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

2023 growing season Report.

April 2024

Fabián Fernández, Karina Fabrizzi, Daniel Kaiser, Yuxin Miao, Paulo Pagliari, Lindsay Pease, Carl Rosen, Jeffrey Strock, Jeffrey Vetsch, and Melissa Wilson

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 this growing season, a specific objective was to evaluate the corn response to N as Urea vs blend of ESN and Urea.

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 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 for Urea and the blends of ESN and Urea applied to corn.

In this preliminary report, we present grain yield, grain N removal, and post-harvest total inorganic N (TIN) data for the 2023 growing season.

RESULTS AND DISCUSSION

Overall, the 2023 growing season was drier than the 30-yr normal with precipitation ranging from 1 to 7.3 inches below normal, except at Lamberton where precipitation was 1.3 inches above normal (Table 2). The dry conditions in general resulted in a mediocre growing season for corn and soybean production. In April, most of the locations were wetter than normal except for Morris and Rochester that were below normal. May was drier than normal for all locations except Lamberton and Waseca that had 3.5 to 2 inches above normal precipitation. These wet conditions might have induced residual N loss. June through August was drier than normal at most of the locations. Some locations, like Morris and Becker received greater precipitation than normal later in the growing season (September-October). Around the third week of July there was hail damage reported for our studies in Becker, and Rochester. In that same week there was substantial wind damage in Morris.

Grain Yield data

During the 2023 growing season, there was no significant interaction between N rate and N source for corn grain yield at all sites (Tables 3, 5, 7). There was a positive response to N application for both CC and CSb cropping systems at all locations (Table 3, 5, 7) but no differences due to N source except in Becker-CC where corn grain yield with 1/3Agrotain-1/3Agrotain-1/3Agrotain were similar to 1/3ESN-1/3Agrotain-1/3Agrotain but greater than 2/3ESN-1/3Agrotain (Table 7). The lack of difference due to N source at most of the sites likely reflects the fact that after fertilizer applications the potential for N loss was low due to the generally low precipitation. Also, the persistent dry conditions and erratic precipitation this season likely reduced corn grain yields in most locations except at the irrigated site (Becker).

Soybean crops in the corn-soybean cropping system showed no difference in yield in response to residual N rates applied during the corn phase at Lamberton, but at Crookston 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 corn-corn cropping systems had a quadratic response to N for Morris and Waseca and lineal plateau for Lamberton, where the EONR was on average 131 lb N/ac with a grain yield plateau of 110 bu/ac at Morris, 160 lb N/ac with a grain yield plateau of 143 bu/ac at Lamberton, and 280 lb N/ac with a grain yield plateau of 190 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 Morris-CC the EONR with Urea was lower (40 lb N/ac) than for the 1/3ESN-2/3Urea treatment (Table 4. Fig. 1). At Lamberton, the 2ESN-1/3Urea had the lowest EONR for this growing season. At Waseca, the calculated EONR was near the maximum N rate, indicating that N loss was likely high. Similar to last year, while there was little potential for N loss after fertilizer applications (Waseca precipitation in May was 6.47 inches with most of it before May 19 and Lamberton precipitation in May was 7.06 inches with most of it before May 15) 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.

Corn grain yield for the CSb cropping systems also had a quadratic plateau response to N where the EONR was on average 141 lb N/ac with a grain yield plateau of 191 bu/ac at Rochester and 99 lb

N/ac with a grain yield plateau of 165 bu/ac at Morris (Table 6, Fig. 2). The EONR for CSb in Rochester was similar to current guidelines at the 0.1 price ratio (142, range of 132 to 155 lb N/ac), but was higher in Morris.

In the CSb the Urea treatment produced greater EONRs relative to the treatments with ESN even though the grain yield at the EONR was not substantially different between N sources at Rochester (Table 6, Fig. 2). At Morris Urea and 2/3ESN-1/3Urea treatment had the lowest EONRs with similar grain yields.

At Becker (irrigated sands site), on average corn grain yield had a quadratic plateau response to N in the CC and CSb cropping system where the EONR was 289 lb N/ac with grain yield plateau of 217 bu/ac for CC and 202 lb N/ac with grain yield plateau of 222 bu/ac for CSb (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 282 lb N/ac similar to the three-way split 1/3ESN-1/3Agrotain-1/3Agrot (279 lb N/ac) and both lower than the EONR of 307 lb N/ac obtained with the two-way split 2/3ESN-1/3Agrotain treatment. Despite differences in EONR between the different N sources, grain yield plateaus were similar (range across treatments of 215 to 222 bu/ac for CC and 219 to 225 bu/ac for CSb)(Table 8).

Residual soil N

Residual soil TIN increases with N rates for all sites under corn (Fig. 4, 5). For those sites with soybeans during the 2023 growing season, residual soil N was low for fine-textured soils at Lamberton 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 than corn after soybean cropping system, 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). This highlights the fact that targeting applications near the EONR ensure lower residual N and lower potential for N loss, as most of the residual N is typically not present by the following growing season. Lamberton, Morris and Waseca under continuous corn had a steeper response than Becker (Figure 4). 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 long-term normal and the 2019 to 2023 growing seasons at each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. cumulative
		inch							
Crookston	Normal(1991-2021)	1.32	2.81	3.82	3.11	2.7	2.56	2.24	18.56
	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
	2023	1.71	0.87	1.20	2.10	1.42	2.48	1.92	11.7
Morris	Normal(1986-2022)	2.28	2.99	3.99	3.64	3.13	2.37	1.88	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
	2023	2.07	0.71	3.05	2.96	3.68	3.57	3.11	19.2
Becker	Normal(1991-2020)	2.76	4.08	4.07	4.04	4.01	3.16	2.61	24.7
	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
	2023	4.95	1.09	1.24	3.05	4.17	3.85	4.11	22.5
Lamberton	Normal(1961-2021)	2.80	3.55	3.95	3.70	3.21	3.16	2.15	22.5
	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
	2023	3.93	7.06	2.88	0.95	1.96	0.60	6.38	23.8
Rochester	Normal(1991-2020)	3.48	4.48	5.32	4.45	4.59	3.62	2.49	28.4
	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
	2023	3.28	3.81	4.55	4.33	4.87	3.64	2.36	26.8
Waseca	Normal(1991-2020)	3.30	4.47	5.38	4.93	4.82	4.12	2.77	29.8
	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
	2023	3.66	6.47	1.56	1.62	3.28	2.17	3.78	22.5

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 2023 growing season.

	Morris CC		**Lamberton CC**		**Waseca CC**	
	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	63 d	31 c	42 c	19 d	54 e	22 e
70	105 ab	57 b	73 b	36 c	104 d	46 d
140	113 a	69 a	135 a	76 b	141 c	69 c
210	96 bc	63 ab	143 a	87 a	156 b	83 b
280	92 c	59 b	143 a	90 a	190 a	100 a
N source						
Urea	93	54	109	62	130	64
1/3 ESN-2/3 Urea	93	56	109	63	132	66
2/3 ESN-1/3 Urea	96	57	104	60	132	62
Statistical (*P* values)						
N source	0.7277	0.5659	0.4266	0.4688	0.4719	0.1087
N rate	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Nsource*Nrate	0.9073	0.8867	0.6188	0.3361	0.8647	0.5349

Within columns, means followed by same letters are not significantly different at P=0.05

Table 4. Economic optimal N rate (EONR) and the corn yield at EONR for continuous corn (CC) at Morris, Lamberton and Waseca for the 2023 growing season.

	Morris CC		**Lamberton CC**		**Waseca CC**	
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	69	99 (QP)	164	149 (LP)	280	189 (Q)
1/3 ESN-2/3 Urea	129	112 (Q)	175	146 (LP)	280	191 (Q)
2/3 ESN-1/3 Urea	133	113 (Q)	143	135 (LP)	280	191 (Q)
Average	131	110 (Q)	160	143 (LP)	280	190 (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 Rochester and Morris for the 2023 growing season.

	Rochester CSb		**Morris CSb**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate				
0	130 c	60 d	103 d	53 c
60	169 b	89 c	153 c	86 b
120	186 a	102 b	157 bc	91 b
180	190 a	109 a	166 ab	102 a
240	194 a	110 a	173 a	107 a
N source				
Urea	173	95	147	86
1/3 ESN-2/3 Urea	174	93	150	88
2/3 ESN-1/3 Urea	175	94	154	90
Statistical (*P* values)				
N source	0.8452	0.6625	0.2521	0.3810
N rate	<.0001	<.0001	<.0001	<.0001
Nsource*Nrate	0.9858	0.6403	0.9335	0.9182

Within columns, means followed by same letters are not significantly different at P=0.05

Table 6. Economic optimal N rate (EONR) and the corn yield at EONR for the corn-soybean cropping system at Rochester and Morris for the 2023 growing season.

	Rochester CSb		**Morris CSb**	
N Treatments	**EONR** lb N/ac	**$Yield_{EONR}$** bu/ac	**EONR** lb N/ac	**$Yield_{EONR}$** bu/ac
Urea	145	190 (QP)	107	162 (QP)
1/3 ESN-2/3 Urea	139	190 (QP)	198	171 (QP)
2/3 ESN-1/3 Urea	139	193 (QP)	91	169 (QP)
Average	141	191 (QP)	99	165 (QP)

Table 7. Effect of N rate and N source on corn grain yield (bu/ac), and N grain removal (lb N/ac) for continuous corn (CC) and corn-soybean (CSb) cropping system at Becker for the 2023 growing season.

	Becker CC		**Becker CSb**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate±				
0/0	64 e	29 e	99 d	43 d
100/80	144 d	68 d	178 c	89 c
200/160	199 c	113 c	208 b	116 b
300/240	214 b	127 b	225 a	133 a
400/320	222 a	136 a	224 a	131 a
N source				
1/3Agrotain-1/3Agrotain-1/3Agrotain	172 a	96	187	103
1/3ESN-1/3Agrotain-1/3Agrotain	168 ab	96	190	104
2/3ESN-1/3Agrotain	165 b	92	184	100
Statistical (*P* values)				
N source	0.0421	0.2400	0.2353	0.3478
N rate	<.0001	<.0001	<.0001	<.0001
Nsource*Nrate	0.8681	0.8172	0.6703	0.8729

±CC/CSb rates. Within columns, means followed by same letters are not significantly different at P=0.05

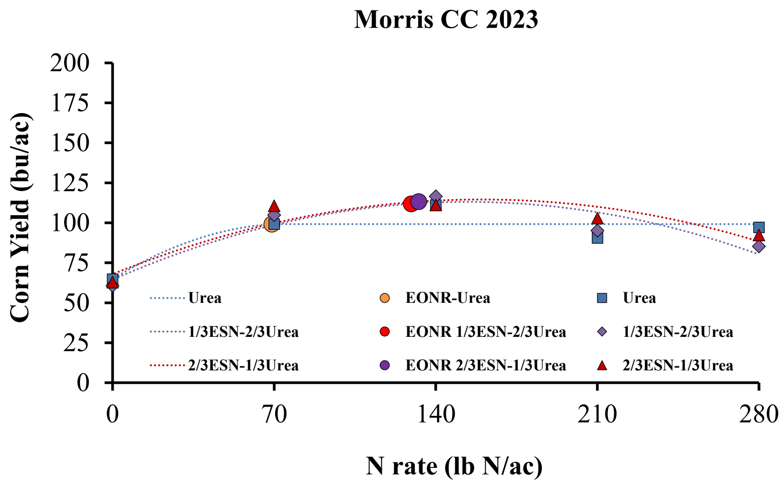
Table 8. Economic optimal N rate (EONR) and the corn yield at EONR for the irrigated continuous corn (CC) and corn-soybean (CSb) cropping system at Becker for the 2023 growing season.

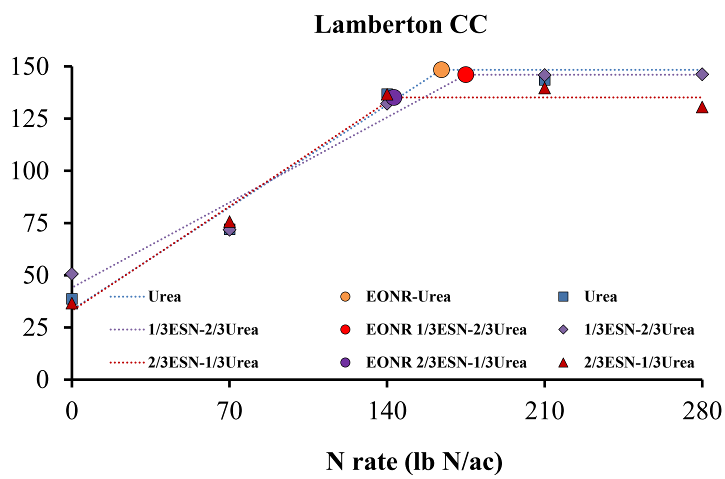
	Becker CC		**Becker CSb**	
N Treatments	**EONR** lb N/ac	**$\mathbf{Yield_{EONR}}$** bu/ac	**EONR** lb N/ac	**$\mathbf{Yield_{EONR}}$** bu/ac
Agrotain	282	222 (QP)	213	225 (QP)
1/3ESN-1/3Agrotain-1/3Agrotain	279	215 (QP)	185	222 (QP)
2/3ESN-1/3Agrotain	307	216 (QP)	202	219 (QP)
Average	289	217(QP)	202	222(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 Lamberton and Crookston for the 2023 growing season.

	Lamberton CSb		**Crookston CSb**	
	Grain Yield (bu/ac)	**N removal (lbN/ac)**	**Grain Yield (bu/ac)**	**N removal (lbN/ac)**
N rate				
0	50	165	35 c	108 bc
60	49	163	34 c	106 c
120	51	168	37 bc	112 bc
180	50	167	39 ab	118 ab
240	51	164	41 a	127 a
N source				
Urea	49	164	37	112
1/3 ESN-2/3 Urea	51	165	37	115
2/3 ESN-1/3 Urea	51	166	38	116
Statistical (*P* values)				
N source	0.2364	0.8332	0.6523	0.6998
N rate	0.5919	0.8278	0.0009	0.0007
Nsource*Nrate	0.8544	0.8097	0.9087	0.7998

Within columns, means followed by same letters are not significantly different at P=0.05





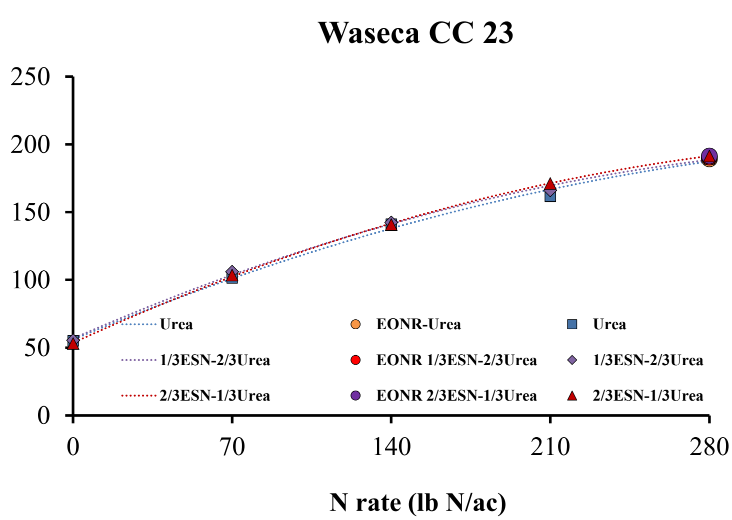


Figure 1. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) cropping system at Morris (a), Lamberton (b), and Waseca (c) for the 2023 growing season.

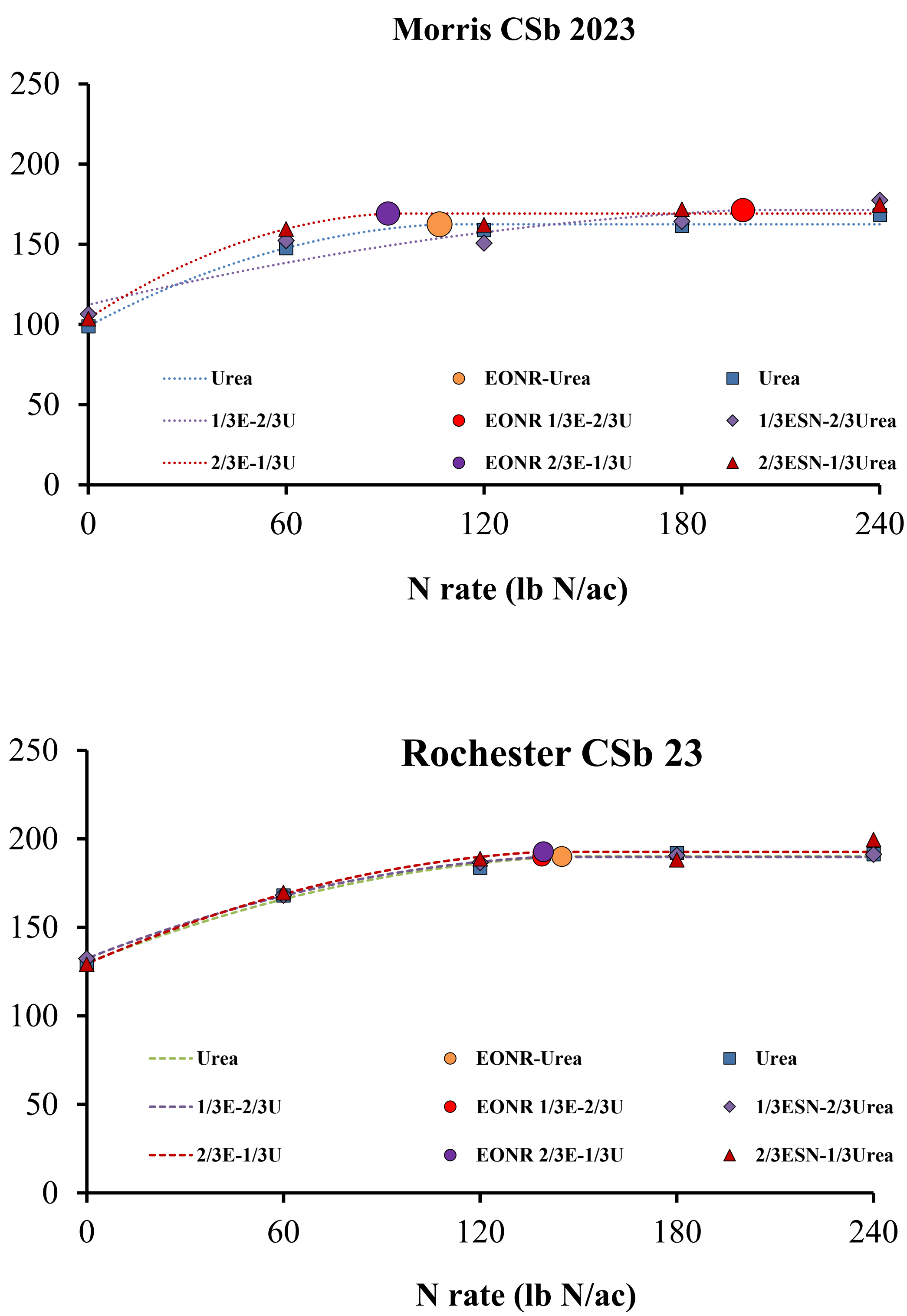


Figure 2. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for corn after soybean (CSb) cropping system at Morris (a) and Rochester (b).

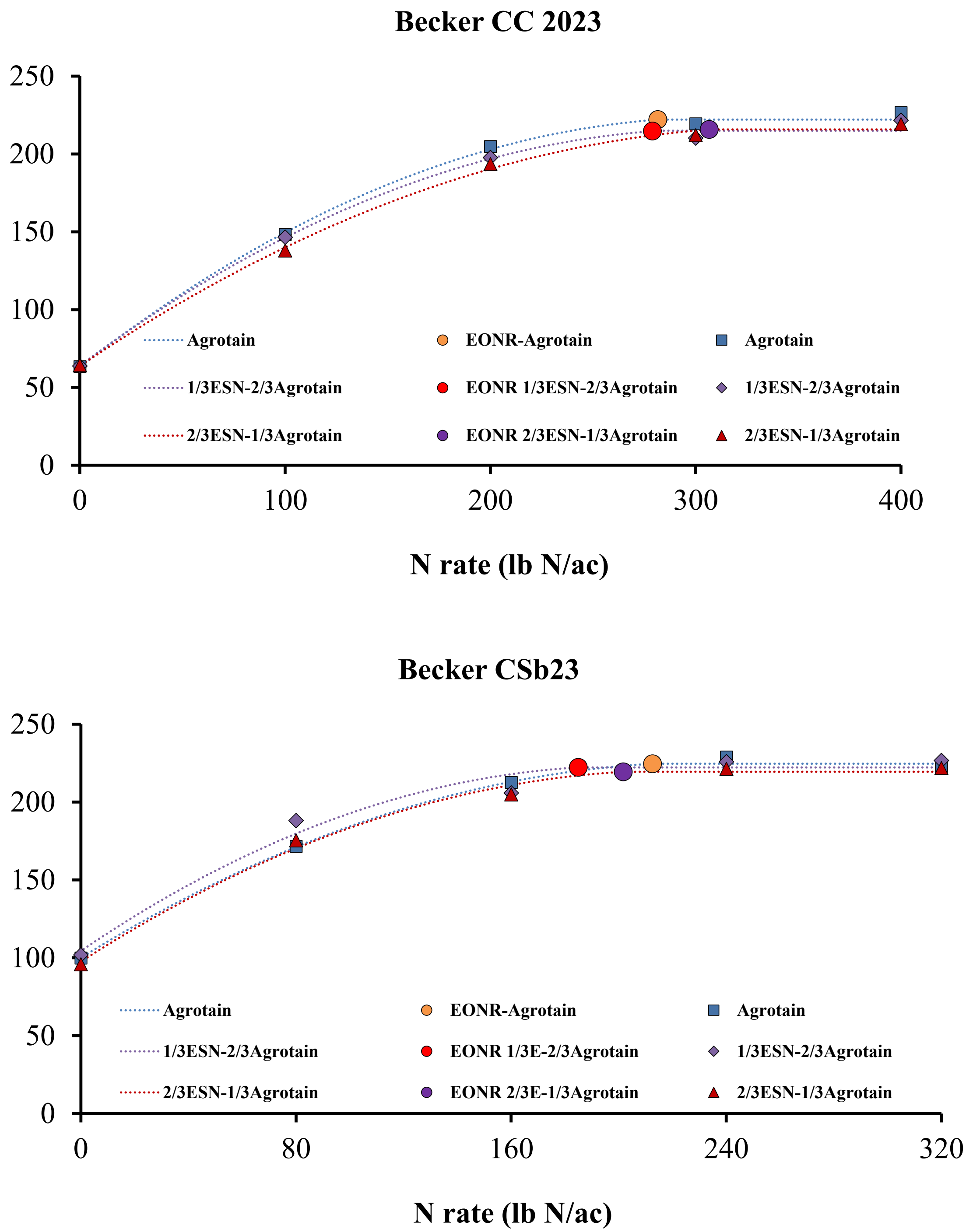


Figure 3. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) and corn-soybean cropping systems at Becker for the 2023 growing season.

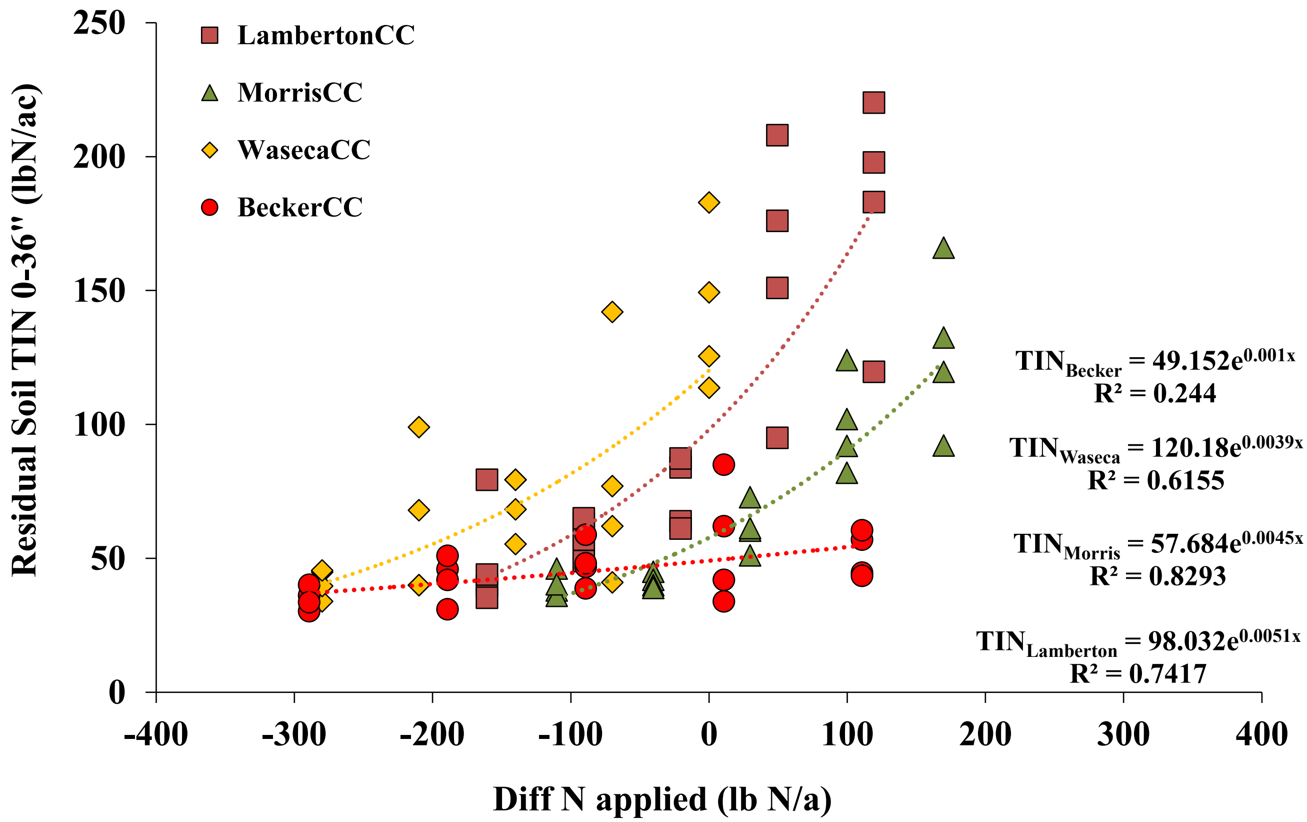


Figure 4. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-36' depth and the difference between N rate and EONR (ΔN Applied, lb N ac^{-1}) for Lamberton, Morris, Waseca (fine-textured soils) and Becker (irrigated sandy soils) under continuous corn (CC) cropping system for the 2023 growing season.

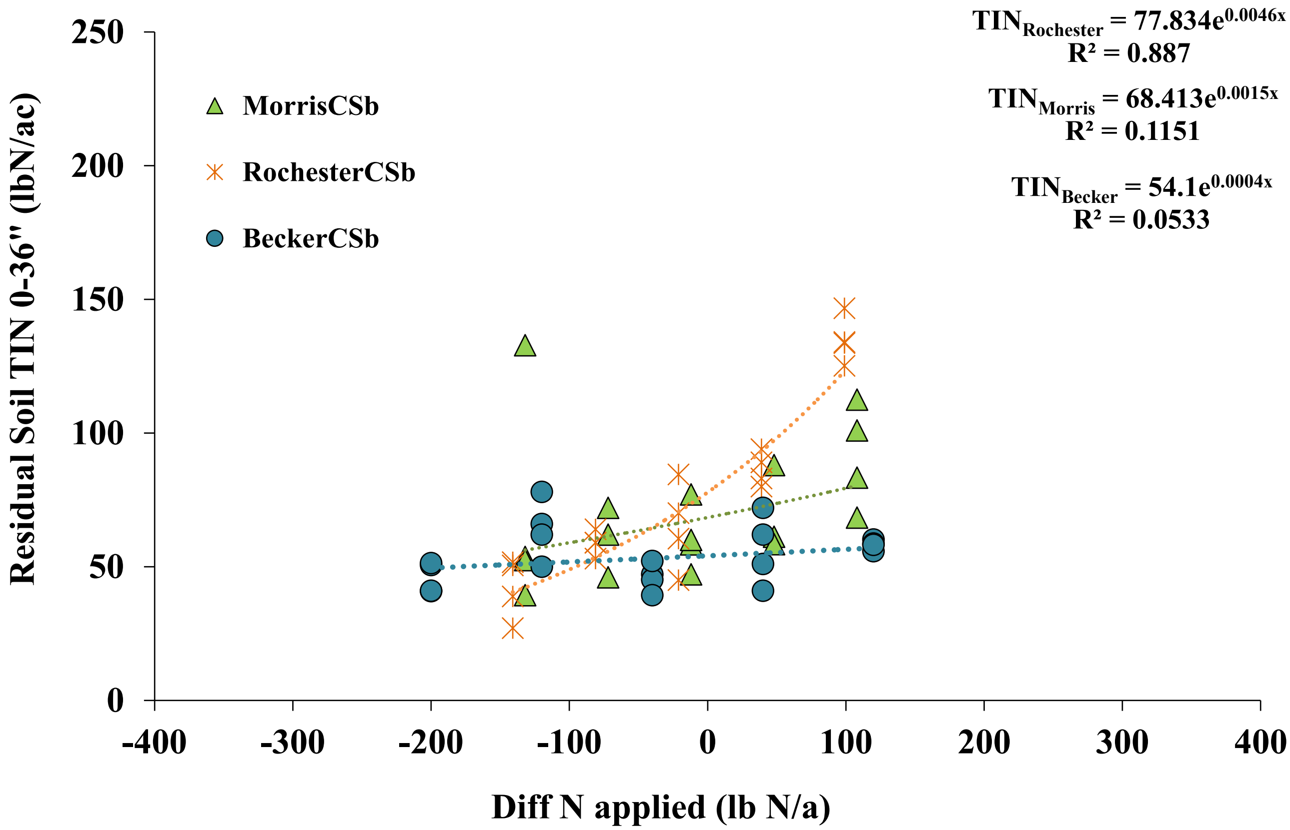


Figure 5. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-36" for Becker, Rochester and Morris, and the difference between N rate and EONR (ΔN Applied, lb N ac^{-1}) under corn after soybean (CSb) cropping system for the 2023 growing season.

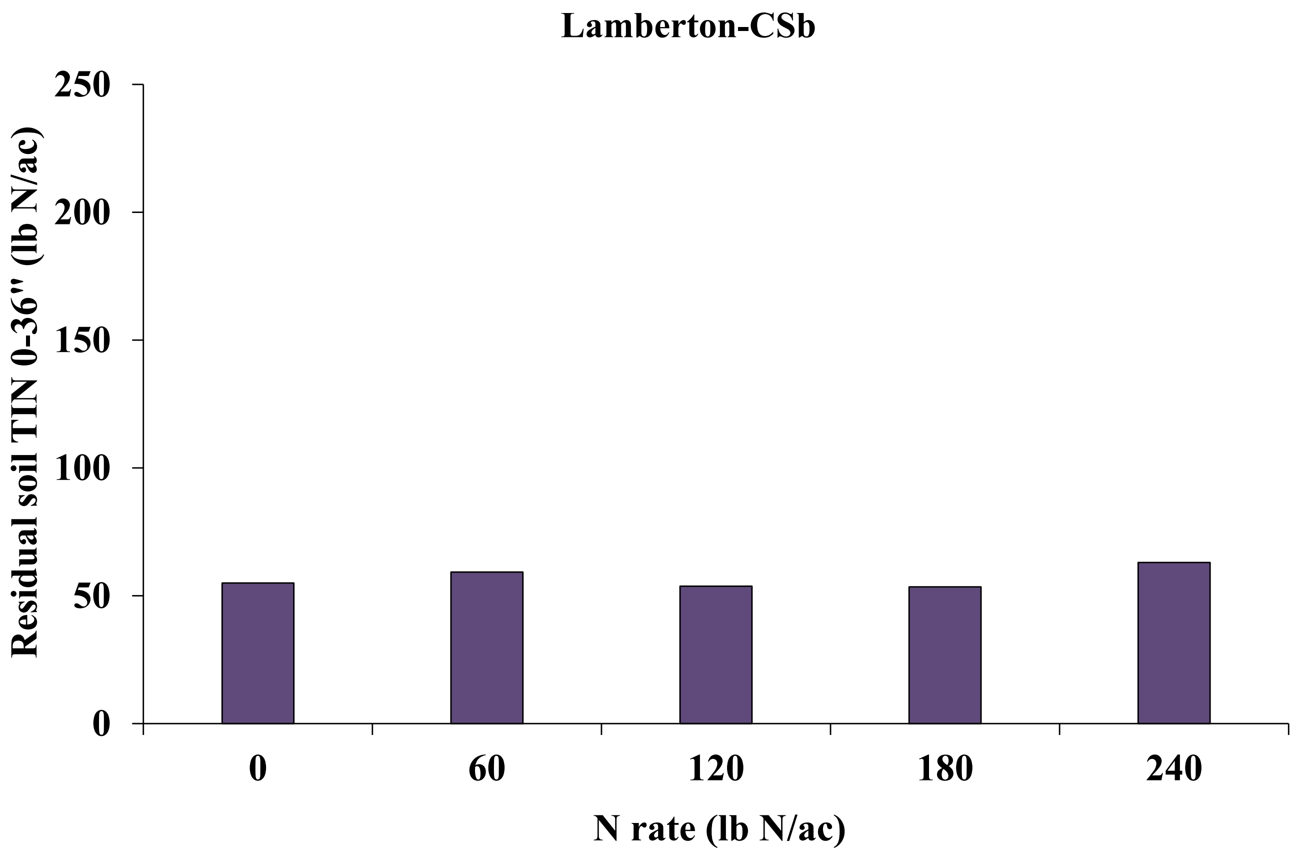


Figure 6. Residual soil Total Inorganic N (TIN) (lbN/ac) at 0-36" after soybean growing season at different N rates applied in the previous corn at Lamberton under corn after soybean (CSb) cropping system.