3.1	3.0
200-N	6.0 a	38.9 a	1.87	8.9 a	2.1	4.9 ab	7.1	5.0	2.9	4.4	3.3	5.1
Time (T)												
Fall	5.8	17.4 b	1.7	6.4	2.1	4.2	7.1	3.9	2.6	3.0	3.1	3.8
Spring	5.8	27.6 a	1.9	7.3	2.3	4.5	6.8	4.0	2.7	3.9	3.1	4.2
	………………………………..……………*P* values ……………………..………………………………											
N rate (N)	0.0327	<.0001	0.9995	0.0003	0.7027	0.0003	0.0649	0.1580	0.1373	0.1451	0.8136	0.2008
Time (T)	0.8978	<.0001	0.0993	0.1321	0.4540	0.2724	0.3136	0.8424	0.3072	0.1239	0.6739	0.4986
N x T	0.2878	0.0044	0.4660	0.3103	0.5828	0.8598	0.8600	0.0900	0.6762	0.1387	0.2440	0.0952

Table 18. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Waseca in corn-soybean (CSb)

	Soil Extractable N (ppm) 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†	7.4	26.6	1.6	7.1	1.9	4.2	7.3	3.6	2.8	2.7	3.0	3.1
ESN/BI	7.3	14.1	2.3	4.9	2.5	4.1	6.8	4.3	2.7	3.3	3.3	4.3
U+I/BI	4.7	17.9	1.9	7.6	2.0	4.3	6.5	3.2	2.7	2.4	3.0	3.3
U+I/SSB	5.5	13.3	1.8	5.2	2.1	3.6	8.3	3.8	3.0	3.1	3.2	4.3
U/BI	6.0	18.2	1.8	6.0	2.2	3.9	6.8	3.4	2.8	2.4	3.1	3.6
U/SSB	6.2	17.6	1.9	7.2	2.1	4.1	6.5	4.7	2.8	3.0	3.4	3.0
Time (T)												
Fall	5.6	16.7	1.8	6.3	2.0	4.3	6.9	3.5	2.7	2.6	2.9 b	3.3
Spring	6.7	19.1	2.1	6.4	2.3	3.8	7.2	4.2	2.9	3.0	3.4 a	3.8
	………………………………………*P* values ………………………………………											
Management(M)	0.3652	0.1438	0.5677	0.4025	0.6571	0.8937	0.1432	0.3896	0.8495	0.8097	0.8528	0.7098
Time (T)	0.1921	0.4180	0.2109	0.9473	0.1198	0.1592	0.4022	0.1143	0.0891	0.4082	0.0370	0.4269
M x T	0.3315	0.6688	0.3637	0.0852	0.0939	0.0758	0.4602	0.6286	0.3909	0.3859	0.5536	0.5607

Table 19. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Crookston in corn-wheat (CWh).

	Soil Extractable N (ppm) at Crookston CWh											
	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	3.0	3.4 d	2.2	4.2 b	2.6	5.3	4.3	1.4	3.3	1.9 b	4.1	2.9 b
40-N	2.6	7.4 cd	1.6	6.8 b	2.3	8.3	4.2	1.3	3.3	1.9 b	3.7	3.0 b
80-N	2.7	13.7 bcd	1.9	6.1 b	1.9	6.3	4.7	1.4	3.6	2.7 b	3.6	3.1 b
120-N	2.4	18.2 bc	1.8	7.6 b	1.7	5.8	4.5	1.3	3.0	3.9 b	4.0	3.6 b
160-N	3.1	23.4 ab	2.4	11.1 a	2.7	8.8	4.2	1.8	3.1	6.6 b	4.2	9.8 ab
200-N	2.8	36.3 a	1.7	13.3 a	2.3	6.9	4.4	1.5	3.3	14.3 a	3.8	15.5 a
Time (T)												
Fall	2.7	13.0 b	1.9	8.1	2.2	6.9	4.3	1.3	3.2	3.6	3.9	5.4
Spring	2.8	21.1 a	1.9	8.3	2.3	6.9	4.5	1.6	3.4	6.8	3.8	7.2
	…………………………………..……………*P* values …………………..……………………………………											
N rate (N)	0.4155	0.0003	0.0669	<.0001	0.0655	0.5495	0.7024	0.6884	0.8991	0.0021	0.5194	0.0025
Time (T)	0.4408	0.0442	0.8079	0.8340	0.5085	0.9741	0.5037	0.1020	0.4703	0.0921	0.6367	0.3767
N x T	0.3741	0.4853	0.2472	0.9919	0.1311	0.7551	0.5181	0.2778	0.6682	0.0073	0.0440	0.1332

Table 20. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Crookston in corn-wheat (C-Wt).

	Soil Extractable N (ppm) at Croosktɔn-CWh											
	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)												
U/BI	2.7	13.7	1.9	6.1	1.9	6.3	4.7	1.4	3.6	2.7	3.6	3.1
U+I/BI	2.9	10.2	1.7	6.2	2.2	9.1	4.3	1.3	3.2	1.4	3.7	2.3
ESN/BI	3.2	12.1	1.7	7.3	2.4	8.9	4.3	1.2	3.1	3.9	3.9	6.7
Time (T)												
Fall	2.8	7.9 b	1.8	6.2	2.1	8.0	4.4	1.3	3.5	1.9	4.0	3.2
Spring	3.1	16.0 a	1.7	6.8	2.3	8.1	4.5	1.2	3.1	3.5	3.5	4.8
………………………………..……………*P* values …………………..………………………………….												
Management(M)	0.6802	0.4787	0.7885	0.4112	0.4298	0.3735	0.4457	0.7157	0.4006	0.1683	0.6256	0.1153
Time (T)	0.4793	0.0030	0.7569	0.4575	0.4657	0.9623	0.6646	0.5173	0.1959	0.1314	0.0771	0.3587
M x T	0.5348	0.0364	0.5410	0.5673	0.4996	0.9236	0.5116	0.3822	0.4342	0.3176	0.1573	0.5047

†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.

Table 21. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Crookston in corn-soybean (CSb).

	Soil Extractable N (ppm) 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	4.6	6.4 b	2.4	7.6 c	2.7	11.6	3.9	1.8	2.3	6.9 b	2.6	9.5
40-N	5.0	11.1 b	3.0	9.2 c	2.8	11.7	3.3	2.4	1.8	7.5 b	2.2	12.2
80-N	5.0	15.9 b	2.9	11.3 abc	2.6	13.6	3.9	2.4	2.1	6.9 b	2.6	13.1
120-N	5.6	29.1 a	2.3	11.6 abc	2.7	15.8	4.3	3.3	2.1	14.3 ab	2.3	17.9
160-N	4.9	26.9 a	2.3	13.2 ab	2.2	14.1	3.5	3.4	1.8	16.6 a	2.2	14.4
200-N	5.1	33.8 a	2.3	14.4 a	2.8	14.3	4.2	2.8	2.0	18.6 a	2.5	18.3
Time (T)												
Fall	5.2	17.5	2.6	10.2	2.6	12.8	3.9	2.7	2.1	9.4	2.6	14.0
Spring	4.9	23.5	2.5	12.2	2.7	14.3	3.8	2.7	1.9	14.2	2.3	14.4
	……………………………………..……………*P* values ……………………..……………………………………											
N rate (N)	0.4021	<.0001	0.2646	0.0279	0.6635	0.6401	0.0532	0.1775	0.1796	0.0268	0.2090	0.2963
Time (T)	0.2210	0.0573	0.8203	0.1023	0.6436	0.3597	0.3615	0.9548	0.0865	0.0719	0.0541	0.8796
N x T	0.1342	0.1961	0.5496	0.8879	0.2867	0.6714	0.4887	0.4086	0.8015	0.9251	0.2717	0.5885

Table 22. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Crookston in corn-soybean (CSb).

	Soil Extractable N (ppm) 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)												
U/BI	5.0	15.9	2.9	11.3	2.6	13.6	3.9	2.4	2.1	3.9	2.6	13.1
U+I/BI	5.4	22.0	2.6	11.3	3.1	17.7	4.0	3.2	2.6	9.9	2.8	18.7
ESN/BI	4.9	16.7	2.6	10.8	2.8	13.6	3.6	4.2	2.3	6.7	2.7	10.3
Time (T)												
Fall	4.9	13.9 b	2.7	9.9	2.9	14.1	3.8	2.8	2.2	6.1	2.6	14.4
Spring	5.3	22.5 a	2.6	12.3	2.7	15.8	3.9	3.7	2.5	9.6	2.8	13.6
	……………………………………*P* values …………………………………………………											
Management(M)	0.6293	0.3709	0.7203	0.9198	0.6252	0.3098	0.3873	0.1173	0.1666	0.4073	0.6828	0.1354
Time (T)	0.4123	0.0171	0.7654	0.0605	0.6019	0.5159	0.4403	0.2298	0.1431	0.1156	0.4572	0.8027
M x T	0.3447	0.9601	0.3390	0.1290	0.5896	0.6920	0.3320	0.4469	0.3329	0.7007	0.8892	0.4745

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

Table 23. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Morris in continuous corn (CC).

	Soil Extractable N (ppm) 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	4.9	2.9 c	2.1	2.9 e	1.9	3.1 c	5.9	1.8	3.4	1.5	2.9	1.06 ab
40-N	4.2	4.1 c	2.0	4.4 de	1.8	3.4 c	6.4	2.0	3.8	1.7	3.4	0.81 bc
80-N	4.3	4.8 c	2.3	5.5 cd	2.0	3.3 c	6.1	1.7	3.3	1.5	3.0	0.98 abc
120-N	5.0	9.2 ab	2.0	7.6 b	1.8	5.1 ab	6.4	1.8	3.6	1.4	3.1	0.63 c
160-N	4.7	6.3 bc	2.4	6.9 bc	2.1	4.1 bc	6.1	2.1	3.3	1.5	3.1	1.0 abc
200-N	4.8	11.7 a	1.9	8.1 b	1.7	5.4 ab	7.1	2.0	3.5	1.9	3.1	1.25 a
240-N	5.8	11.8 a	2.2	10.9 a	1.9	5.8 a	6.2	2.2	3.0	1.6	2.8	1.38 a
Time (T)												
Fall	4.9	5.5 b	2.1	6.6	1.8	4.2	6.5	2.1	3.4	1.5	3.0	0.96
Spring	4.8	9.0 a	2.1	6.7	2.0	4.4	6.2	1.8	3.4	1.7	3.1	1.07
	………………………………….……………*P* values ………………….……………………………………											
N rate (N)	0.2291	<.0001	0.7788	<.0001	0.6231	0.0064	0.6372	0.8847	0.3193	0.9164	0.6196	0.0135
Time (T)	0.7352	0.0006	0.9865	0.8296	0.2479	0.5823	0.3627	0.2758	0.8040	0.5103	0.3551	0.3080
N x T	0.4561	0.0028	0.9466	0.3711	0.8194	0.9846	0.7039	0.5107	0.1042	0.1915	0.2004	0.0046

Table 24. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Morris in continuous corn (CC).

	Soil Extractable N (ppm) 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†	4.8	6.6 b	1.9	11.5	1.5	7.3	6.4	2.1	3.5	1.6	3.3	1.31
ESN/BI	8.0	19.3 a	2.1	11.8	2.0	5.3	6.3	2.1	6.5	1.6	2.7	0.88
U+I/BI	5.0	7.6 b	2.5	6.7	2.5	4.4	6.1	1.9	3.3	1.3	2.4	0.94
U+I/SSB	5.1	7.6 b	2.0	6.2	1.8	4.1	6.0	2.1	3.8	1.2	3.5	1.06
U/BI	5.0	9.2 b	2.0	7.6	1.8	5.1	6.4	1.8	3.6	1.4	3.1	0.63
U/SSB	3.8	6.5 b	1.9	10.1	1.8	4.9	6.5	2.0	3.4	1.2	3.3	0.69
Time (T)												
Fall	4.8	6.9 b	2.1	9.0	1.9	5.2	6.0	2.1	3.7	1.3	3.1	1.02
Spring	5.8	12.0 a	2.1	8.9	1.9	5.1	6.5	1.9	3.4	1.4	3.0	0.81
	……………………………………*P* values ……………………………………											
Management(M)	0.1273	0.0047	0.6197	0.1035	0.5517	0.0902	0.9181	0.9667	0.7443	0.3306	0.0537	0.1864
Time (T)	0.2380	0.0156	0.8380	0.9187	0.9430	0.8707	0.1193	0.4818	0.1704	0.5042	0.4627	0.2088
M x T	0.5311	0.1882	0.5031	0.8981	0.6616	0.3757	0.5498	0.5005	0.3818	0.4189	0.4164	0.1399

†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.

Table 25. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N rate and time of application at Morris in corn-soybean (CSb).

	Soil Extractable N (ppm) 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	3.1	19.5	1.5	8.2	1.4	5.6	4.6	2.1	2.9	1.3 c	2.5	2.3
40-N	3.8	23.0	1.9	7.8	1.7	5.4	4.7	2.9	2.6	2.4 bc	2.3	3.1
80-N	3.1	23.6	1.4	7.3	1.6	6.1	5.1	3.3	2.5	4.0 abc	2.4	4.6
120-N	4.3	33.6	2.0	8.9	1.6	8.5	4.7	2.5	2.7	2.8 bc	2.5	5.1
160-N	3.5	27.9	1.4	8.6	1.3	7.1	4.5	3.3	2.3	5.6 ab	2.1	5.9
200-N	3.9	32.8	1.6	10.4	1.6	8.2	4.8	4.1	2.4	7.6 a	2.1	7.5
Time (T)												
Fall	3.3	26.0	1.5	8.9	1.4 b	7.5	4.8	2.9	2.6	3.6	2.3	5.2
Spring	3.9	27.4	1.8	8.2	1.7 a	6.1	4.6	3.1	2.5	4.3	2.3	4.4
	……………………………………..…………….*P* values ……………………..………………………………….											
N rate (N)	0.2915	0.0832	0.0847	0.7427	0.6596	0.3069	0.8718	0.3214	0.5232	0.0430	0.5112	0.1072
Time (T)	0.0900	0.6559	0.0790	0.5298	0.0499	0.1629	0.4058	0.6540	0.4637	0.5391	0.6587	0.4733
N x T	0.8853	0.4874	0.3349	0.4091	0.9418	0.1300	0.7584	0.1337	0.8934	0.1432	0.5241	0.0608

Table 26. Soil extractable N concentrations for different soil depths at V4 development stage and post-harvest in response to N source and placement and time of application at Morris in corn-soybean (CSb).

	Soil Extractable N (ppm) 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†	4.3	29.7	1.6	7.1	1.9	5.2	5.0	3.1	2.8	4.8	2.3	5.1
ESN/BI	4.4	30.9	1.8	8.6	1.5	6.7	5.0	3.1	2.8	4.9	2.6	6.4
U+I/BI	4.1	21.9	2.0	6.3	1.6	5.4	4.4	2.9	2.5	3.2	2.2	4.6
U+I/SSB	6.8	23.5	1.5	7.2	1.6	5.5	4.8	2.6	2.7	2.8	2.1	3.6
U/BI	3.1	23.6	1.4	7.3	1.6	6.1	5.1	3.3	2.5	4.0	2.4	4.6
U/SSB	3.2	23.1	1.6	7.3	1.8	5.6	4.3	3.9	2.4	5.8	2.0	4.5
Time (T)												
Fall	3.5	25.3	1.5	7.5	1.7	5.9	4.8	3.3	2.5	4.7	2.3	5.4
Spring	5.1	25.6	1.8	7.0	1.7	5.6	4.8	3.0	2.7	3.8	2.2	4.2
	……………………………………*P* values ……………………………………………											
Management(M)	0.4053	0.3835	0.2879	0.7494	0.5609	0.8194	0.2801	0.7948	0.7132	0.8550	0.3610	0.7864
Time (T)	0.1546	0.9010	0.0706	0.5777	0.8852	0.6126	0.9645	0.6725	0.4342	0.5640	0.5305	0.2841
M x T	0.8748	0.1605	0.8178	0.1278	0.5438	0.0045	0.3252	0.1062	0.5848	0.2216	0.9608	0.0043

†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.

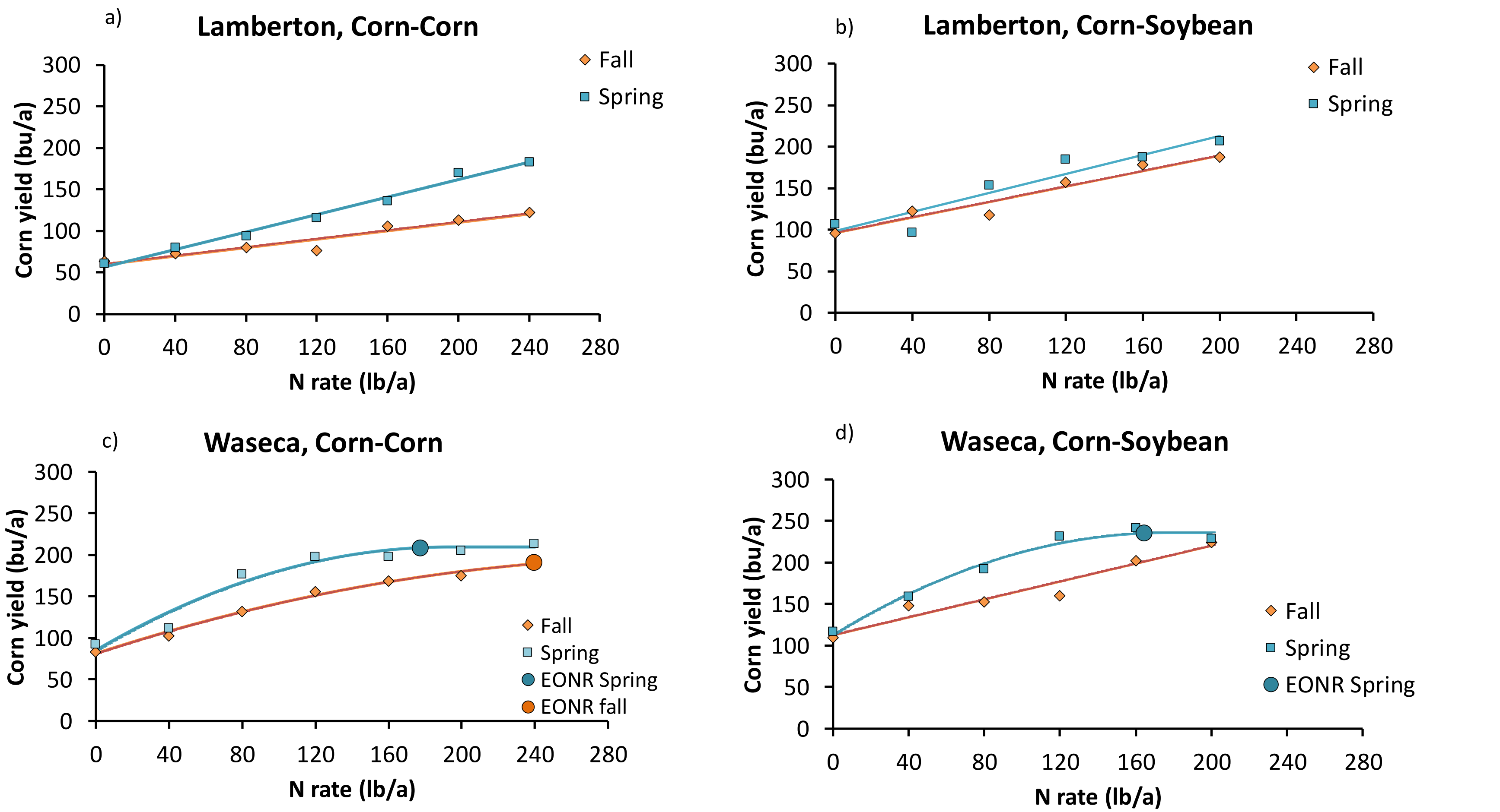


Figure 1 Yield response to N rate for different locations (Lamberton, Waseca) and crop rotations when urea was applied in the fall or the spring. The large dot symbols represent the economic optimum N rate (EONR) calculated at a 0.1 N price: corn price ratio (i.e. $0.40/lb N and $4.00/bu corn).

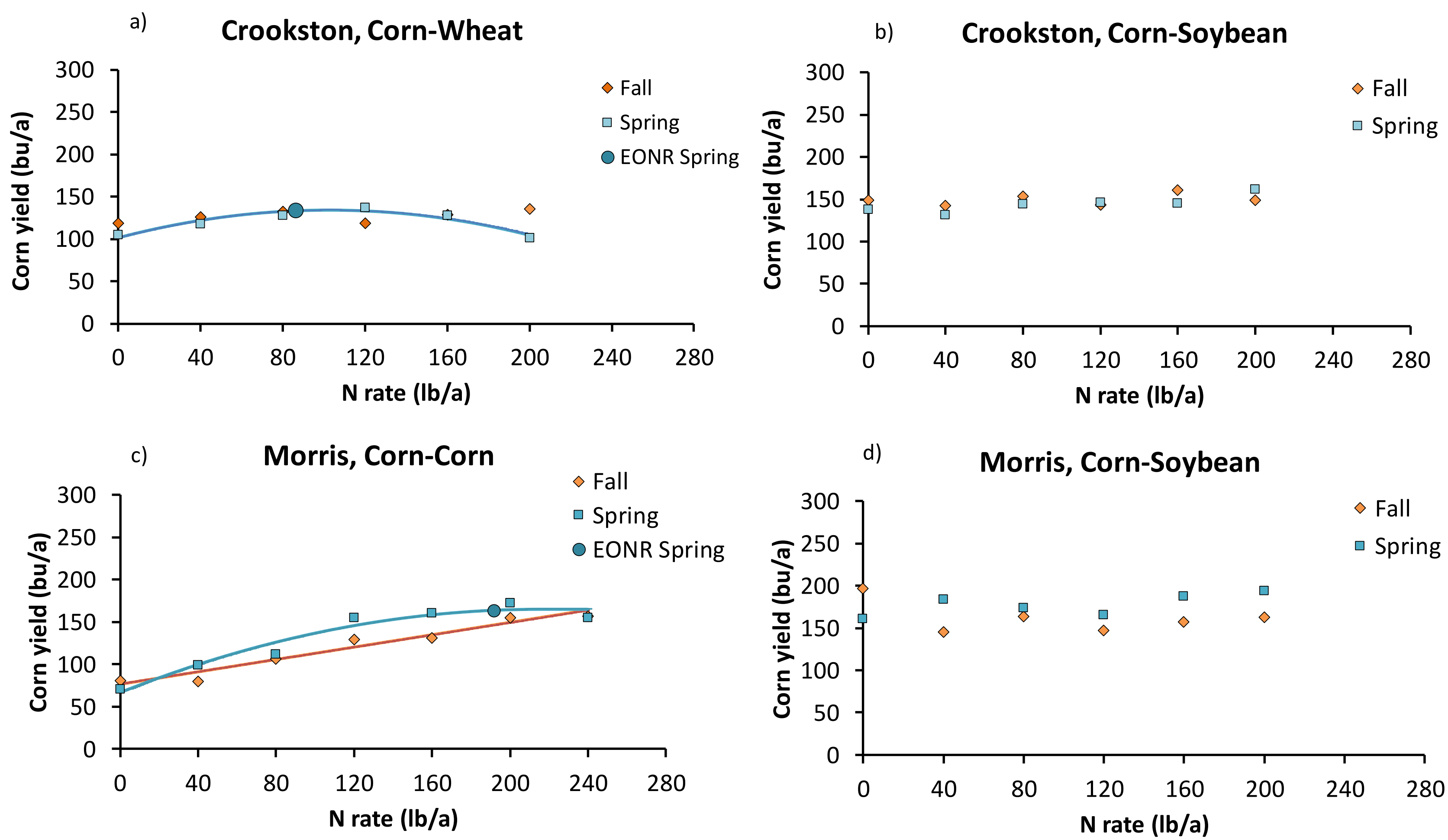


Figure 2 Yield response to N rate for different locations (Crookston, Morris) and crop rotations when urea was applied in the fall or the spring. The large dot symbols represent the economic optimum N rate (EONR) calculated at a 0.1 N price: corn ratio (i.e. $0.40/lb N and $4.00/bu corn).

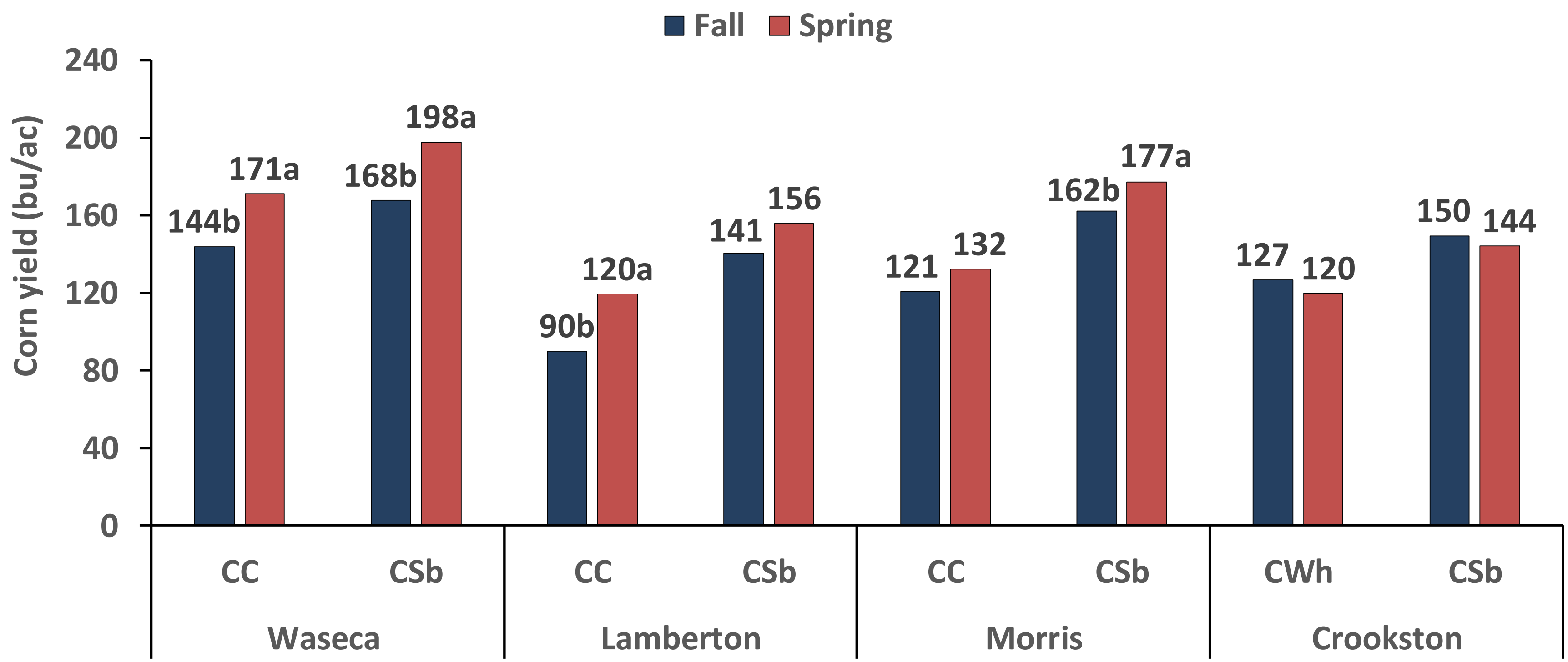


Figure 3 Yield response to N timing for different locations and crop rotations for the 2018 growing season.

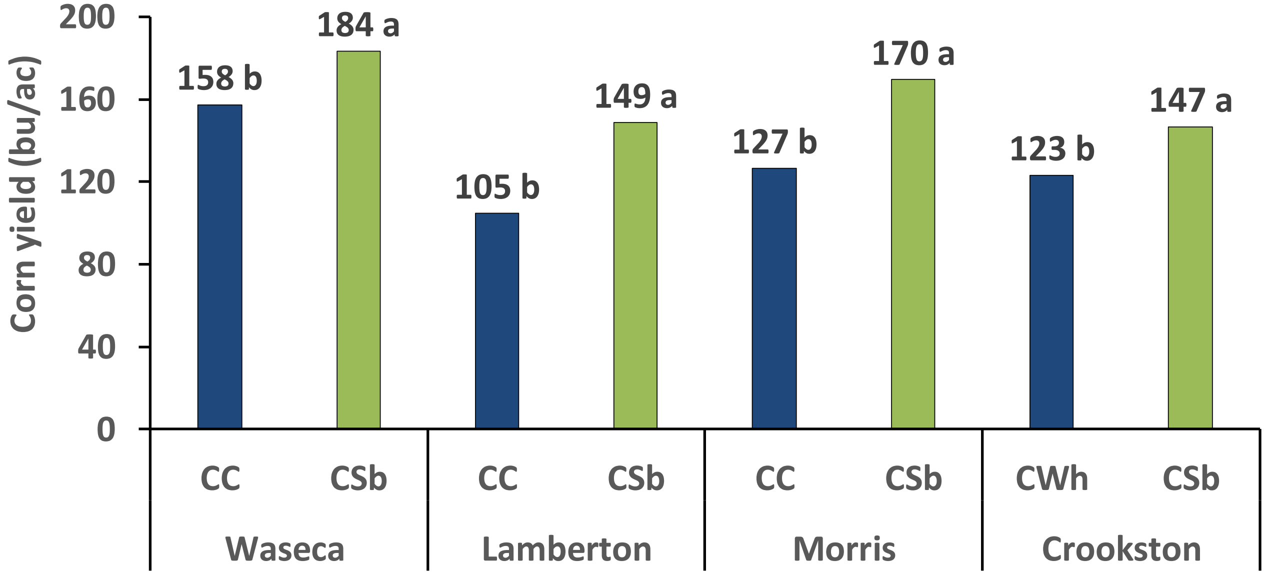


Figure 4. Corn grain yield response to crop rotation across N rates and time of application for the 2018 growing season.

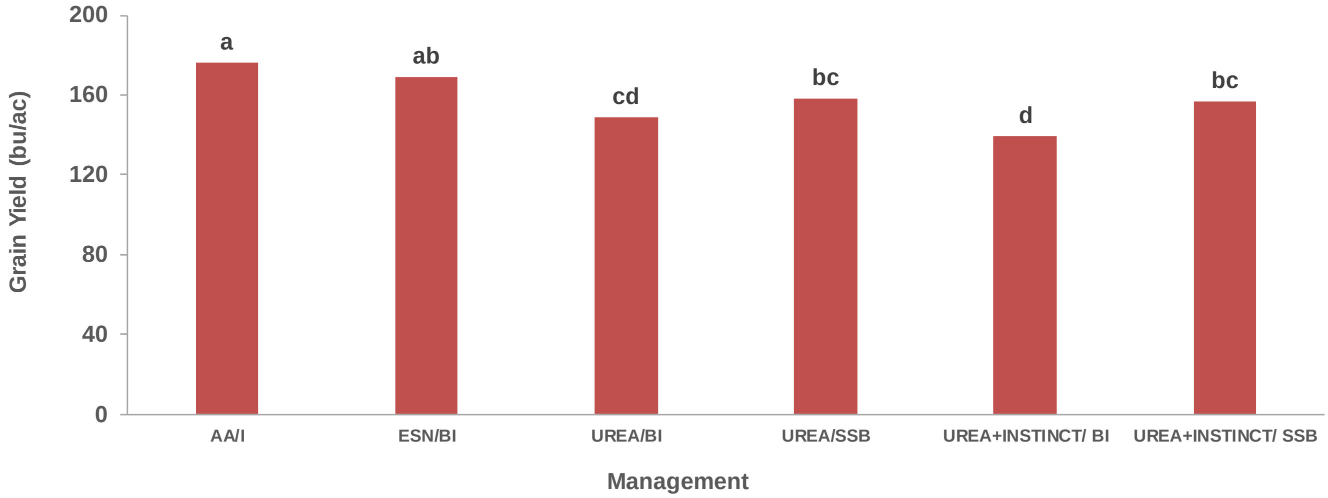
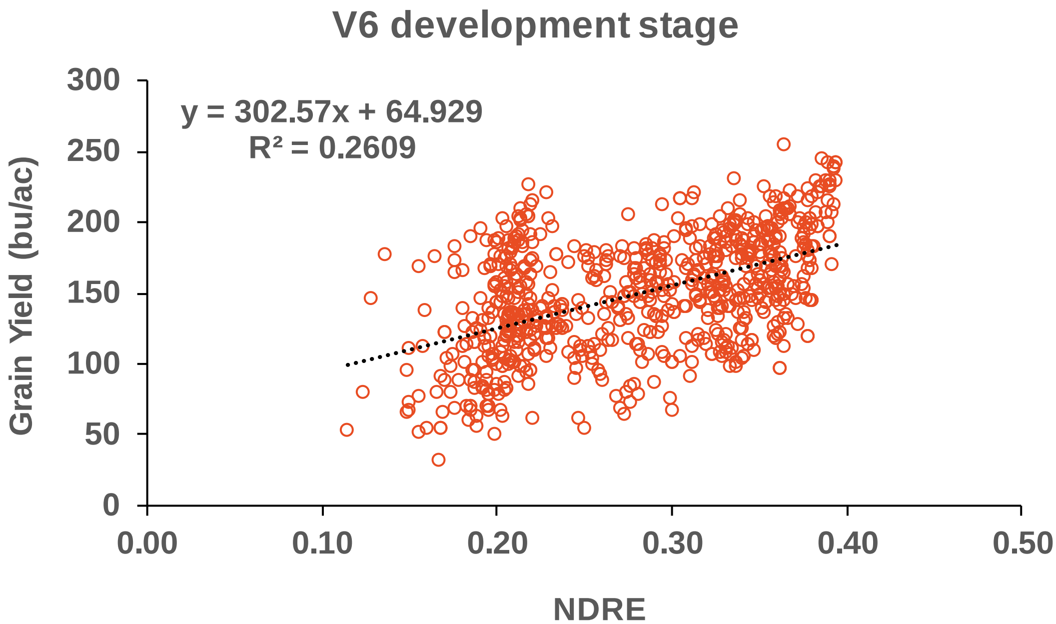


Figure 5. Corn grain yield response to N source and application method averaged across all sites (Lamberton, Waseca, Morris), application times, and crop rotations during the 2018 growing season. Anhydrous ammonia was applied at 120 lb N/ac in all crop rotations whereas all other treatments were applied at 120 lb N/ac in CC but at 80 lb N/ac in CSb, thus the comparison of AA with other treatments in this figure must be interpreted with caution.



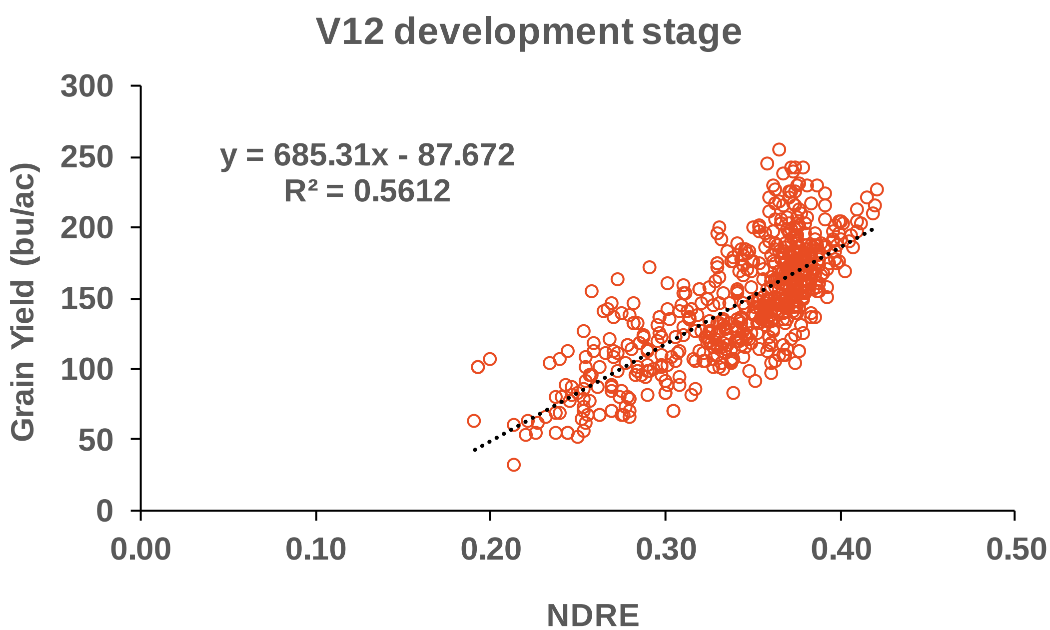


Figure 6. Relationship of grain yield and Crop Circle normalized difference red-edge (NDRE) index calculated for the V6 and V12 development stages averaged across all variables in the study for 2018 growing season.