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

2019 Report

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

BRIEF OVERVIEW

Nitrogen fertilizer is an essential input in modern corn production because corn is highly responsive to nitrogen. At the same time, nitrogen fertilizer can impact soil organic carbon stocks by influencing crop residue production and decomposition rates. These rates are extremely important as they affect the amount of nitrogen fertilizer that is needed to optimize crop production. Despite the fact that it is well known that nitrogen fertilization results in important changes in soil organic carbon and nitrogen cycling, the impact of long-term nitrogen and its effect on soil organic carbon quality and quantity as they relate to the fate of nitrogen fertilizer inputs and soil productivity (or soil health) is poorly understood. The parameters and functions mentioned above are not easily detectable in the short term. Establishment of long-term experiments allows researchers to investigate not only the effect of long-term nitrogen management on various properties, but also to evaluate how the resulting properties impact various agronomic practices (such as fertilizer recovery efficiency).

The objectives are to 1) establish long-term nitrogen management sites in five locations throughout Minnesota in continuous corn and a corn-soybean cropping system, 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 nitrogen fertilizer rates, the changes in soil physical, chemical, and biological characteristics, and 2) impose various nitrogen treatments on the gradient of soil conditions previously crated to evaluate how those resulting properties impact nitrogen management practices.

MATERIALS AND METHODS

Five long-term (10 to 15-year) sites were established 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), 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 a continuous corn (CC) and corn-soybean (CSb) cropping system were establish in 2019, except at Rochester and Crookston where only a corn-soybean rotation was established. In Crookston and Lamberton the CSb rotation was planted with soybean in 2019 whereas all others were planted with corn. In addition, in fall 2019 a site was secured at the Southern Research and Outreach Center (SROC) in Waseca for a continuous corn cropping system.

Each study consisted of five N rates that cover the range of corn grain yield response to nitrogen (below optimal, optimal, and above optimal); these N rates are reported in Table 1. Each rate was 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). For the 2019 growing season, each subplot received the same N rate.

A detailed intensive soil characterization sampling on the first and second year of the project consisted on measurement of physical, chemical, and biological properties. Some of the properties include: bulk density, penetration resistance, infiltration rate, aggregate stability, soil texture, electrical conductivity, cation exchange capacity, pH, macro- and micro-nutrient content, total organic carbon and nitrogen, total carbon and nitrogen, carbon and nitrogen mineralization potential, and soil microbial community structure by soil phospholipid fatty acid analysis (PLFA).

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 economic optimum N rate (EONR) was calculated at the 0.1 nitrogen 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 report, we present data from completed data sets. Some sampling protocols were partially done or samples were collected but not processed by the time of the report. This information will be reported during the next report.

RESULTS AND DISCUSSION

Overall, the 2019 growing season was wetter than normal with precipitation ranging from 4.6 to 13.3 inches above normal across the sites (Table 2). Crookston was near normal or drier than normal during April to July and above normal for August to October. In Morris, except for April that was near normal, every month was wetter than normal. Becker was wetter than normal in April and May (especially May with 3.4 inches above normal) and at the end of the season in September and October, whereas the summer months (June-August) were near normal. Lamberton was overall wetter than normal except for June and August that were drier than normal. Rochester had near normal precipitation in April and except for a dry August (2.6 inches below normal), the season was wetter than normal with monthly precipitation during May, July and September exceeding 3.5 inches above the normal every month.

Grain Yield data

At the Morris site for both cropping systems, grain yield and N removal had a significant response to N application (Fig. 1a, b). The average EONR was 152 and 202 lb N/ac with the grain yield plateau of 258 and 280 bu/ac for CC and CSb cropping system, respectively (Fig. 3 a, b).The EONR variability among the subplots ranged from 124 to 203 lb N/ac for CC, and 186 to 225 lb N/ac for CSb rotation (Fig. 4 a, b).

At the Becker site, both rotations had a quadratic response to N (Fig. 1 c, d), and grain N removal increased with N rates (Fig.1 c, d). The average EONR was 240 and 200 lb N/ac with grain yield plateau of 219 and 216 Bu/ac for CC and CSb cropping system, respectively (Fig. 3 c, d). The EONR variability among the subplots ranged from 203 to 258 lb N/ac for CC, and 158 to 226 lb N/ac for CSb rotation (Fig. 4 c, d).

Corn yield and grain N removal had a significant response to N at Lamberton under the CC cropping system (Fig. 1e). The average EONR was 134 lb N/ac with the grain yield plateau of 95 bu/ac (Fig. 3 e). The EONR variability among the subplots ranged from 120 to 148 lb N/ac (Fig. 5 a). For soybean, since this is the first year of the study there were no residual N rate treatments applied to the corn phase of the rotation. Soybean yields and N removal were similar across N rate treatments (Fig. 2a). They also showed low variability in grain yield among the subplots (Fig. 5 b).

Rochester site under CSb rotation also showed a significant effect of N rates on corn yield and grain N removal (Fig. 1 f). The response to N fitted a quadratic plateau and the average EONR was 165 lb N/ac with the grain yield plateau of 204 bu/ac (Fig. 3 f). The EONR variability among the subplots ranged from 156 to 181 lb N/ac (Fig. 5 c).

As for the CSb cropping system in Lamberton, in Crookston the soybean crop had no previous history of corn residual N rate treatments. Soybean yields and N removal were similar across N rate treatments (Fig. 2b) with low variability in the grain yield data (Fig. 5 d).

The current maximum return to nitrogen (MRTN) guidelines at a 0.1 nitrogen to corn price ratio for Minnesota suggest for non-irrigated corn following corn 165 lb N/ac with a range of 152 to 180 and for corn following soybean 130 lb N/ac with a range of 120to 145. For corn after corn in irrigated sands, the MRTN is 210 lb N/ac with a range of 190 to 225 and for corn after soybean it is 30 lb N/ac less than for corn after corn. In Becker CC had an EONR 30 lb N/ac above the guideline and CSb had an EONR 20 lb N/ac above the guideline. For both cropping systems, some of the subplot EONRs fell within the MRTN range. For the non-irrigated fine textured sites in the study in CC the EONRs were 13 lb N/ac and 31 lb N/ac below the MRTN for Morris and Lamberton, respectively. The range of EONRs for Lamberton (120-148 lb N/ac) also fell below the MRTN range 152-180 lb N/ac). The grain yields in Lamberton were extremely low as well. The yield at the EONR was 95 bu/ac. The low yield at this location is likely the result of planting under suboptimal conditions. The crop was planted in very wet soil and compaction or seedling establishment might be responsible for the poor crop performance. Unlike the CC locations, for CSb the EONRs were 72 lb N/ac and 35 lb N/ac above the MRTN for Morris and Rochester, respectively. Likewise, the range of EONRs was above the MRTN range for the CSb cropping system in Morris and Rochester. The within field variability was greater for the sandy sites at Becker where the difference between the highest and lowest EONR in CC was 55 lb N/ac and in CSb was 68 lb N/ac. At the other sites, the differences range from 21 to 39 lb N/ac. Except for Lamberton CC, the yields at the EONR were competitive, ranging across the sites and cropping systems from 204 to 280 bu/ac.

Post-Harvest soil N

At the Morris sites, total inorganic N follows the pattern of NO_3^--N since similar amount of NH_4^+-N were observed among N rates (Table 3). Total inorganic N (TIN) significantly increased with N rates at 0-24- and 0-36-inch soil depth for CC rotation (Table 3). For CSb rotation, total inorganic N was similar between 0 and 120 N rate but significantly increased with the 240 N rate at both depths (Table 3).

At the Becker sites, TIN amounts were lower compared to other sites at the 0-24 inch depth, and were similar among the 0 and 160 N rate in CSb and the 0 and 200 N rate in CC (Table 3). For both cropping systems, residual N increases substantially with the highest N rate.

At Lamberton for CC, similar to Morris, total inorganic N follows the pattern of NO_3^--N because NH_4^+-N levels were similar among N rates (Table 4). Total inorganic N significantly increased with N rates at 0-24- and 0-36-inch soil depth for the CC cropping system (Table 4). In the CSb site, since no differential amount of N had been applied, there were no differences due to treatment (Table 4).

At the Rochester site, total inorganic N was similar between 0 and 120 N rate but significantly greater for the 240 N rate at both depths (Table 4).

Consistently across all sites, the soil data clearly showed that N applications above the EONR result in increased residual inorganic N in the soil. At the same time, rates close to the EONR do not differ substantially in the amount of residual N compared to suboptimal N rates. Ammonium constituted a large portion of the TIN in our study. Across all sites and cropping rotations, NH_4^+-N represented 65% of TIN in the top 36 inch depth of the soil. While we did not measure soil N in season, based on data from other Minnesota studies, the amount of TIN in the soil during the later stages of development of the crop are often very low regardless of N rate. A large portion of the residual N is mineralized after the crop reaches physiological maturity. While some of that N was nitrified, a substantial amount remained in the ammonium form at the time of sampling in late fall.

In the top 24-inch depth, coarse-textured soils had 1.8 times less NO_3^--N, 3.0 times less NH_4^+-N and 2.1 times less TIN than fine-textured soils. This indicates that the coarse texture soils have very little capacity to retain nitrogen. In addition, because of the low organic matter content of these coarse-textured soils, there is little amount of mineralization that takes place between the time the crop reaches physiological maturity and post-harvest soil sampling.

The Lamberton site allows us to look at residual soil N differences due to cropping system. The soil after a soybean crop had more residual N than any of the soils after a corn crop, even at the highest N rate applied to the corn crop. The fact that there is more TIN present after soybean and the potential for immobilization with soybean residue is lower than with corn residue, may lead to greater potential for N loss after soybean than after corn. Even when corn was over-fertilized the amounts of residual N were similar to the unfertilized soybean field.

Table 1. N rates (lb N/ac) at each experimental site.

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

Table 2. Mean monthly cumulative precipitation for the 30-yr normal (1990-2019) and the 2019 growing season at each experimental site.

		Precipitation (inches)							
Location	**Year**	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Apr.-Oct. cumulative**
Crookston	30-yr normal	1.14	3.04	3.81	3.14	2.89	2.89	1.89	18.8
	2019	1.56	1.38	1.39	3.32	4.72	6.92	4.15	23.4
Morris	30-yr normal	2.27	3.00	4.00	3.66	3.05	2.32	1.84	20.1
	2019	2.23	4.06	5.47	4.54	5.53	6.64	3.02	31.5
Becker	30-yr normal	2.69	3.36	4.50	3.68	4.09	3.61	2.60	24.5
	2019	3.68	6.74	3.96	4.40	3.69	5.16	4.61	32.2
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
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

Table 5. Soil inorganic N as nitrate (NO_3^--N), ammonium (NH_4^+-N), total inorganic N (TIN) in lb/ac at 0-24- and 0-36-inches soil depth

		N-NO_3^- 0-24”	N-NH_4^+ 0-24”	TIN 0-24”	N-NO_3^- 0-36”	N-NH_4^+ 0-36”	TIN 0-36”
			…………………lb/ac……………………				
Morris- CC	0	14.7 c	42.3	57.0 c	19.2 c	55.1	74.3 c
	70	22.0	42.0	64.0	30.5	61.0	91.5
	140	22.8 b	44.5	67.2 b	29.8 b	58.8	88.6 b
	210	33.0	48.5	81.5	49.5	65.8	115.3
	280	38.3 a	43.8	82.1 a	58.3 a	58.6	117.0 a
Morris- CSb	0	136 b	48.0	61.6 b	16.7 b	64.1	80.8 b
	60	16.5	41.8	58.3	21.5	56.0	77.5
	120	16.8 b	47.0	63.9 b	21.8 b	65.8	87.5 b
	180	36.5	45.8	82.3	46.5	60.8	107.3
	240	33.8 a	48.1	81.9 a	46.9 a	65.9	112.8 a
Becker- CC	0	10.3 b	16.6 a	27.0 b	-	-	-
	100	10.5	16.5	27.0	-	-	-
	200	13.1 b	12.8 b	25.9 b	-	-	-
	300	25.5	18.5	44.0	-	-	-
	400	26.1 a	13.6b	39.7 a	-	-	-
Becker- CSb	0	10.8 b	11.6	22.4 b	-	-	-
	80	12.5	14.8	27.3	-	-	-
	160	14.1 b	11.7	25.8 b	-	-	-
	240	7.6	16.5	33.5	-	-	-
	320	22.0 a	11.8	33.8 a	-	-	-

Within a column and location/cropping system, different letters indicate significant differences among N rates (0, 120/140, 240/280) at $P < 0.01$. Only highlighted treatments were analyzed statistically because samples were collected from all subplots and replications. The other treatments had only a few samples collected randomly across all subplots.

Table 6. Soil inorganic N as nitrate (NO_3^--N), ammonium (NH_4^+-N), total inorganic N (TIN) in lb/ac at 0-24- and 0-36-inches soil depth

		N-NO_3^- 0-24″	N-NH_4^+ 0-24″	TIN 0-24″	N-NO_3^- 0-36″	N-NH_4^+ 0-36″	TIN 0-36″
		…………………lb/ac……………………					
Lamberton- CC	0	9.8 c	39.9	49.7 c	18.3 c	52.1	70.5 c
	70	12.5	43.0	55.5	22.5	55.0	77.5
	140	15.6 b	42.3	57.8 b	27.8 b	54.8	82.7 b
	210	20.0	48.5	68.5	34.5	61.3	95.8
	280	28.8 a	41.6	70.4 a	46.5 a	53.3	99.8 a
Lamberton- CSb	0	18.5	57	75.5	29.0	72.5	101.5
	60	20.5	56.8	77.3	30.0	70.8	100.8
	120	18	58.8	76.8	30.5	74.5	105.0
	180	16.5	59.3	75.8	28.5	75.5	104.0
	240	17.5	58.5	76.0	29.0	74.5	103.5
Rochester- CSb	0	17.2 b	27.3 a	44.5 b	20.8 b	42.3 a	63 b
	60	25.0	23.8	48.8	30.5	39.8	70.3
	120	17.8 b	26.3 a	44.1 b	21.8 b	41.3 a	63.2 b
	180	25.5	25.0	50.5	32.0	42.5	74.5
	240	36.6 a	23.0 b	59.6 a	56.6 a	36.3 b	92.8 a

Within a column and location/cropping system, different letters indicate significant differences among N rates (0, 120/160/200, 240/320/400) at $P < 0.01$. Only highlighted treatments were analyzed statistically because samples were collected from all subplots and replications. The other treatments had only a few samples collected randomly across all subplots.

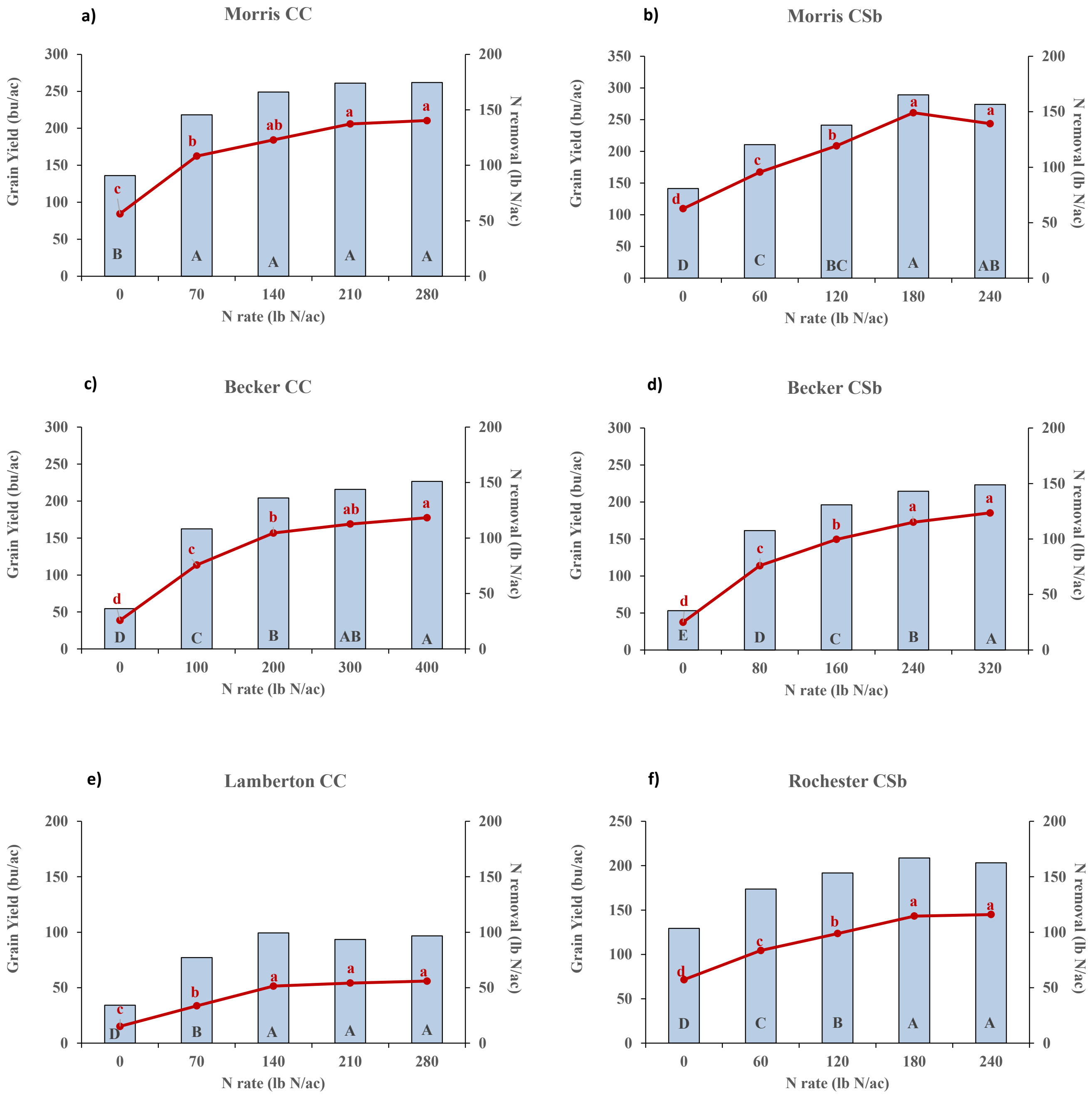


Figure 1. Corn grain yield (bu/ac) and N removal (lb N/ac) for the different N rates in the corn-corn (CC) and corn-soybean (CSb) cropping systems at Morris and Becker site, CC at Lamberton site and CSb at Rochester site.

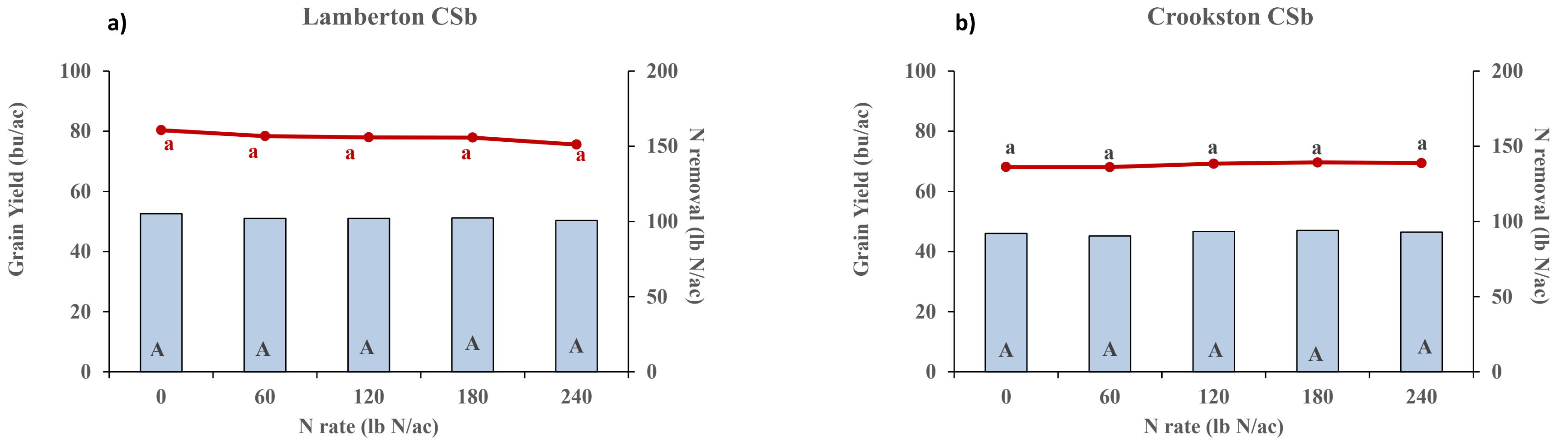


Figure 2. Soybean yield (bu/ac) and N removal (lb N/ac) for the different N rates at Lamberton site under corn-soybean (CSb) rotation at Lamberton and Crookston site.

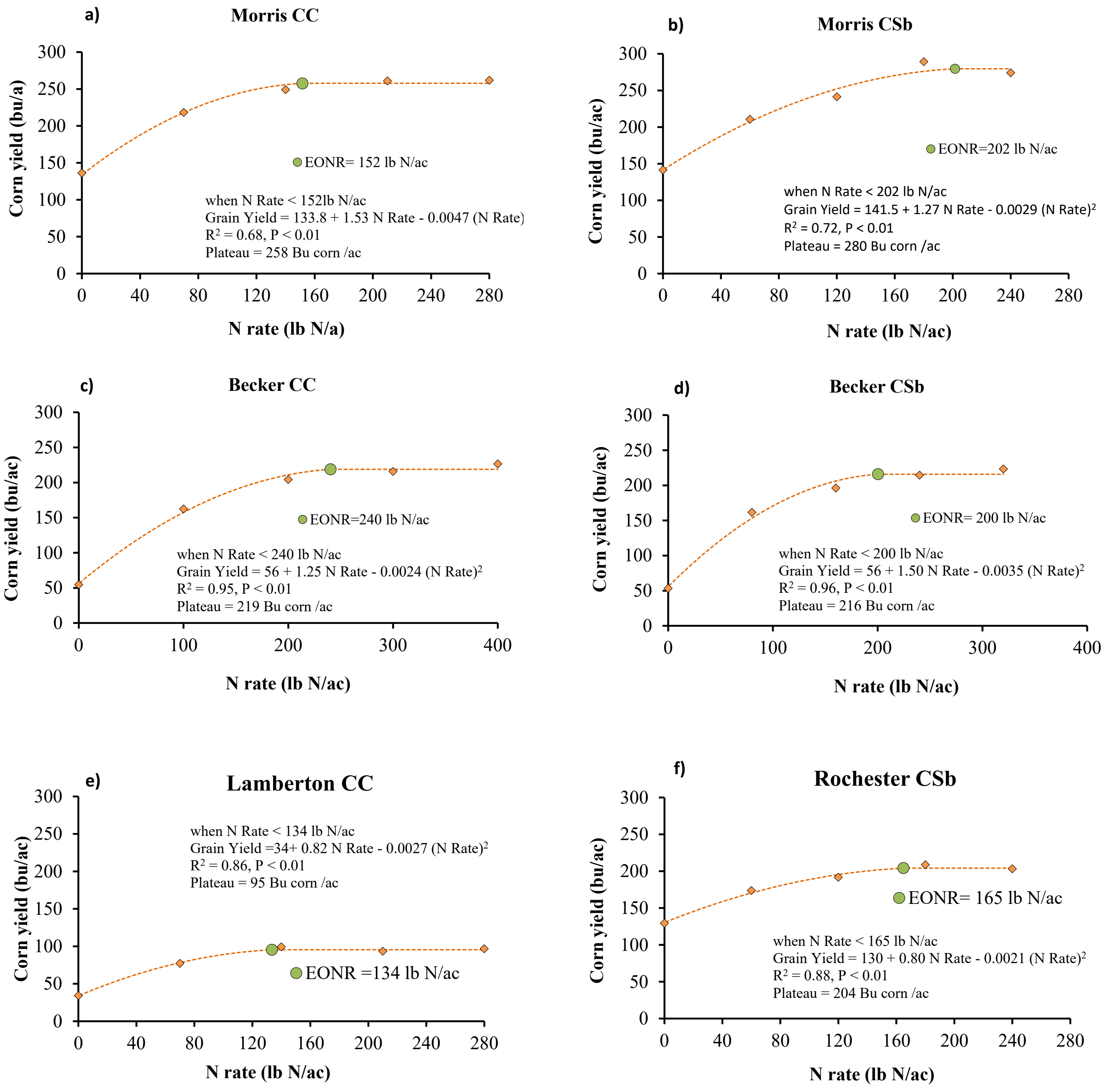


Figure 3. Corn grain yield response to N application at different sites averaged across all subplots and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 nitrogen to corn price ratio.

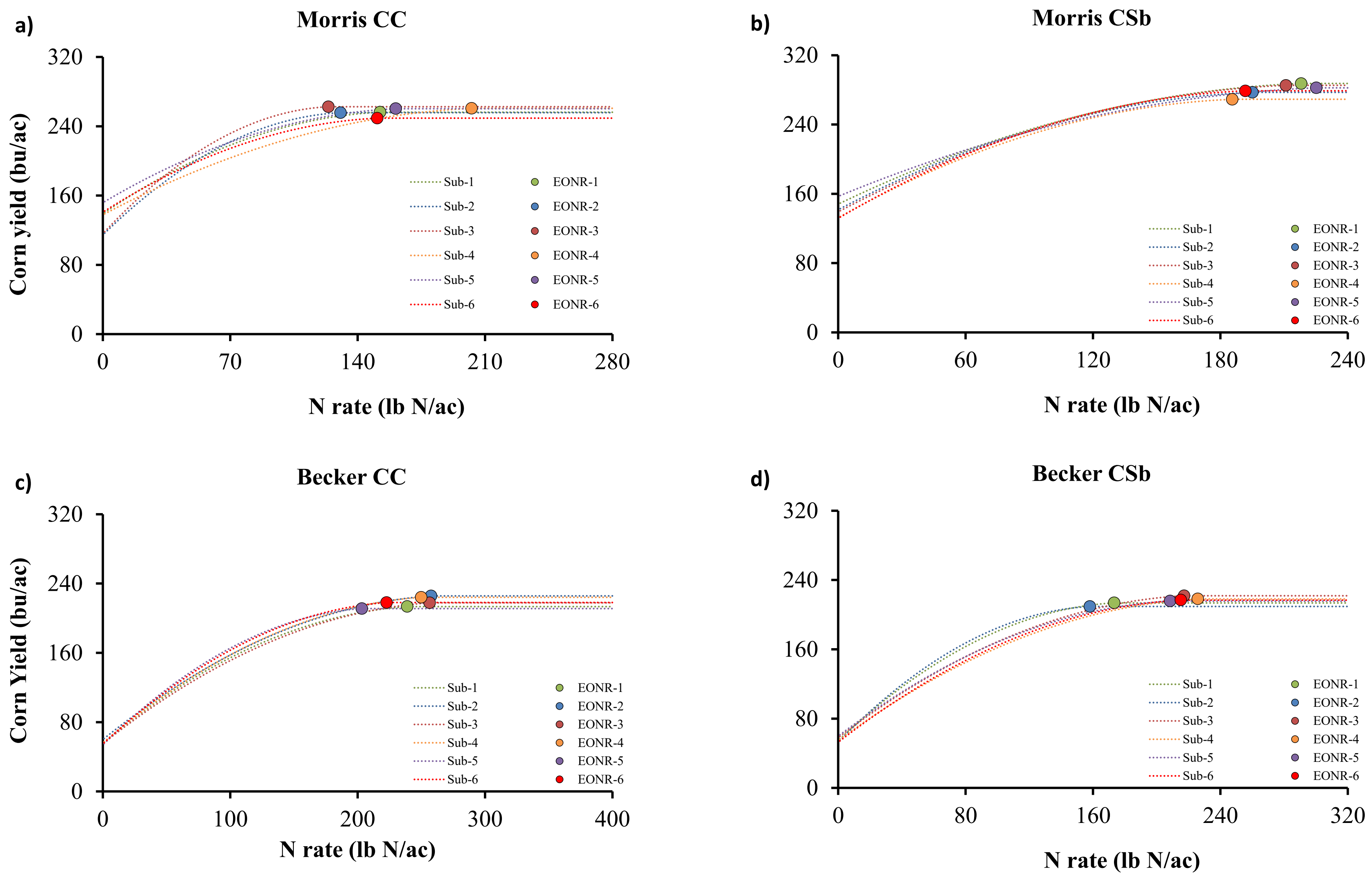
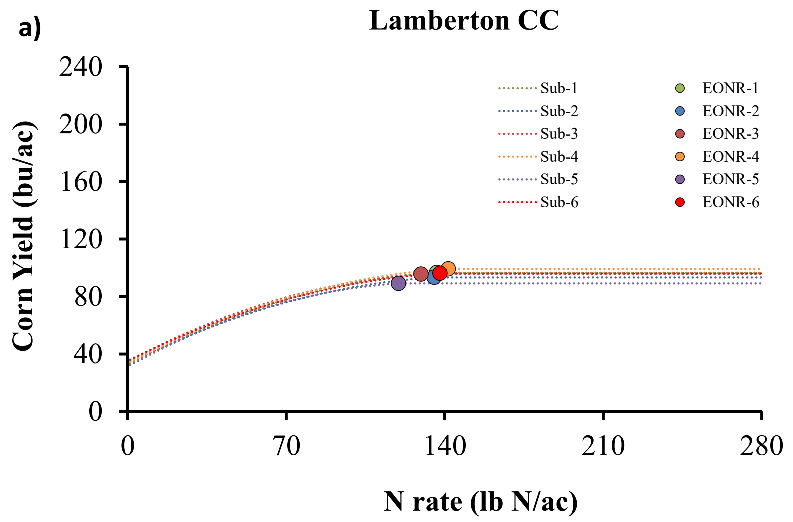
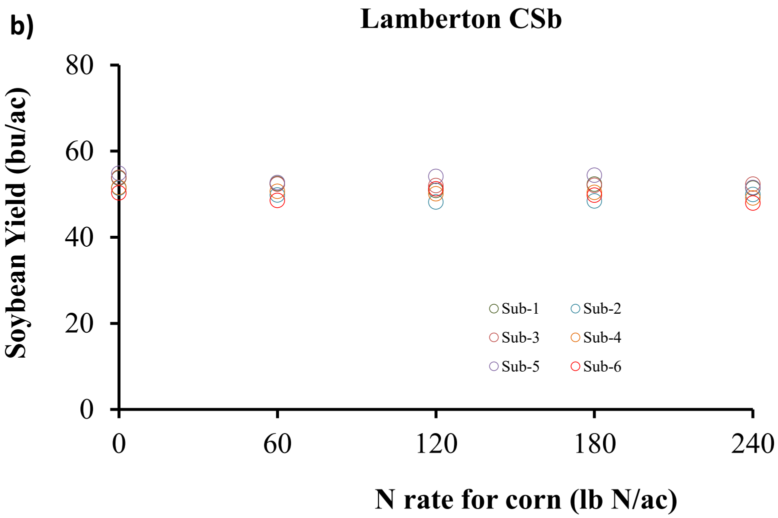
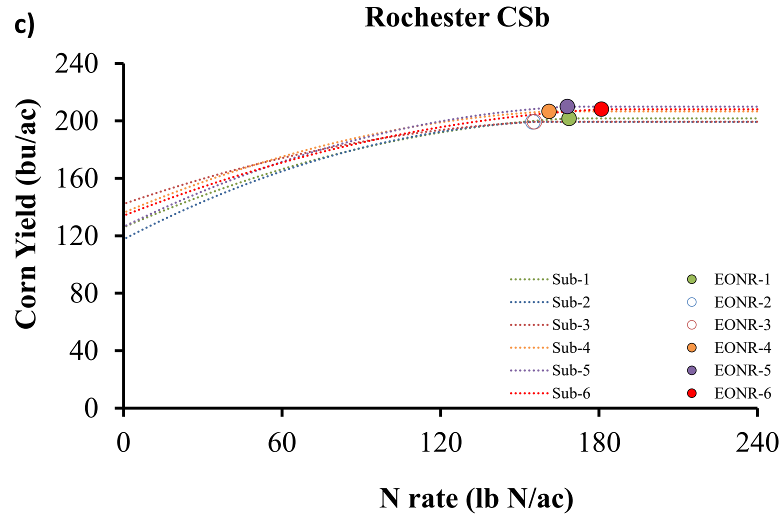


Figure 4. Corn grain yield and economic optimum N rate (EONR) variability at Morris and Becker site under corn-corn (CC) and corn-soybean (CSb) rotation. Each EONR was calculated for each sub-plot with four replications using a 0.1 nitrogen to corn price ratio.


a)
Lamberton CC
Corn Yield (bu/ac)
240
200
160
120
80
40
0
0
70
140
210
280
N rate (lb N/ac)
Sub-1
Sub-2
Sub-3
Sub-4
Sub-5
Sub-6
EONR-1
EONR-2
EONR-3
EONR-4
EONR-5
EONR-6


b)
Lamberton CSb
Soybean Yield (bu/ac)
80
60
40
20
0
0
60
120
180
240
N rate for corn (lb N/ac)
Sub-1
Sub-2
Sub-3
Sub-4
Sub-5
Sub-6


c)
Rochester CSb
Corn Yield (bu/ac)
240
200
160
120
80
40
0
0
60
120
180
240
N rate (lb N/ac)
Sub-1
Sub-2
Sub-3
Sub-4
Sub-5
Sub-6
EONR-1
EONR-2
EONR-3
EONR-4
EONR-5
EONR-6

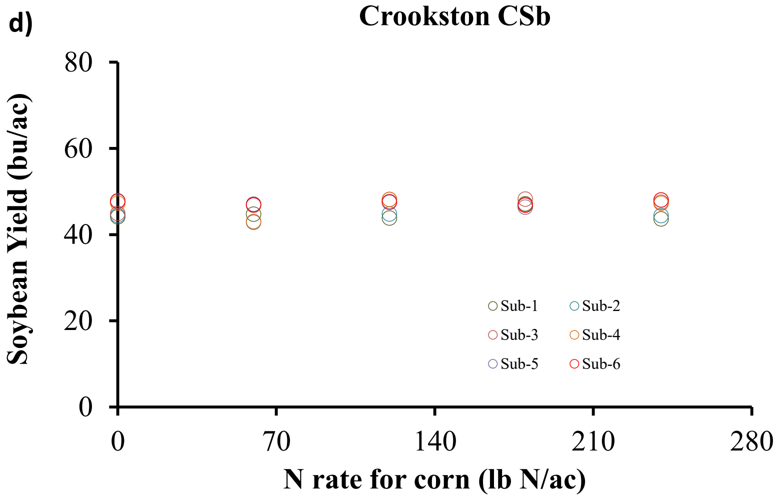

d)
Crookston CSb
Soybean Yield (bu/ac)
80
60
40
20
0
0
70
140
210
280
N rate for corn (lb N/ac)
Sub-1
Sub-2
Sub-3
Sub-4
Sub-5
Sub-6

Figure 5. Corn grain yield and economic optimum N rate (EONR) variability at Lamberton continuous corn (CC) and Rochester corn-soybean (CSb) rotation; and soybean yield variability at Lamberton and Crookston under corn-soybean (CSb) rotation. Each EONR was calculated for each sub-plot with four replications using a 0.1 nitrogen to corn price ratio.