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

2021 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. Decomposition rates are extremely important as they impact 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 impact various agronomic practices, such as fertilizer recovery efficiency and crop yield.

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) evaluate the within field variability of the economic optimum N rate (EONR). An additional objective added in the 2021 growing season was to compare N responses of different N sources and blends, specifically compared the standard application of urea (or Agrotain if the fertilizer is not incorporated with tillage) to blending it with 1/3 or 2/3 polymer coated urea (ESN) (See Methods Table 1). At the sandy site in Becker, an additional variable was to compare a three- and two-way split application of fertilizer. In each case the N rate variables remained unchanged from the original design.

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 in 2019, 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 CSb system was planted with soybean in 2019 whereas all others were planted with corn.

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, each subplot received N broadcast and incorporated with tillage. 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. At each location with corn plots in 2021 the six 10-by-60 ft subplots were paired into three 20-by-60 ft subplots within each of the N rates to accommodate the treatments listed in Methods Table 1. :

Methods Table 1. Sub treatments added in 2021 using different N sources maintaining the total N rate uniform across these variables.

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

Non-irrigated sites received N as a single pre-plant application with the source or blend of sources indicated. Irrigated sites were applied in two to three different increments V2 - V6 - V8/V10 with the different sources indicated

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 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. Ultimately, the two subplots for the different N source variables were averaged for this report.

Due to lab analysis delays, not all the plant and soil samples have been analyzed for this report.

RESULTS AND DISCUSSION

Grain Yield data

During the 2021 growing season, no interaction between N rate and N source was observed for corn grain yield at all sites (Fig.1,2), but there was a positive response to N application for both CC and CSb cropping systems at all locations (Fig. 1,2). This indicates that all N sources responded similarly to N rate within each location and crop rotation. The only exception was Lamberton CC in which N source had a significant difference in yield, where 2/3Urea-1/3ESN (86 bu/ac) blend had similar grain yield than Urea (85 bu/ac), but significantly greater than 1/3Urea-2/3ESN (79 bu/ac). This growing season was generally drier (across locations 22.3-17.7 inches) than normal (across location 26.8-27.3 inches). Rochester was dry only in April and June. Waseca started with adequate moisture (April 2.9 inch above normal precipitation) that likely helped to reduce the negative effect of dry conditions in May through July, when precipitation was lower than normal, but with some timely rains. Because of these conditions in Rochester and Waseca, grain yields were not as limited as other rainfed locations. Becker had below normal precipitation from April to October but yields were not negatively impacted because of irrigation. In the same soils in a different study in close proximity to ours, but without irrigation, there was no grain yield produced regardless of N rate. This illustrates the importance of irrigation in sandy sites, especially in dry seasons like in 2021, to take advantage of the N fertilization. In Lamberton and Morris, persistent dry conditions until August severely limited grain yield. It is possible that the prevailing dry conditions in Lamberton between April and July (8.4" below normal for that time period) also resulted in less N availability and lower grain yields for the treatment with 2/3 ESN—as previously mentioned— that requires moisture to solubilize urea and release N through the polymer coating. Finally, as with corn, soybean grain yields were limited by drought conditions and there were no difference in response to residual N rates applied during the corn phase of the rotation in Lamberton CSb and Crookston CSb (Fig. 3).

At Morris CC, average across N sources corn grain yield had a quadratic plateau response to N where the EONR was on average 82 lb N/ac with a grain yield plateau of 155 bu/ac (Table 3, Fig. 4a). Urea treatment had greater EONR (116 lb N/ac) than 2/3Urea-1/3ESN (70 lb N/ac) and 1/3Urea-2/3ESN (58 lb N/ac) with grain yield plateau of 118, 115, and 113 bu/ac respectively (Table 3).

At Morris CSb, average across N sources corn grain yield had a lineal response to N (Table 4, Fig. 4b). Since there was a linear response for the CSb cropping system, the EONR was established at the maximum N rate of 240 lb N/ac with a grain yield of 149 bu/ac (Table 4). Each N source treatment responded differently to N application. Urea had a lineal response with the EONR established at the maximum N rate of 240 lb N/ac with a grain yield of 148 bu/ac. The 2/3Urea-1/3ESN had a lineal plateau response with EONR of 217 lb N/ac with a grain yield plateau of 151 bu/ac. The 1/3Urea-2/3ESN blend had a quadratic plateau response with EONR of 196 lb N/ac with a grain yield plateau of 147 bu/ac.

At Lamberton CC, average across N sources corn grain yield had a lineal plateau response to N (Table 3, Fig. 4c) with an average EONR of 230 lb N/ac and a grain yield plateau of 110 bu/ac. The 1/3Urea-2/3ESN blend had greater EONR (248 lb N/ac) than Urea (238 lb N/ac) and 2/3Urea-1/3ESN (210 lb N/ac) with grain yield plateau of 104, 114, and 112 bu/ac respectively (Table 3).

At Waseca CC, corn grain yield had a quadratic plateau response to N where the EONR was 270-280 lb N/ac with a grain yield plateau of 208-210 bu/ac for all N sources treatment (Table 3, Fig. 5b). The calculated EONR was near the maximum N rate. Only April had substantial (2.9 inches) above normal precipitation, but N in this study was applied on April 30 and there was very little potential for N loss after the application because May-July were dry. It is surprising the EONR was so high. This is normally an indication that there was N loss, but for this growing season we suspect moisture was the greatest limiting factor.

At Rochester CSb, average across N sources corn grain yield had a quadratic plateau response to N where the EONR was 182 lb N/ac and the grain yield plateaued at 253 bu/ac (Table 4, Fig. 5a). Urea treatment had similar EONR (184 lb N/ac) than 1/3Urea-2/3ESN (183 lb N/ac) but greater than 2/3Urea-1/3ESN (178 lb N/ac) with grain yield plateau of 255, 253, and 253 bu/ac respectively (Table 4).

The current MRTN guidelines at a 0.1 N to corn price ratio for Minnesota suggest for non-irrigated CC 165 lb N/ac with a range of 152 to 180 lb N/ac, and for CSb 131 lb N/ac with a range of 118 to 144 lb N/ac. For the 2021 growing season, EONRs were greater than the MRTN guidelines for CC and CSb cropping systems at all sites, except at Morris CC (Table 3,4). For the non-irrigated fine textured sites in the study in CC the EONRs were 55 to 115 lb N/ac above the MRTN for Lamberton and Waseca, respectively; and 83 below the MRTN for Morris CC (Table 3). For CSb cropping systems, the EONRs were 109 lb N/ac and 51 lb N/ac above the MRTN for Morris and Rochester, respectively (Table 4).

Because this year had very low potential for N loss, it was surprising that the EONRs were high. Given that the grain yields were in general reduced substantially relative to what is typical, it is likely that dry conditions were the most limiting factor and greater N rates partially help to reduce the limitation imposed by lack of moisture. While this was not measured, a possible explanation could be that additional N might have induced greater early season vigor and root development. A well-developed root system could have a critical role during dry years to tap into more soil volume and access to water.

At Becker, averaged across N sources corn grain yield had a quadratic plateau response to N in the CC and CSb cropping system. In CC the EONR was 161 lb N/ac with grain yield plateau of 190 bu/ac, and in CSb the EONR was 73 lb N/ac with grain yield plateau of 193 bu/ac (Table 5, Fig. 5c,d). The blend treatments tended to have a lower EONR than the Agrotain treatment (Table 5). While this was a dry year and the potential for N loss was very low, we have observed in other studies that having controlled release N fertilizers in sandy soils is typically advantageous.

For CC in irrigated sands, the MRTN guideline is 210 lb N/ac with a range of 190 to 225 lb N/ac and for CSb 180 lb N/ac with a range of 160 to 195 lb N/ac. Both sites had EONRs lower than MRTN where the EONR was lower than the MRTN by 49 lb N/ac in CC and by 107 lb N/ac for CSb. These results highlight the fact that in more typical growing season, even when best management practices are followed, there is a high potential for N loss because of the combination of high water infiltration rates and low water and nutrient holding capacity of these soils.

Residual soil N

Residual soil N (0-36-inches soil depth) increase with N rates for all sites under corn except for Morris CSb (Fig. 6,7). There was not a clear pattern of differences in residual N in response to N sources, though in several sites the higher N rates containing the highest proportion of ESN sometimes showed more residual N. This may be the result of slow release of N during the growing season due to the dry conditions that could have limited N release from the polymer coated urea. Residual soil N tended to be greater under CC than CSb, especially at high rates. It was also clear that residual soil N at post-harvest was greater when N was applied above the EONR regardless of the site, though the response varied depending on different locations, likely due to soil type (Fig. 9).

Residual soil N was similar across N rate variables for the sites with soybean during the 2021 growing season. Since no N was applied directly to the soybean crop, this shows that any residual N that might have been present from the previous corn crop is not detectable after soybean. This could be because residual N after corn, that is typically greater at the higher N rates (as we observed in the CC and CSb sites this year), is fixed or immobilized in the soil, lost to the environment, or used by the soybean crop. The residual N levels were very low for Crookston (Fig. 8a) and closer to what is typical in Lamberton (Fig. 8b).

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 30-yr normal (1990-2019) and the 2019, 2020 and 2021 growing season at each experimental site.

Location	Year	April	May	June	July	Aug.	Sept.	Oct.	Apr.-Oct. cumulative
		——inch——							
Crookston	30-yr normal	1.20	2.44	4.01	3.33	2.81	2.61	2.10	18.5
	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
Morris	30-yr normal	2.26	3.00	4.02	3.66	3.10	2.38	1.86	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
Becker	30-yr normal	2.68	3.36	4.47	3.67	4.1	3.59	2.58	24.5
	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
		2.67	3.08	1.29	1.23	3.71	2.78	1.86	16.6
Lamberton	30-yr normal	2.78	3.55	4.15	3.73	3.2	3.22	2.15	22.8
	2019	5.91	4.80	2.35	6.86	2.22	6.02	4.00	32.2
	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
Rochester	30-yr normal	3.28	3.81	4.55	4.33	4.87	3.64	2.36	26.8
	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
Waseca	30-yr normal	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

Table 3. N rates and cropping systems [continuous corn (CC) or corn-soybean (CSb)] at each experimental site.

	Continuous corn systems					
	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	116	118 (QP)	238	114 (LP)	270	208 (Q)
2/3Urea – 1/3 ESN	70	115 (QP)	210	112 (LP)	280	210 (Q)
1/3 Urea – 2/3 ESN	58	113 (QP)	248	104 (LP)	278	209 (Q)
Average	82	115 (QP)	230	110 (LP)	280	210 (Q)

Table 4. N rates and cropping systems [continuous corn (CC) or corn-soybean (CSb)] at each experimental site.

	Corn-Soybean systems			
	Morris CSb		Rochester CSb	
N Treatments	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac
Urea	240	148 (L)	184	255 (QP)
2/3Urea – 1/3 ESN	217	151 (LP)	178	253 (QP)
1/3 Urea – 2/3 ESN	196	147 (QP)	183	253 (QP)
Average	240	149 (L)	182	253 (QP)

Table 5. N rates and cropping systems [continuous corn (CC) or corn-soybean (CSb)] at each experimental site.

	Irrigated systems			
	Becker CC		Becker CSb	
N Treatments	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac	**EONR** lb N/ac	**Yield$_{EONR}$** bu/ac
Agrotain	164	193 (QP)	98	196 (QP)
2/3Agrotain – 1/3 ESN	161	189 (QP)	70	196 (QP)
1/3 Agrotain – 2/3 ESN	159	189 (QP)	71	190 (QP)
Average	161	190(QP)	73	193 (QP)

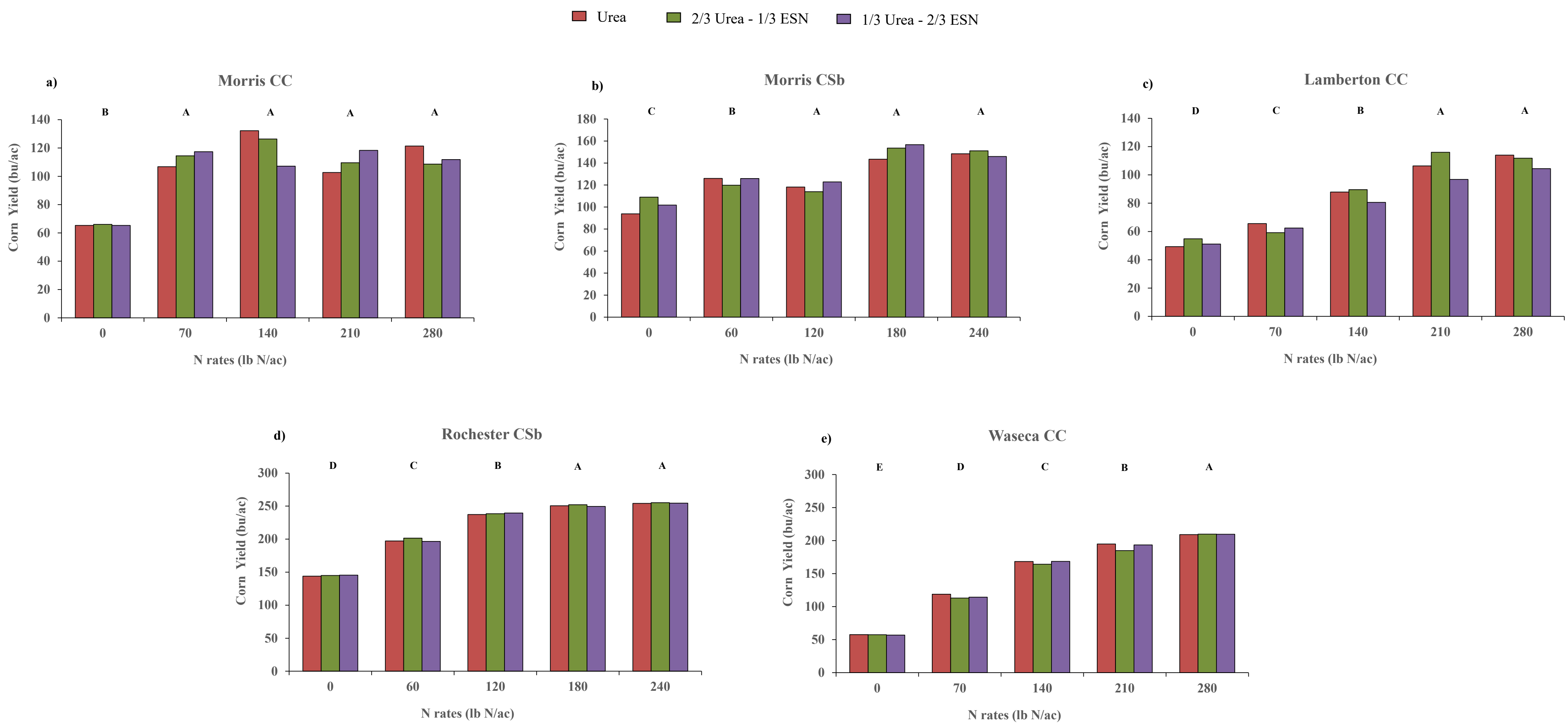

Figure 1. Corn grain yield in response to N sources 1) Urea; 2) 2/3Urea-1/3ESN; 3) 1/3Urea-2/3ESN for different N rates in continuous corn (CC) at Morris (a), Lamberton (c), Waseca (e) and Waseca(e), and corn after soybean (CSb) at Morris (b) and Rochester (d). Interaction NSource x Nrate was not significant. Letters indicate significant differences among N rates at P=0.05.

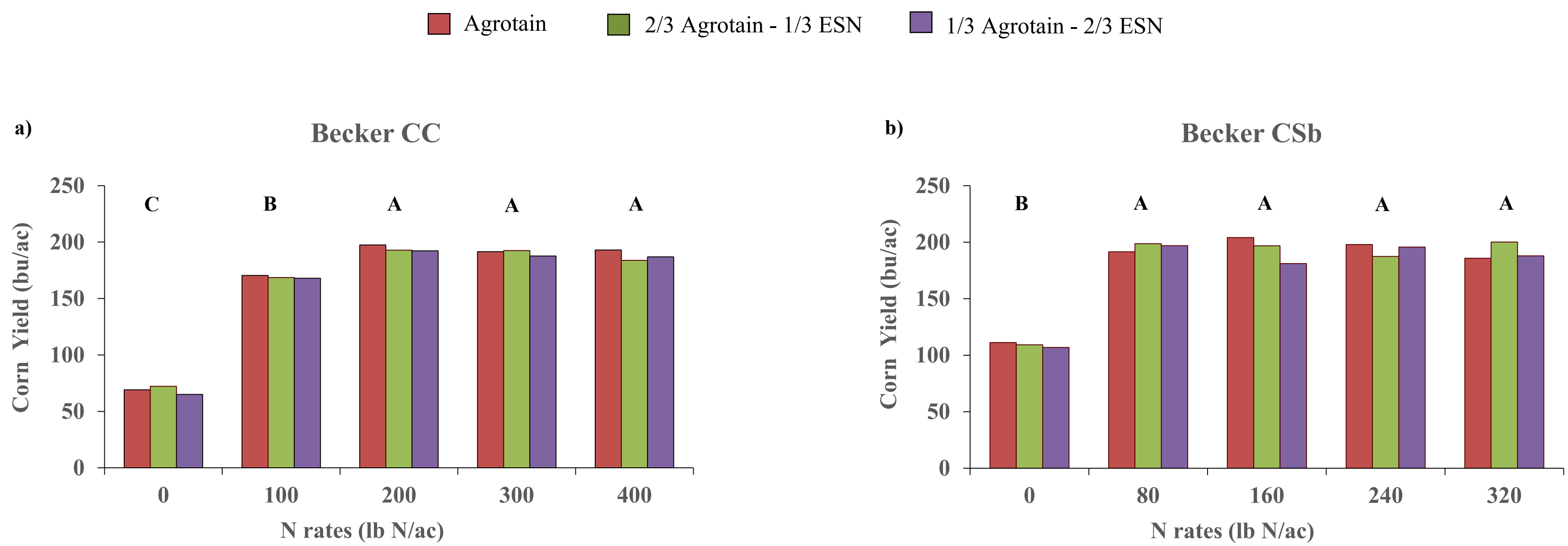

Figure 2. Corn grain yield in response to N sources 1) Agrotain; 2) 2/3Agrotain-1/3ESN; 3) 1/3Agrotain-2/3ESN for different N rates in continuous corn (CC) (a), and corn after soybean (CSb) (b) at Becker. Interaction NSource x Nrate was not significant. Letters indicate significant differences among N rates at P=0.05.

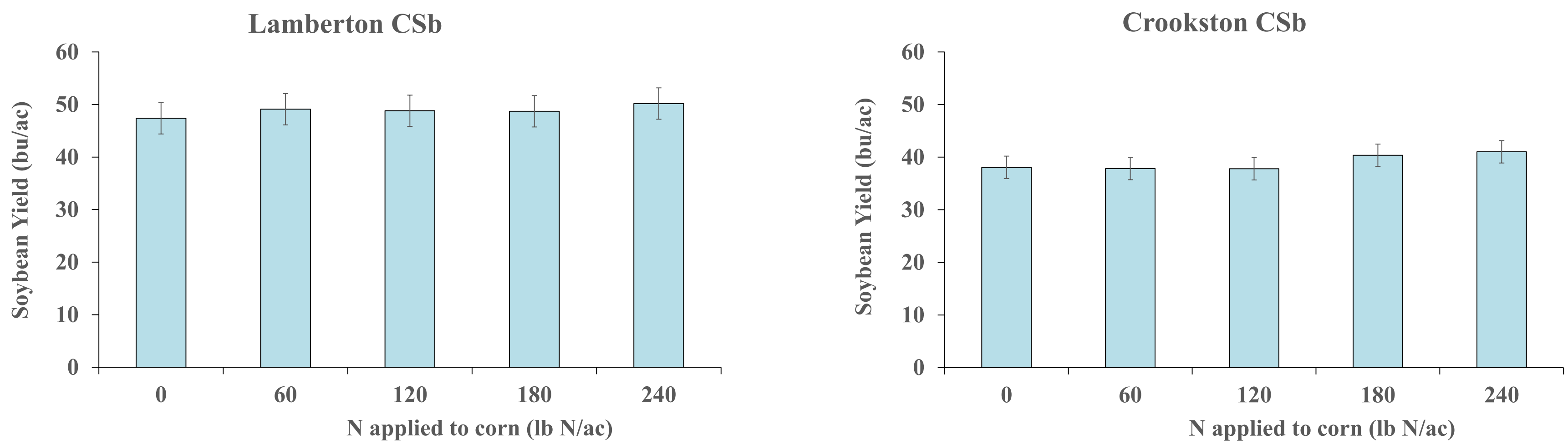

Figure 3. Soybean yield in response to residual N rates applied on the corn phase at Lamberton(a), and Crookston (b). Bars with same letters are not statistically different at P=0.05.

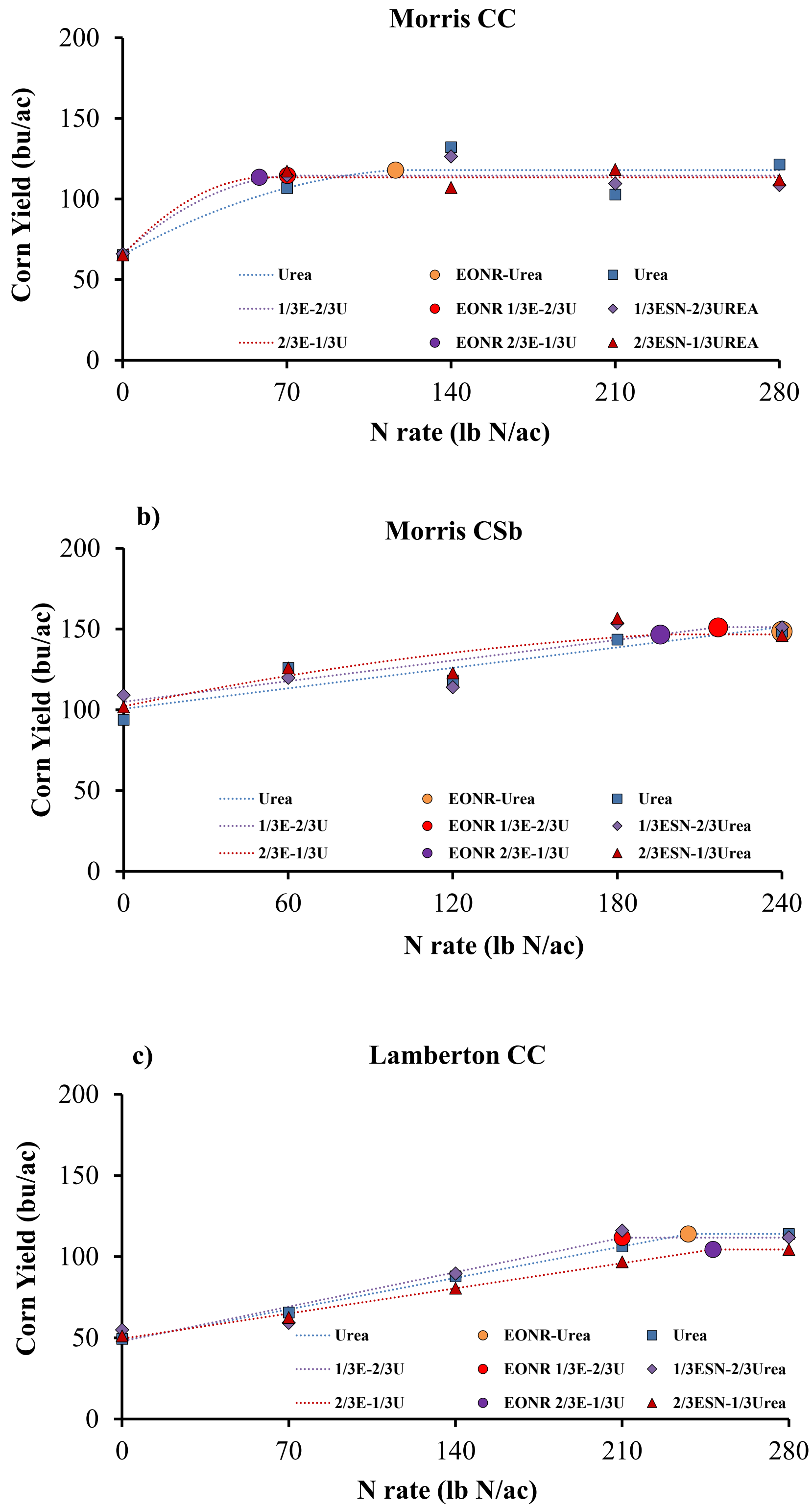

Figure 4. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) at Morris (a), Lamberton (c), and for corn after soybean (CSb) at Morris (b).

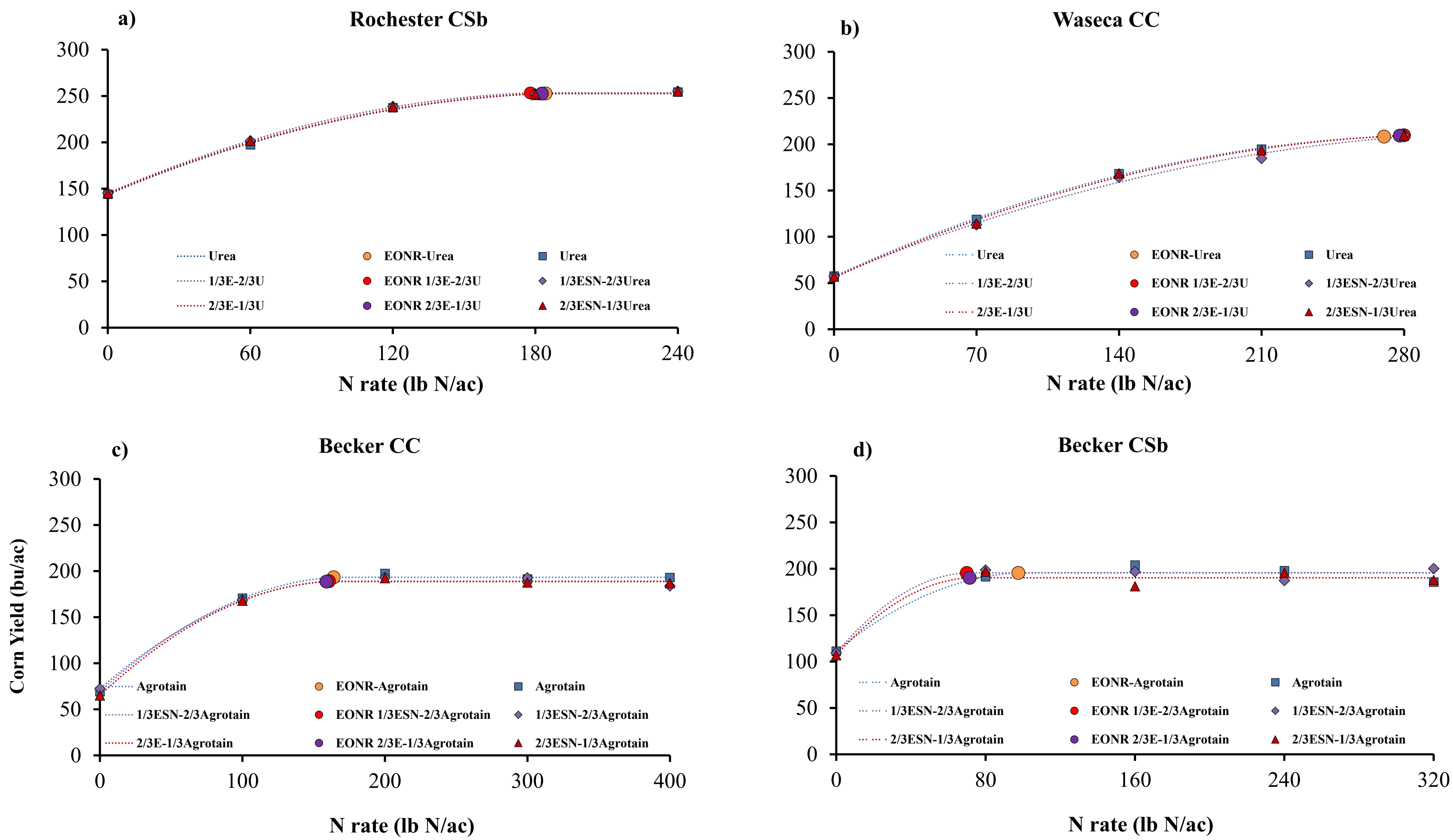

Figure 5. Corn grain yield response to N application and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for corn after soybean (CSb) at Rochester (a) and Becker (d), and continuous corn (CC) at Waseca (b), and Becker (c).

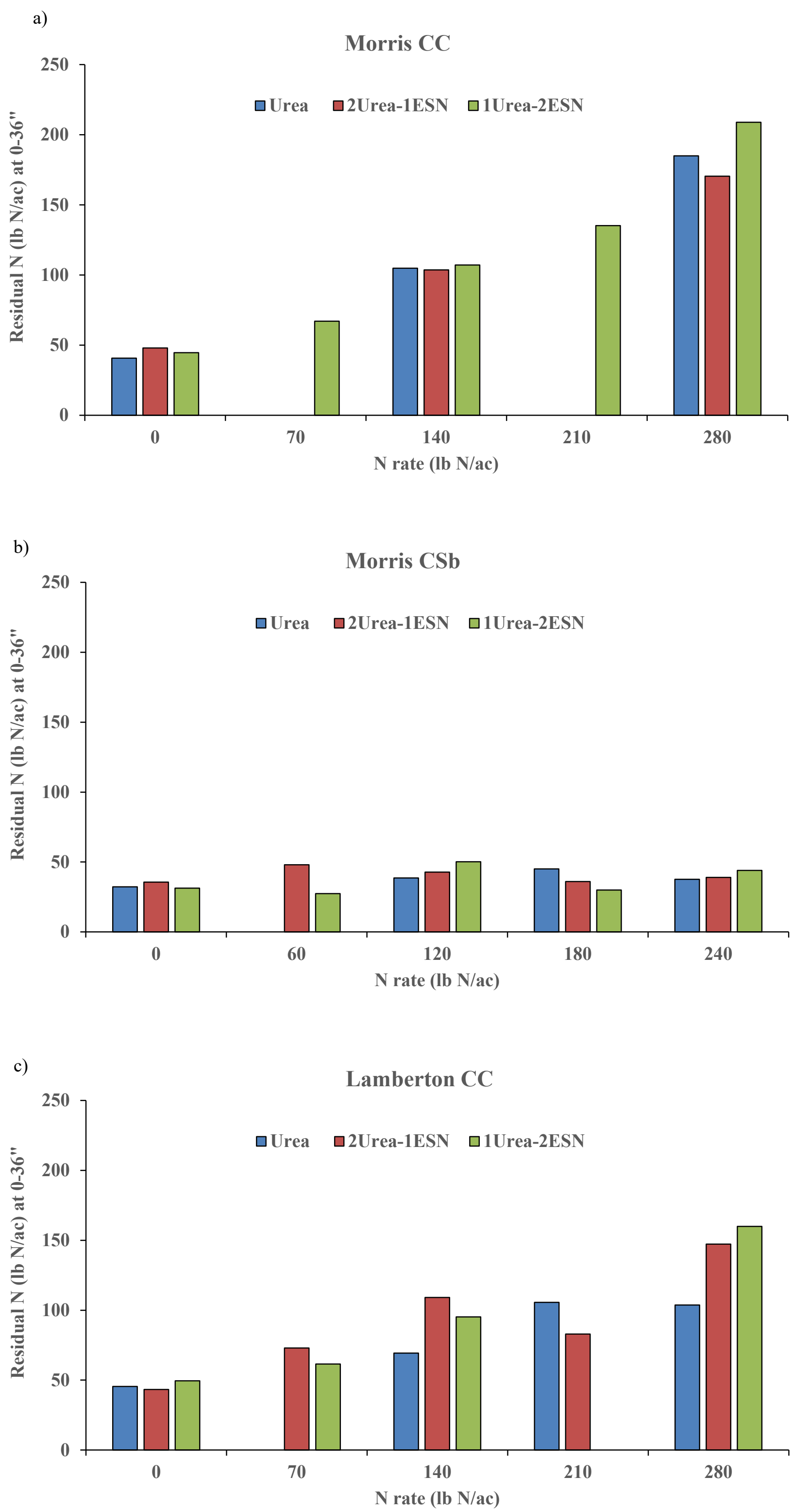

Figure 6. Residual soil N (lb N/ac) for continuous corn (CC) at Morris (a), Lamberton (c), and for corn after soybean (CSb) at Morris (b).

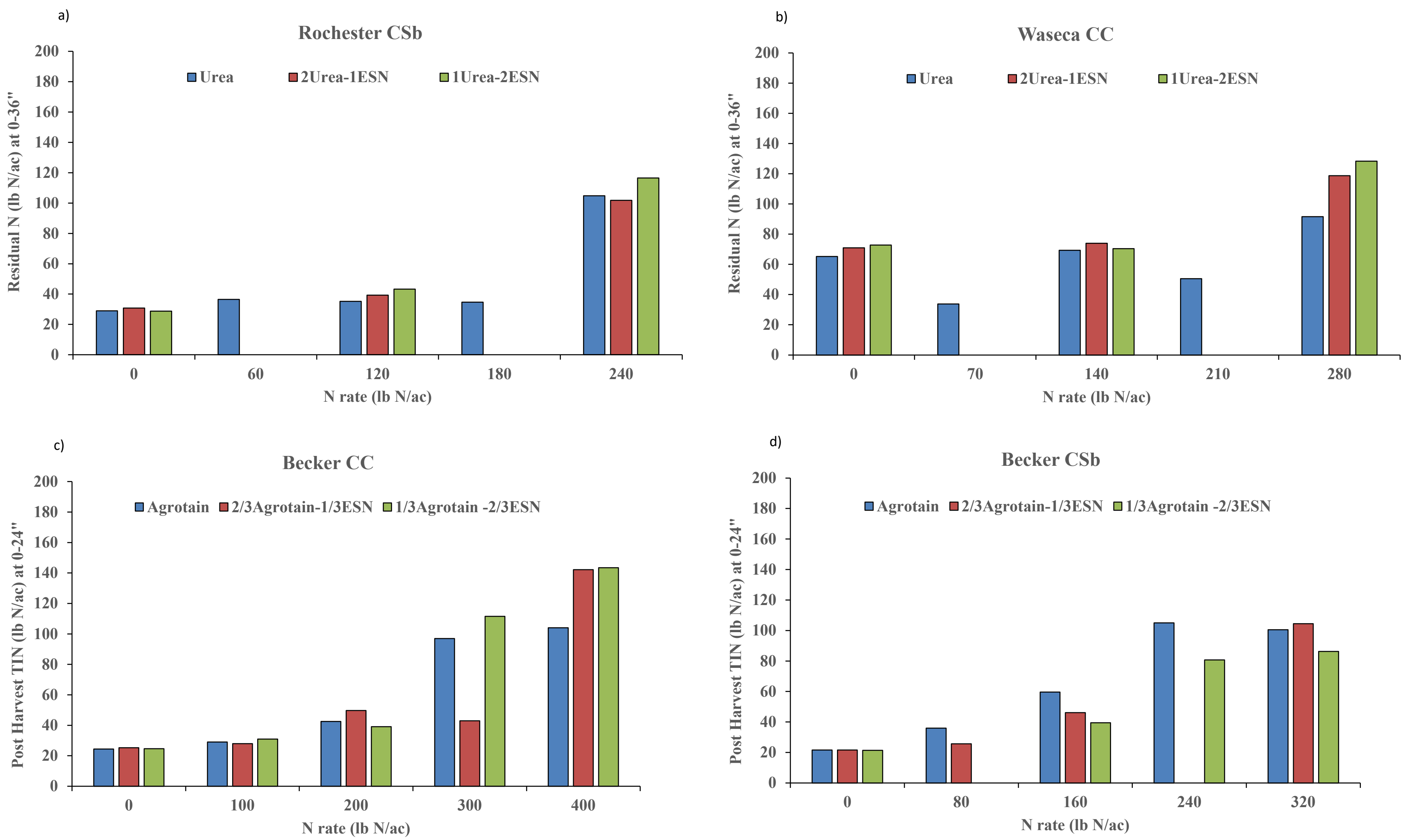

Figure 7. Residual soil N (lb N/ac) for corn after soybean (CSb) at Rochester (a) and Becker (d), and continuous corn (CC) at Waseca (b), and Becker (c).

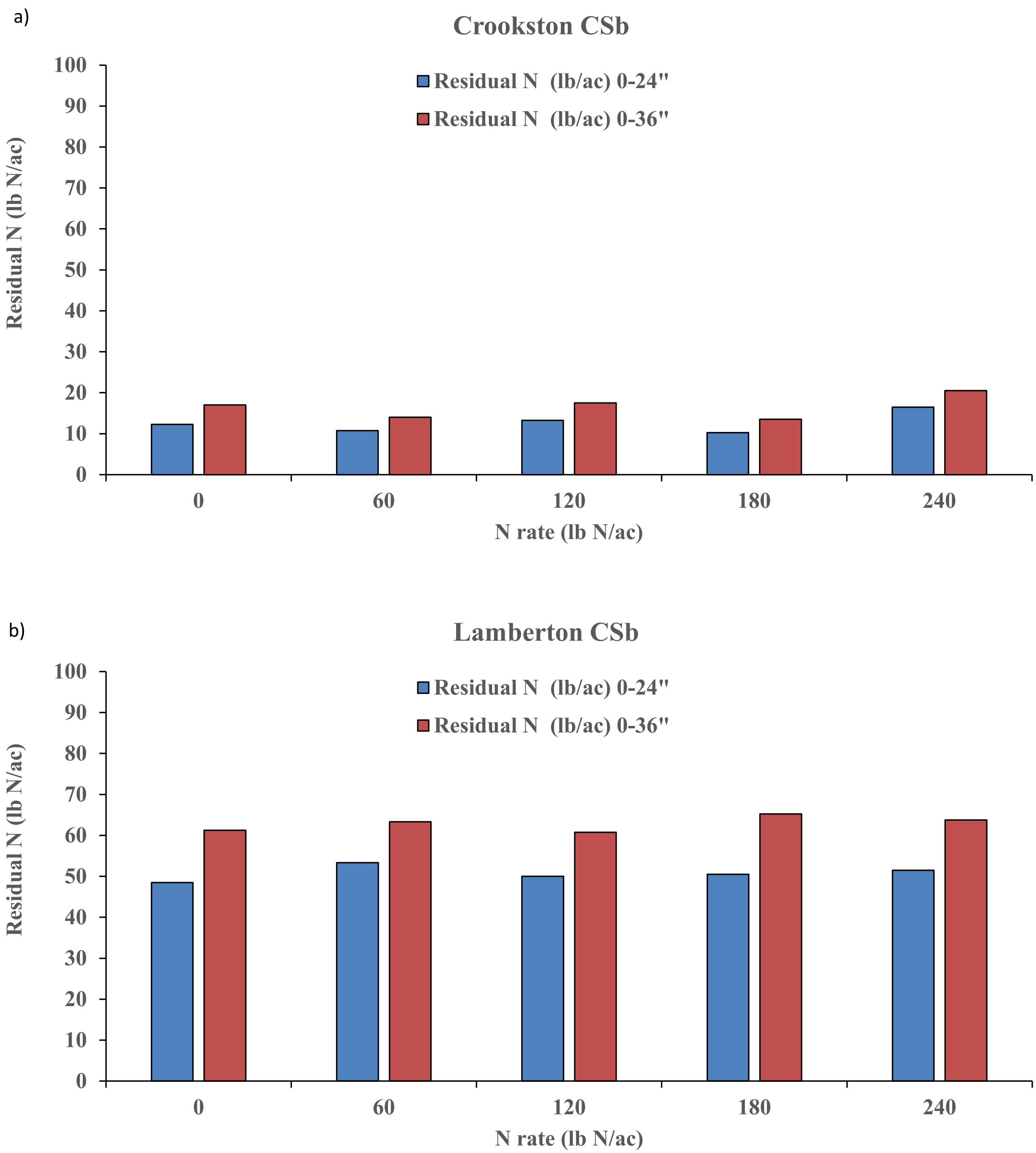

Figure 8. Residual soil N (lb N/ac) for those sites that were on soybean during the 2021 growing season, Crookston CSb (a), and Lamberton CSb (b). N rates were applied on the previous year for the corn phase of the rotation.

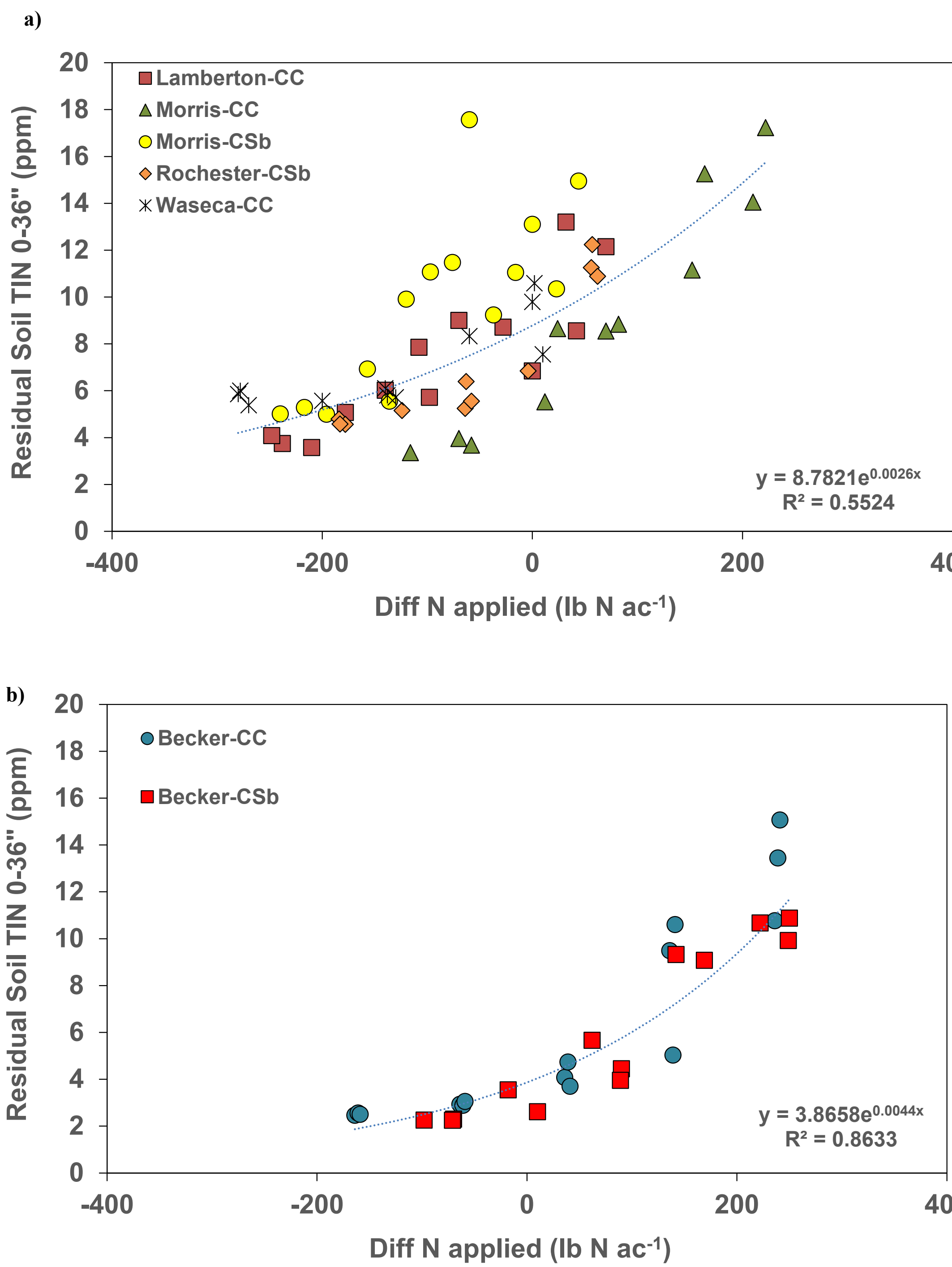

Figure 9. Post harvest residual soil Total Inorganic N (TIN) (ammonium-N plus nitrate-N) concentrations (ppm, mg N kg-soil^{-1}) in the 0-36 inch depth in relation to the difference between N rate and EONR (ΔN Applied, lb N ac^{-1}) where 0 equals the EONR for each site and cropping system for non-irrigated (a) and irrigated (b) soils.