Long-Term Impact of Nitrogen Fertilization on Corn Production, Soils and Nitrogen Cycling Processes in Minnesota

2022 growing season Report.

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BACKGROUND:

Nitrogen (N) fertilizer is an essential input in modern corn production because corn is highly responsive to N. At the same time, N fertilizer can impact soil organic carbon (C) stocks by influencing crop residue production and decomposition rates. These rates are extremely important as they affect the amount of N fertilizer that is needed to optimize crop production. Further, soil organic C influences many important physical, chemical, and biological properties and functions in the soil (soil health), including water infiltration and retention, root penetrability and access to nutrients and water, microbial activity, soil pH and acidity, basic cation depletion, nutrient cycling, soil productivity, soil aggregate stability, soil color, etc. It is well known that N fertilization results in important changes in soil organic C and N cycling. However, long-term N management effects on soil organic C quality and quantity as they relate to the fate of N fertilizer inputs and soil productivity or soil health are poorly understood. The parameters and functions mentioned above are not easily detectable in the short term. Once a gradient of soil conditions is established with various N rates applied over a prolonged period, these sites become a highly valuable asset for research. Such sites allow researchers to investigate not only the effect of long-term N management on various properties, but also to evaluate how the resulting properties affect various agronomic practices, such as fertilizer recovery efficiency.

OBJECTIVES:

Our objectives are to 1) establish long-term N management sites in six locations throughout Minnesota in continuous corn and corn-soybean cropping systems, and 2) conduct an in-depth characterization of soil properties at the start of the project. Our goals are to 1) quantify, after 10-15 years of consistent application of various N fertilizer rates, the changes in soil physical, chemical, and biological characteristics, and 2) impose various N treatments on the gradient of soil conditions previously crated to evaluate how those resulting properties impact N management practices. While the long-term benefits of this work are the most important aspects of this work, during the "waiting period" to develop long-term conditions, we have shorter, year-to-year objectives that add great value to this work. Our short-term objectives are to 1) gather N response data from all these sites to increase the size of the database for the maximum return to N (MRTN) calculator (http://cnrc.agron.iastate.edu/) that farmers in Minnesota use to determine their N needs, and 2) in 2022 growing season, a specific objective evaluate the N response to Urea vs blend of ESN and Urea applied to corn.

MATERIALS AND METHODS

Five long-term (10 to 15-year) sites were established in 2019, and a new site was incorporated in 2020 (Waseca), at the following locations from north to south in Minnesota: the Northwest Research and Outreach Center at Crookston (NWROC), the West-Central Research and Outreach Center at Morris (WCROC), the Sand Plain Research Farm (SPRF) at Becker, the Southwest Research and Outreach Center at Lamberton (SWROC), the South Central Research and Outreach Center at Waseca (SROC), and the Lawler Farm in the southeast near Rochester. These locations were selected as they represent major soils and crop production regions of Minnesota. At each location continuous corn (CC) and corn-soybean (CSb) cropping systems were establish, except at Rochester and Crookston where only a corn-soybean cropping system was established and at Waseca where only a continuous corn cropping system was established. In Crookston and Lamberton the corn phase of the CSb system happens during even years and at all the other sites during the odd years.

Each study consisted of five N rates that cover the range of corn grain yield response to N (below optimal, optimal, and above optimal); these N rates are reported in Table 1. Each rate was applied to 60-ft wide by 60-ft long plots (66-by-60 ft. in Crookston) replicated four times. Each N rate had six subplots of 10-by-60 ft. (11-by-60 ft. in Crookston). Across all locations except Becker for the 2019 and 2020 growing seasons, each subplot received N as urea (46-0-0) broadcast and incorporated with tillage before planting. At Becker, fertilizer was applied in three equal amounts at V2, V6, and V8/V10. Even though we irrigated as soon as possible after fertilizer application at Becker, we used the urease inhibitor Agrotain to minimize any potential for N volatilization. While the rate and time of application remains the same, since the 2021 growing season, the six subplots were paired within each of the original N rates shown in Table 1, to accommodate the following N source variables:

Non-irrigated (Morris-Lamberton-Waseca-Rochester)	Irrigated sands (Becker)
100% Urea	1/3Agrotain-1/3Agrotain-1/3Agrotain
1/3ESN-2/3Urea	1/3ESN -1/3Agrotain-1/3Agrotain
2/3 ESN-1/3 Urea	2/3ESN-1/3Agrotain

Plant dry biomass and N uptake were measured at R6 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 (Crookston only the top two depths) and analyzed for ammonium-N and nitrate-N and total inorganic N (TIN) was calculated. Statistical analysis was performed using the SAS software. Differences were established at P=0.05. The EONR was calculated at the 0.1 N to corn price ratio using all six subplot and four replications of data. We also calculated EONRs for each of the six subplots using four replications for each to quantify the variability within each field.

In this preliminary report, we present grain yield, grain N removal, and post-harvest total inorganic N (TIN) data for the 2022 growing season.

RESULTS AND DISCUSSION

Overall, the 2022 growing season was drier than the 30-yr normal with precipitation ranging from 0.86 to 8.45 inches below normal, except at Rochester where precipitation was near normal (Table 2). The dry conditions in general resulted in a mediocre growing season for corn and soybean production. In April, all locations were wetter than normal except for Morris that was near normal. These wet conditions, especially in Rochester and Crookston, might have induced residual N loss. May was wetter than normal for all locations except Rochester that had near normal precipitation. June through October was drier than normal at all locations with the exception of Becker in August and Rochester and Waseca in July and August that were close to- or wetter than-normal.

Grain Yield data

During the 2022 growing season, there was no significant interaction between N rate and N source for corn grain yield at any site, except at Crookston (Tables 3, 5, 7). There was a positive response to N application for both CC and CSb cropping systems at all locations but no differences due to N source (Table 3, 5, 7). The lack of difference due to N source likely reflects the fact that after fertilizer applications the potential for N loss was low due to the generally low precipitation. The persistent dry conditions this season likely reduced corn grain yields except at the irrigated site (Becker). In addition, at Crookston grain yield was reduced by a pathogen (Goss'Wilt).

Soybean crops in the corn-soybean cropping system showed no difference in yield in response to residual N rates applied during the corn phase of the rotation at Becker and Rochester, but at Morris yield increased with higher N rates applied on the previous crop (Tables 7, 9). At all sites N grain removal in corn and soybean followed the same response as grain yield (Table 3, 5, 7, 9).

Grain yield for all corn-corn cropping systems had a quadratic plateau response to N where the EONR was on average 130 lb N/ac with a grain yield plateau of 128 bu/ac at Morris, 132 lb N/ac with a grain yield plateau of 145 bu/ac at Lamberton, and 257 lb N/ac with a grain yield plateau of 166 bu/ac at Waseca (Table 4). At Morris and Lamberton, the EONRs were lower than our guideline, whereas the opposite was true for Waseca even though at all sites the grain yield was lower than what is typical for these locations. The current MRTN guidelines at a 0.1 N to corn price ratio for Minnesota suggest for non-irrigated CC 173 lb N/ac with a range of 159 to 189 lb N/ac. The CC system is normally a more stressful environment than CSb, and dry conditions likely exacerbated this stress. The lower EONRs in a year with low N loss potential are not surprising in light of the lower grain yields that likely illustrate that water was a large limiting factor this year.

At all three CC locations the EONR with Urea was greater (between 1 and 17 lb N/ac, average of 11 lb N/ac) than for the 1/3ESN-2/3Urea treatment (Table 4. Fig. 1). While there was little potential for N loss after fertilizer applications, this results hints to the fact that adding a small fraction of ESN in pre-plant applications can be beneficial, even when N loss potential is low. If the N loss potential is high, it is highly possible that the addition of ESN in a pre-plant application would be even more advantageous. It is our interest to test this hypothesis over the next few growing seasons if, hopefully, conditions are not as dry as in the last two seasons. However, in CC where immobilization tends to be high and N availability early in the season is low, having the majority of N applied as ESN might limit N availability too much for the crop and result in less favorable outcomes. In 2022, the EONR for the 2/3ESN-1/3Urea treatment was higher than for Urea in Lamberton and Waseca.

As with CC, corn grain yield for the CSb cropping systems also had a quadratic plateau response to N where the EONR was on average 147 lb N/ac with a grain yield plateau of 182 bu/ac at Lamberton and 89 lb N/ac with a grain yield plateau of 146 bu/ac at Crookston (Table 6, Fig. 2). The EONR for CSb in Lamberton was similar to current guidelines at the 0.1 price ratio (142, range of 132 to 155 lb N/ac), but was lower in Crookston. We have observed lower N needs in Crookston in other studies as well, but currently we do not have a sufficiently large dataset to adjust the N rate guidelines for the Northwest region. The lower N requirements may be related to lower yield potential, but more research is needed. For these reason, currently we suggest using the lower end of the N rate range to ensure a greater likelihood for economic advantage.

Unlike the responses for the CC system, in CSb the Urea treatment produced the lowest EONRs relative to the treatments with ESN even though the grain yield at the EONR was not substantially different between N sources (Table 6, Fig. 2). The contrasting data between CC and CSb during a generally dry season illustrates that it is difficult to generalize and further points out the importance of conducting studies over several years and environments (given the large variability in N response we observe under field conditions), to come to a more complete understanding of what is a likely outcome.

At Becker (irrigated sands site), on average corn grain yield had a quadratic plateau response to N in the CC cropping system where the EONR was 241 lb N/ac with grain yield plateau of 216 bu/ac (Table 8, Fig. 3). This rate is higher than the N rate guideline of 210 lb N/ac with a range of 190 to 225 lb N/ac. The three-way split Agrotain treatment had an EONR of 247 lb N/ac similar to the two-way split 2/3ESN-1/3Agrotain (252 lb N/ac) and both higher than the EONR of 220 lb N/ac obtained with the three-way split 1/3ESN-2/3Agrotain treatment. Despite differences in EONR between the different N sources, grain yield plateaus were similar (range across treatments of 214 to 218 bu/ac (Table 8).

Residual soil N

Residual soil TIN increases with N rates for all sites under corn (Fig. 4, 5). For those sites with soybean during the 2022 growing season, residual soil N was low for both fine-textured soils (Morris CSb and Rochester CSb) and irrigated sands (Becker CSb) (Fig. 6), and was similar across the N rates applied to the previous corn.

Residual soil TIN for the corn phase tended to be greater under continuous corn rotation than corn after soybean rotation, especially at high rates (Fig. 4 and 5).

Residual soil TIN at post-harvest was greater when N was applied over the EONR at all sites, but the response varies depending on different soil type and location (Fig. 4 and 5). Lamberton and Morris under continuous corn had a steeper response than Waseca and Becker (Figure 4). The fact that at the EONR all fine-textured locations had similar amounts of residual soil N, despite the fact that Waseca had a higher EONR highlights the fact that targeting applications near the EONR ensure lower potential for N loss later, as we know that residual N is likely to be available for crop uptake on the following growing season. The lower residual N at Becker, even for the high N rates highlight that N loss during the growing season is high for this site.

Table 1. N rates and cropping systems [continuous corn (CC) or corn-soybean (CSb)] at each experimental site.

Crookston	Morris		Becker		Lamberton		Rochester	Waseca
CSb	CC	CSb	CC	CSb	CC	CSb	CSb	CC
lb N/ac								
0	0	0	0	0	0	0	0	0
60	70	60	100	80	70	60	60	70
120	140	120	200	160	140	120	120	140
180	210	180	300	240	210	180	180	210
240	280	240	400	320	280	240	240	280

Table 2. Mean monthly cumulative precipitation for the normal and the 2019, 2020, 2021, 2022 growing season at each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. cumulative
		inch							
Crookston	Normal(1991-2021)	1.28	2.83	3.83	3.28	2.75	2.5	2.22	18.69
	2019	1.56	1.38	1.39	3.32	4.72	6.92	4.15	23.4
	2020	1.92	1.00	4.52	7.52	3.02	0.44	0.49	18.9
	2021	0.67	0.95	1.65	0.32	2.30	2.41	4.95	13.3
	2022	5.82	4.73	2.78	1.66	0.46	1.10	0.18	16.7
Morris	Normal(1986-2021)	2.25	2.97	4.0	3.65	3.13	2.38	1.89	20.3
	2019	2.23	4.06	5.47	4.54	5.53	6.64	3.02	31.5
	2020	0.98	0.83	4.67	3.66	3.01	0.71	0.83	14.7
	2021	4.24	0.94	0.82	2.13	5.06	2.53	5.57	21.3
	2022	2.45	6.14	2.08	1.64	2.23	0.92	1.29	16.8
Becker	Normal(1991-2020)	2.76	4.07	4.06	4.03	3.99	3.15	2.6	24.66
	2019	3.68	6.74	3.96	4.40	3.69	5.16	4.61	32.2
	2020	1.17	1.74	3.12	4.21	4.68	1.15	2.24	18.0
	2021	2.67	3.08	1.29	1.23	3.71	2.78	1.86	16.6
	2022	3.3	6.69	2.34	1.87	5.78	2.9	0.87	23.8
Lamberton	Normal(1961-2021)	2.79	3.54	4.0	3.73	3.21	3.2	2.18	22.65
	2019	5.91	4.80	2.35	6.86	2.22	6.02	4.00	32.2
	2020	1.33	3.48	4.20	5.68	3.80	1.04	1.00	20.5
	2021	1.43	2.74	0.49	1.17	4.75	4.97	3.32	18.9
	2022	3.63	3.90	1.07	1.59	2.98	0.72	0.29	14.2
Rochester	Normal(1991-2020)	3.47	4.47	5.32	4.46	4.59	3.63	2.48	28.42
	2019	3.37	7.57	5.58	8.8	2.28	7.46	5.07	40.1
	2020	1.51	5.55	5.34	3.01	4.31	3.59	1.55	25
	2021	0.97	4.21	1.63	5.25	6.94	2.22	1.11	22.3
	2022	6.83	4.2	4.28	5.01	6.53	0.97	0.7	28.5
Waseca	Normal(1991-2020)	3.21	3.93	4.69	4.42	4.75	3.67	2.67	27.3
	2020	1.53	4.27	5.83	5.43	7.03	1.91	1.93	27.9
	2021	0.62	2.66	2.00	2.73	4.82	1.92	2.98	17.7
	2022	3.75	4.74	4.36	4.60	5.50	0.78	0.36	24.1

Table 3. Effect of N rate and N source on corn grain yield (bu/ac) and N grain removal (lb N/ac) for continuous corn (CC) cropping system at Morris, Lamberton and Waseca for the 2022 growing season.

	Morris CC- corn		**Lamberton CC- corn**		**Waseca CC- corn**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate						
0	72 c	34 c	83 d	36 c	64 e	31 e
70	112 b	63 b	126 c	66 b	103 d	52 d
140	132 a	77 a	152 a	88 a	141 c	78 c
210	131 a	81 a	141 b	83 a	159 b	86 b
280	124 a	77 a	146 ab	87 a	167 a	96 a
N source						
Urea	113	65	130	73	126	66
1/3 ESN-2/3 Urea	116	68	131	71	127	68
2/3 ESN-1/3 Urea	114	67	128	72	128	71
Statistical (*P* values)						
N rate	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
N source	0.5100	0.5687	0.7896	0.7737	0.6365	0.1603
Nrate*Nsource	0.8917	0.9968	0.8105	0.7768	0.8927	0.9505

Table 4. Economic optimal N rate (EONR) and the corn yield at EONR for continuous corn at Morris, Lamberton and Waseca for the 2022 growing season.

	Morris		**Lamberton**		**Waseca**	
N Treatments	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac
Urea	134	128 (QP)	128	145(QP)	254	165 (Q)
1/3 ESN-2/3 Urea	120	126 (QP)	127	145 (QP)	237	162 (Q)
2/3 ESN-1/3 Urea	133	127 (QP)	141	145 (QP)	280	173 (Q)
Average	130	128 (QP)	132	145 (QP)	257	166 (Q)

Table 5. Effect of N rate and N source on corn grain yield (bu/ac) and N grain removal (lb N/ac) for corn-soybean (CSb) cropping system at Lamberton and Crookston for the 2022 growing season.

	Lamberton		**Crookston**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate				
0	133 d	63 d	119 c	74 c
60	161 c	86 c	141 b	94 b
120	179 b	100 b	144 ab	97 b
180	180 ab	108 b	149 a	103 a
240	187 a	116 a	148 a	105 a
N source				
Urea	171	96	138	94
1/3 ESN-2/3 Urea	167	95	141	94
2/3 ESN-1/3 Urea	166	92	141	95
Statistical (*P* values)				
N rate	<.0001	<.0001	<.0001	<.0001
N source	0.2221	0.3641	0.3440	0.8188
Nrate*Nsource	0.4849	0.5363	0.0611	0.0612

Table 6. Economic optimal N rate (EONR) and the corn yield at EONR for the corn-soybean cropping system at Lamberton and Crookston for the 2022 growing season.

	Lamberton		**Crookston**	
N Treatments	**EONR** lb N/ac	**$Yield_{EONR}$** bu/ac	**EONR** lb N/ac	**$Yield_{EONR}$** bu/ac
Urea	112	183 (QP)	90	143 (QP)
1/3 ESN-2/3 Urea	168	181 (QP)	143	147 (QP)
2/3 ESN-1/3 Urea	177	183 (QP)	113	149 (QP)
Average	147	182 (QP)	89	146 (QP)

Table 7. Effect of N rate and N source on corn grain yield (bu/ac), soybean yield (bu/ac), and N grain removal (lb N/ac) for continuous corn (CC) and corn-soybean (CSb) cropping system at Becker for the 2022 growing season.

	Corn Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Soybean Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate±				
0/0	58 d	27 d	60	172 b
100/80	158 c	75 c	64	184 a
200/160	206 b	121 b	64	182 ab
300/240	216 a	133 a	65	189 a
400/320	220 a	135 a	65	184 a
N source				
1/3Agrotain-1/3Agrotain-1/3Agrotain	169	96	64	183
1/3ESN-1/3Agrotain-1/3Agrotain	175	101	64	182
2/3ESN-1/3Agrotain	170	97	63	182
Statistical (*P* values)				
N rate	<.0001	<.0001	0.1160	0.0786
N source	0.1088	0.0878	0.8873	0.9876
Nrate*Nsource	0.6635	0.3183	0.9811	0.9441

±CC/CSb rates

Table 8. Economic optimal N rate (EONR) and the corn yield at EONR for the irrigated continuous corn site at Becker for the 2022 growing season.

N Treatments	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac
Agrotain	247	214 (QP)
1/3ESN-1/3Agrotain-1/3Agrotain	220	218 (QP)
2/3ESN-1/3Agrotain	252	215 (QP)
Average	241	216(QP)

Table 9. Effect of N rate and N source on soybean grain yield (bu/ac) and N grain removal (lb N/ac) for corn-soybean (CSb) cropping system at Morris and Rochester for the 2022 growing season.

	Morris		**Rochester**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate				
0	44 bc	130 b	65	168
60	39 d	116 c	63	164
120	43 cd	129 b	64	164
180	49 a	147 a	63	160
240	48 ab	143 a	64	167
N source				
Urea	43.5	130	63.8	165
1/3 ESN-2/3 Urea	45.1	134	64.0	165
2/3 ESN-1/3 Urea	45.0	135	63.8	164
Statistical (*P* values)				
N rate	0.0003	0.0002	0.2938	0.1743
N source	0.5670	0.4788	0.9597	0.9083
Nrate*Nsource	0.9951	0.9770	0.8890	0.5132

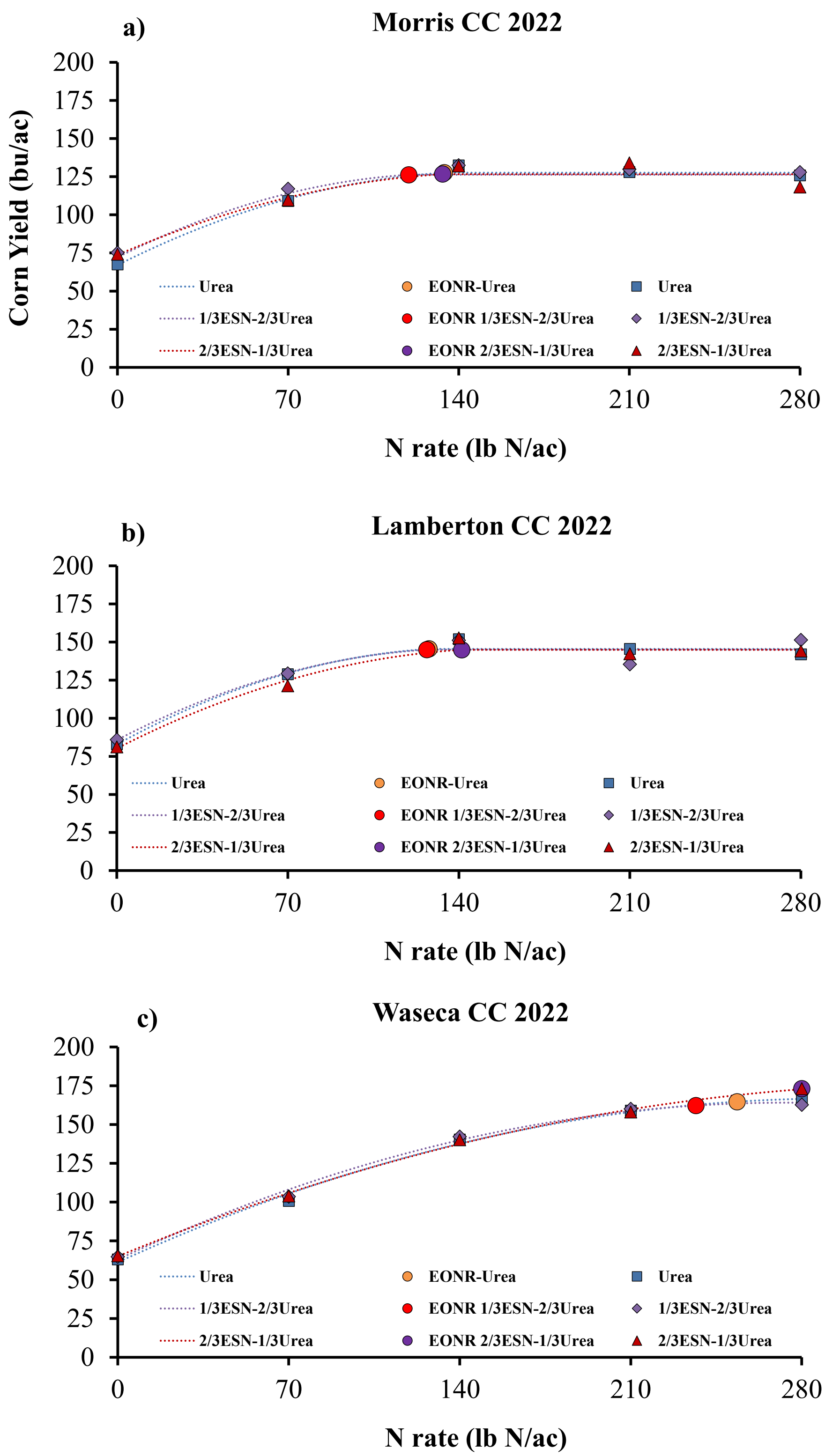

Figure 1. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) at Morris (a), Lamberton (b), and Waseca (c).

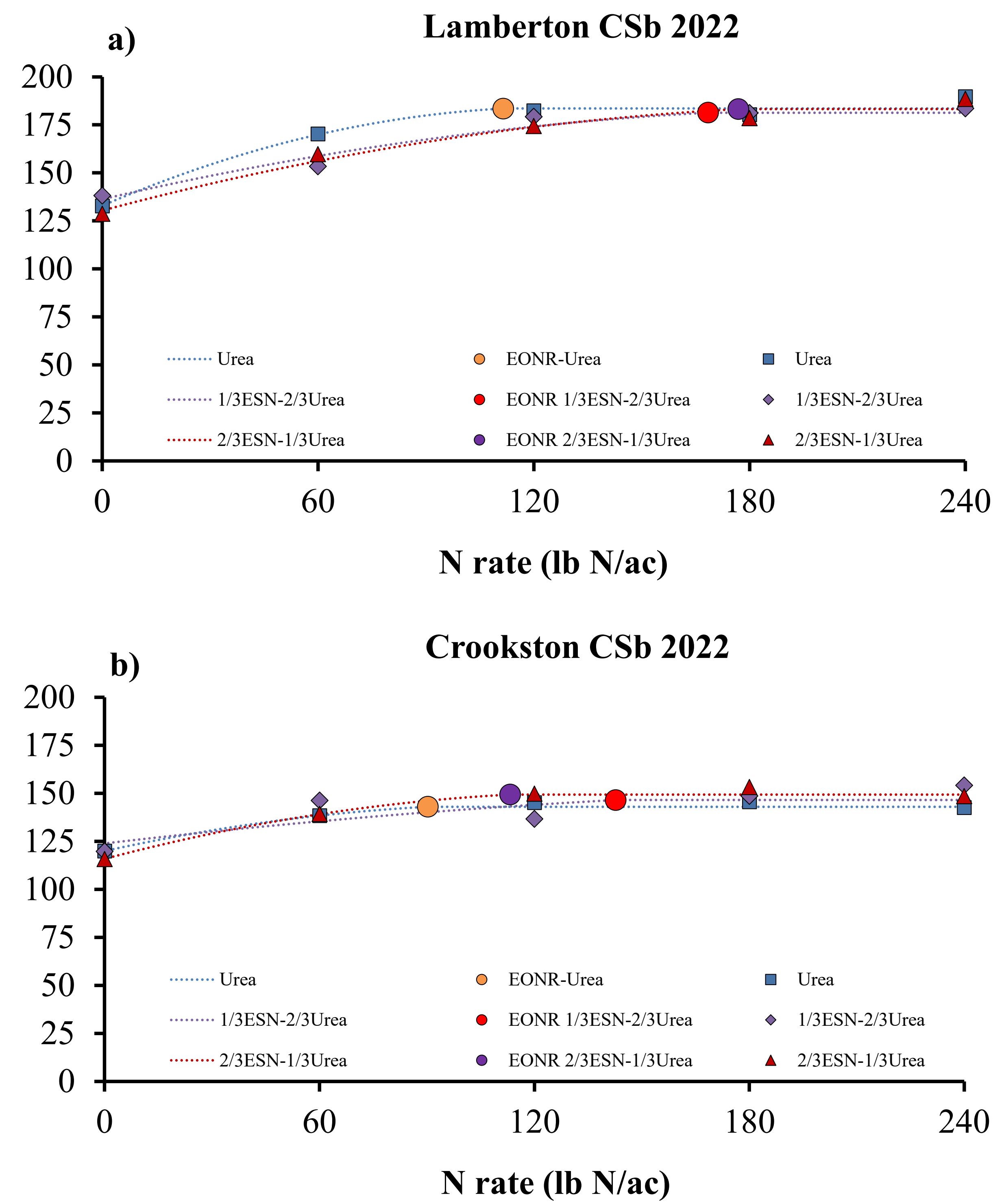

Figure 2. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for corn after soybean (CSb) at Lamberton (a) and Crookston (b).

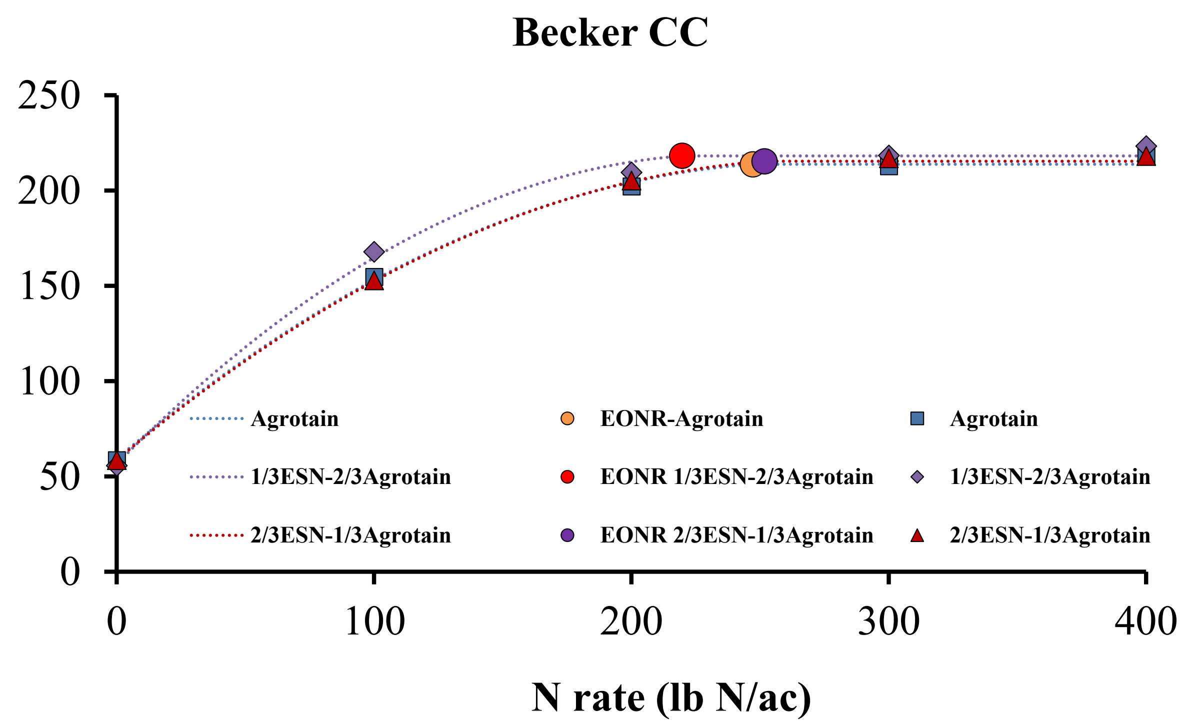

Figure 3. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) at Becker.

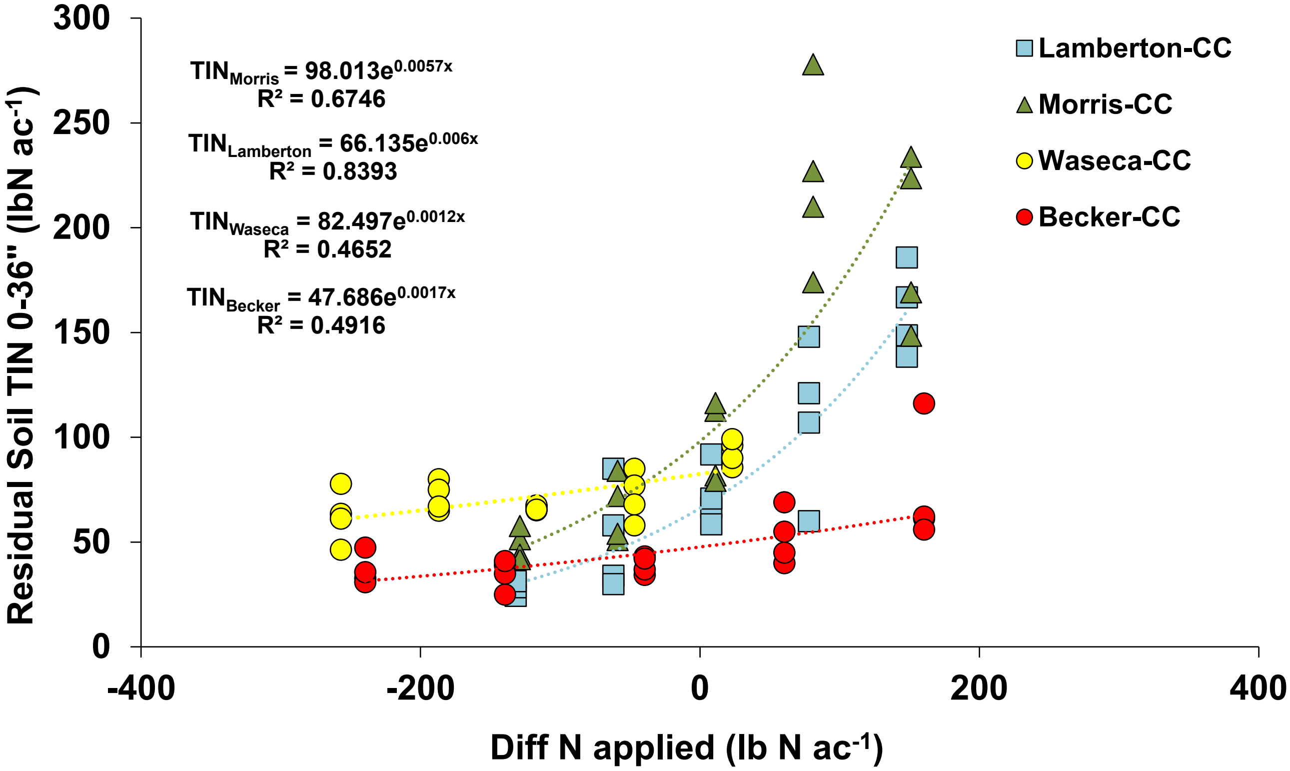

Figure 4. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-36' depth and the difference between N rate and EONR (ΔN Applied, lb N ac^{-1}) for Lamberton, Morris, Waseca (fine-textured soils) and Becker (irrigated sandy soils) under continuous corn (CC) cropping system.

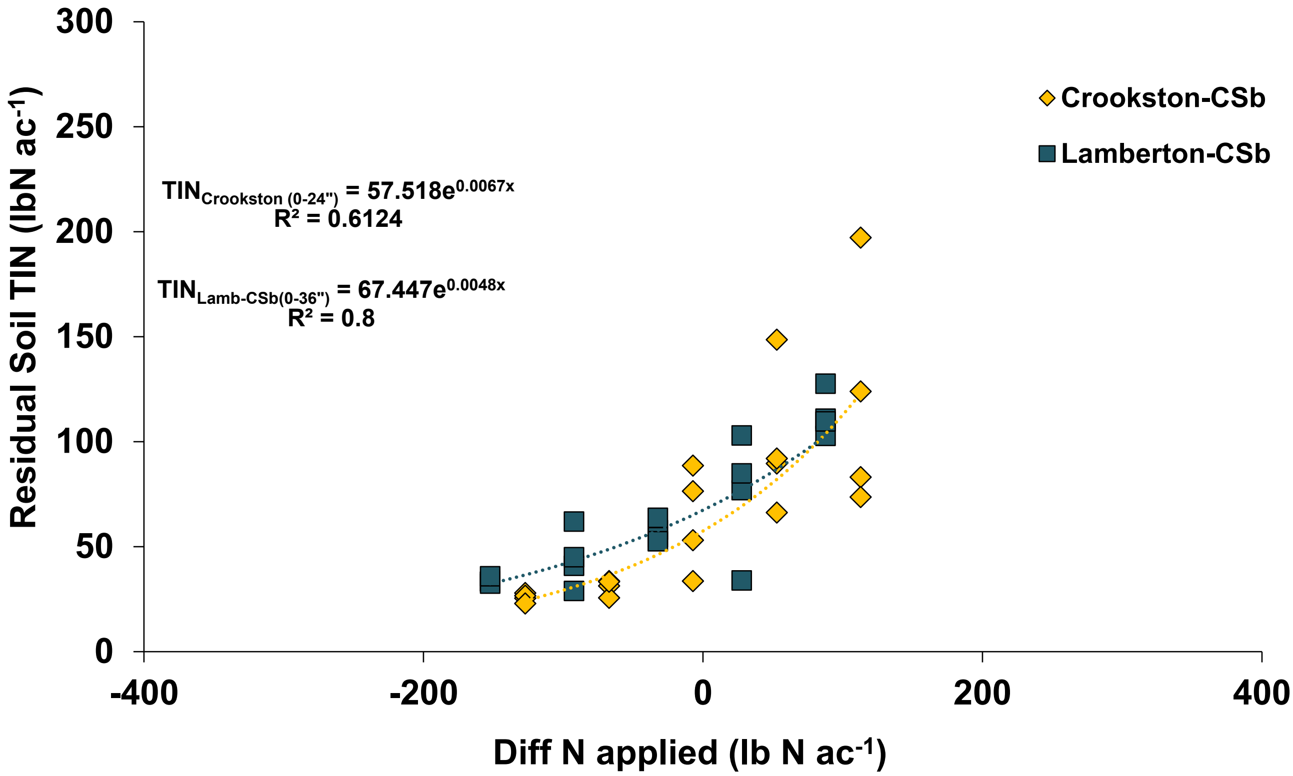

Figure 5. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-24" for Crookston and 0-36" for Lamberton, and the difference between N rate and EONR (ΔN Applied, lb N ac^{-1}) under corn after soybean (CSb) cropping system.

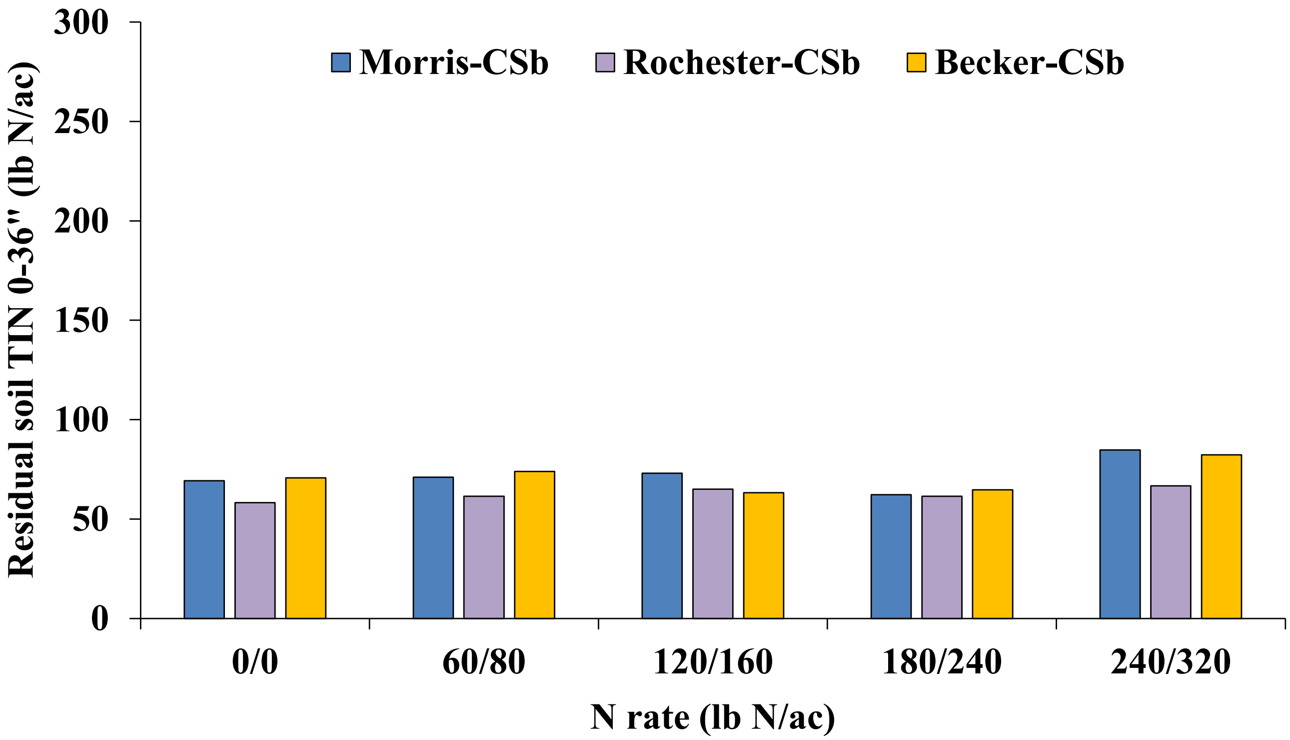

Figure 6. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-36" after soybean growing season at different N rates applied in the previous corn at Morris and Rochester under corn after soybean (CSb) cropping system.

Note first N rate corresponded to the sites on the fine textured soils (Morris and Rochester), second N rate to the irrigated sands site at Becker