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

2020 Final 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 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.

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).

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 for the 2019 and 2020 growing seasons, each subplot received N as urea (46-0-0) 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.

A detailed intensive soil characterization sampling on the first and second year of the project consisted of 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 C and N, total C and N, C and N 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 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 data for the 2020 growing season, and a summary of all properties measured throughout the growing season. Grain N and post-harvest soil samples are being processed and will be send to the Laboratories for further analysis.

RESULTS AND DISCUSSION

Overall, the 2020 growing season was near the 30-yr normal or drier than normal with precipitation ranging from 1.98 to 6.14 inches below normal, and 0.4 to 0.6 inches above normal across the sites (Table 2). Crookston was near drier than normal during May, September, and October, and above normal for April, June, July, and August. In Morris, except for July that was near normal, and June that was wetter than normal, the other months were drier than normal. Becker was wetter than normal in July and August, and at the other months were drier than normal. Lamberton was wetter than normal in June, July, and August, but April, May, September, and October were drier than normal. Rochester had near normal precipitation in September, wetter than normal in May and June, and drier than normal in April, July, August, and October. Waseca had wetter than normal from April to August, and drier than normal in April, September, and October.

Grain Yield data

There was a positive response to N application for both CC and CSb cropping systems at all locations (Fig. 1). Except for Crookston and Morris CC where the yields were substantially lower, all the other locations had yield levels that are typically expected. At all locations the soybean crop showed no difference in yield in response to residual N rates applied during the corn phase of the rotation (Fig. 2) and there was low variability in grain yield among the subplots with the greatest range in Morris (Fig. 5).

At Becker, corn grain yield had a quadratic plateau response to N in the CC cropping system where the EONR was 306 lb N/ac with grain yield plateau of 209 bu/ac (Fig. 3a). The EONR variability among the subplots ranged from 288 to 329 lb N/ac and the grain yield plateau between 199 to 212 bu/ac (Fig. 4a). Soybean showed low variability in grain yield among the subplots in response to residual N (Fig. 5a).

At Morris, corn grain yield had a quadratic plateau response to N where the EONR was 170 lb N/ac with a grain yield plateau of 143 bu/ac (Fig. 3b). The EONR variability among the subplots ranged from 139 to 188 lb N/ac and the grain yield plateau between 139 and 146 bu/ac (Fig. 4b). Soybean showed low variability in grain yield among the subplots (Fig. 5 b).

At Lamberton, corn grain yield had a lineal response to N in CC and a quadratic plateau response in the CSb cropping system (Fig. 3c, d). Since there was a linear response for the CC cropping system, the EONR was established at the maximum N rate of 280 lb N/ac with a grain yield of 178 bu/ac (Fig. 3c). The EONR was 176 lb N/ac with a grain yield plateau of 192 bu/ac for the CSb cropping system (Fig. 3d). The EONR variability among the subplots ranged from 210 to 280 lb N/ac and the grain yield plateau between 179 and 200 bu/ac for CC (Fig. 4c). The EONR variability among the subplots ranged from 163 to 189 lb N/ac and the grain yield plateau between 195 and 203 bu/ac for CSb (Fig. 4d).

At Waseca, corn grain yield had a quadratic plateau response to N where the EONR was 279 lb N/ac with a grain yield plateau of 221 bu/ac (Fig. 3e). However, the calculated EONR was near the maximum N rate, indicating that N loss was likely high. The EONR variability among the subplots ranged from 266 to 280 lb N/ac and the grain yield plateau between 215 and 225bu/ac (Fig. 4e). The fact that the individual sub-plot EONRs were also near the highest N rate indicates that N loss was consistent for the entire study site.

At Crookston, corn grain yield had a quadratic plateau response where the EONR was 154 lb N/ac with a grain yield plateau of 83 bu/ac (Fig. 3f). The yield was very low due to poor planting conditions in wet soils and flooding. In fact, for the the EONR calculations some of the subplots were not used because of the very poor crop stand obtained. The EONR variability among the subplots ranged from 120 to 182 lb N/ac and the grain yield plateau between 76 and 88 bu/ac (Fig. 4f).

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 CC in irrigated sands, the MRTN 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.

In Becker CC had an EONR 116 lb N/ac above the guideline, and the subplot EONRs were greater than the MRTN range.

For the non-irrigated fine textured sites in the study in CC the EONRs were 5 lb N/ac and 114 lb N/ac above the MRTN for Morris and Waseca, respectively. Lamberton CC had a lineal response indicating that there was still response to N at the maximum N rate (280 lb N/ac). For CSb cropping systems, the EONRs were 45 lb N/ac and 10 lb N/ac above the MRTN for Lamberton and Crookston sites, respectively. The within field variability was greater for Lamberton CC, Crookston CSb and Morris CC, where the difference between the highest and lowest EONR was 70 lb N/ac, 62 lb N/ac and 49 lb N/ac, respectively. At the other sites, the differences range from 14 to 41 lb N/ac.

Initial Soil measurements

A summary of all initial soil measurements taken at each experimental site is presented in Table 3. Samples will be process over time as funding allows, and results will be presented in future reports. Most of these baseline measurements are not important by themselves at this stage, but will be critically important to compare with new samples collected midway and at the end of the project to evaluate the changes associated with long-term N management.

Biological properties

Soil sampling to determine the initial biological properties were taken at all the locations during 2019 and 2020 growing seasons. Four samples were taken at random from each block and composited into a sample. Total of 12 samples for each cropping system site were taken at 0-2", 2-6", and 18-20" and stored in -80ºC for further analysis to measure total organic matter (TOM), particulate organic matter (POM), aggregate separation C and N, biomass N, Mineralizable N and C.

Chemical properties

Soil sampling to characterize chemical properties at all experimental sites were collected during the 2019 and 2020 growing seasons. Four samples were taken at random from each block and composited into a sample. A total of 12 samples for each cropping system site were taken at 0-6", 6-12", 12-24", and 24-36" and stored for further analysis to measure P, K, Ca, Mg, pH, EC, CEC, S, Micronutrients, TN, TIN, (NH_4 and NO_3), TON, PMN, TC, TIC, TOC, Solvita (Mineralizable C), Permangenate Oxidizable C (POXC or active C), and POC.

Apparent soil EC has not been taken at any experiments, but will be taken during the 2021 growing season.

Physical properties

Taxonomic characterization of each experimental site was also performed during the 2019 and 2020 growing season by horizon to a 36" depth. Soil samples were stored for texture, pH, EC, CEC, TC, TOC, TIC, and OM analysis.

Bulk density and aggregate stability measurements were taken also during both growing season at all the experimental sites at 0-6, 6-12, 12-24, and 24-36 inches.

Infiltration and Penetrometer/Soil moisture measurements were taken at Rochester, Waseca, Crookston, and Becker sites during 2019 or 2020 growing season. Penetrometer measurements need to be conducted at Becker CSb, Morris, and Lamberton during the 2021 growing season.

PLANS FOR THE 2021 SEASON

For two years we maintain the same rate and N source across all 6 10'x60' sub-plots and 4 replications in order to evaluate EONR variability within each field. Starting in 2021, we will subdivide the 6 sub-plots into three 20'x60' sub-plots that will receive different N sources or time of applications. To stay true to the main goal of the project the total N rate applied to each subplot will continue to be the same as in previous years. Adding these variables will increase the utility of the study as we continue to develop the long-term effects of different N rates. In the non-irrigated sites the three N source sub-treatments will be broadcast and incorporated by tillage applications of 1) 100% urea (same as done in

2019 and 2020), 2) 1/3 ESN and 2/3 urea as a blend, and 3) 2/3 ESN and 1/3 urea as a blend. At Becker the applications will be done as a split (V2 - V6 - V10) with equal amounts of N for each split to match the total N rate with the following N sources/timing combinations: 1) Agrotain - Agrotain - Agrotain (same as done in 2019 and 2020), 2) ESN - Agrotain – Agrotain, and 3) 2/3 ESN - 1/3 Agrotain - xxx (only a two-split application to match the total N rate).

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 and 2020 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
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
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
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
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
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

Table 3. Summary of the initial soil properties taken at each experimental site either in 2019 or 2020 growing seasons.

	Becker CC	**Becker CSb**	**Lamberton CC**	**Lamberton CSb**	**Morris CC**	**Morris CSb**	**Rochester CSb**	**Waseca CC**	**Crookston CSb**
Initial Biological sampling	χ	χ	χ	χ	χ	χ	χ	χ	χ
Initial Chemical sampling Soil C, Nutrients, and Chemical Properties	χ	χ	χ	χ	χ	χ	χ	χ	χ
Bulk density	χ	χ	χ	χ	χ	χ	χ	χ	χ
Taxonomic characterization	χ	χ	χ	χ	χ	χ	χ	χ	χ
Aggregate stability	χ	χ	χ	χ	χ	χ	χ	χ	χ
Penetrometer/Soil moisture	χ	ND	ND	ND	ND	ND	χ	χ	χ
Infiltration	χ	χ	ND	ND	ND	ND	χ	χ	χ
Soil conductivity	ND	ND	ND	ND	ND	ND	ND	ND	ND

χ- Measurement taken in 2019 or 2020 growing season. **ND**- Measurements will be taken during the 2021 growing season.

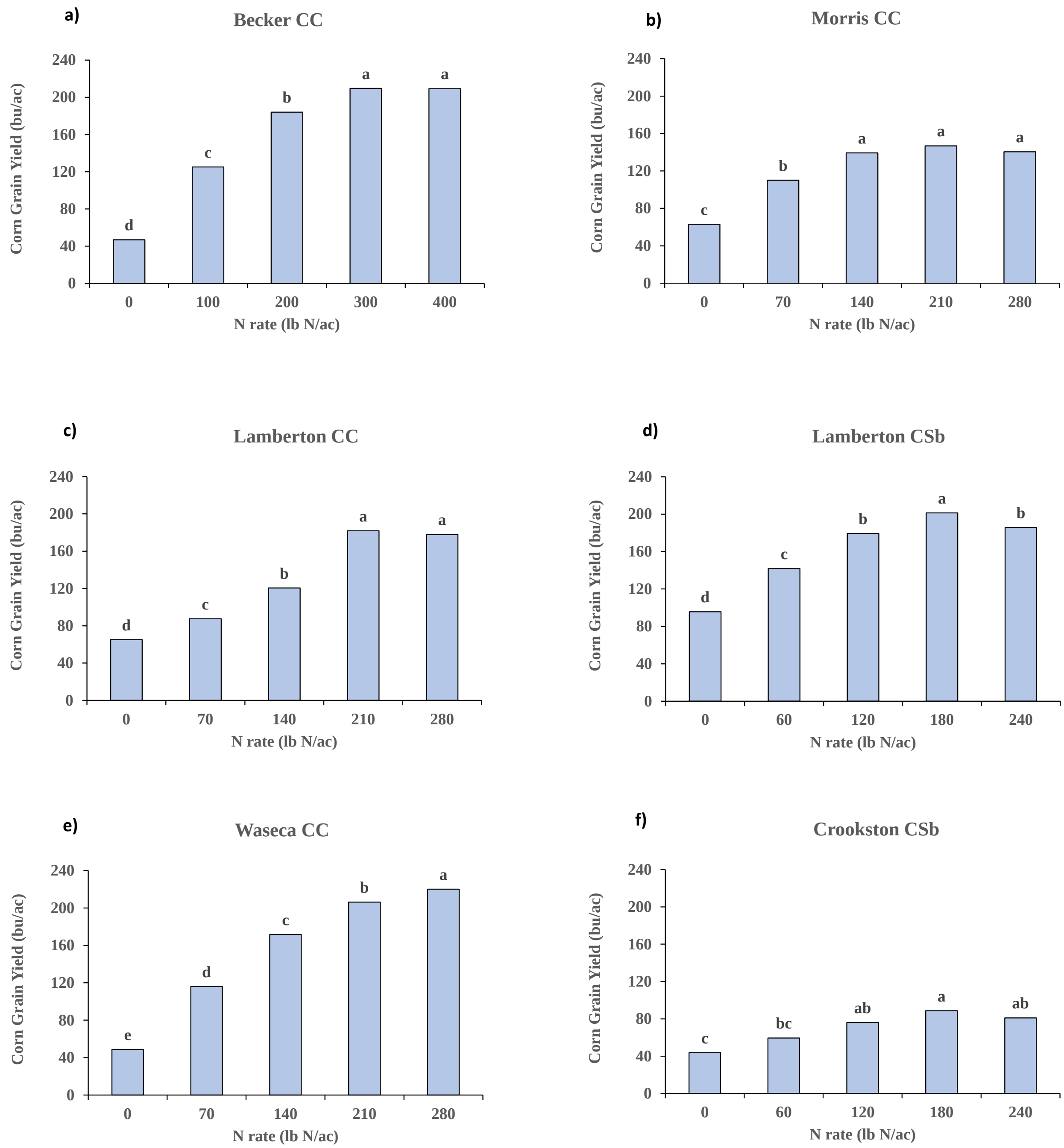

Figure 1. Corn grain yield in response to N rates in continuous corn (CC) at Becker (a), Morris (b), Lamberton (c) and Waseca(f), and corn after soybean (CSb) at Lamberton (d) and Crookston (g). Bars with same letters are not statistically different at P=0.05.

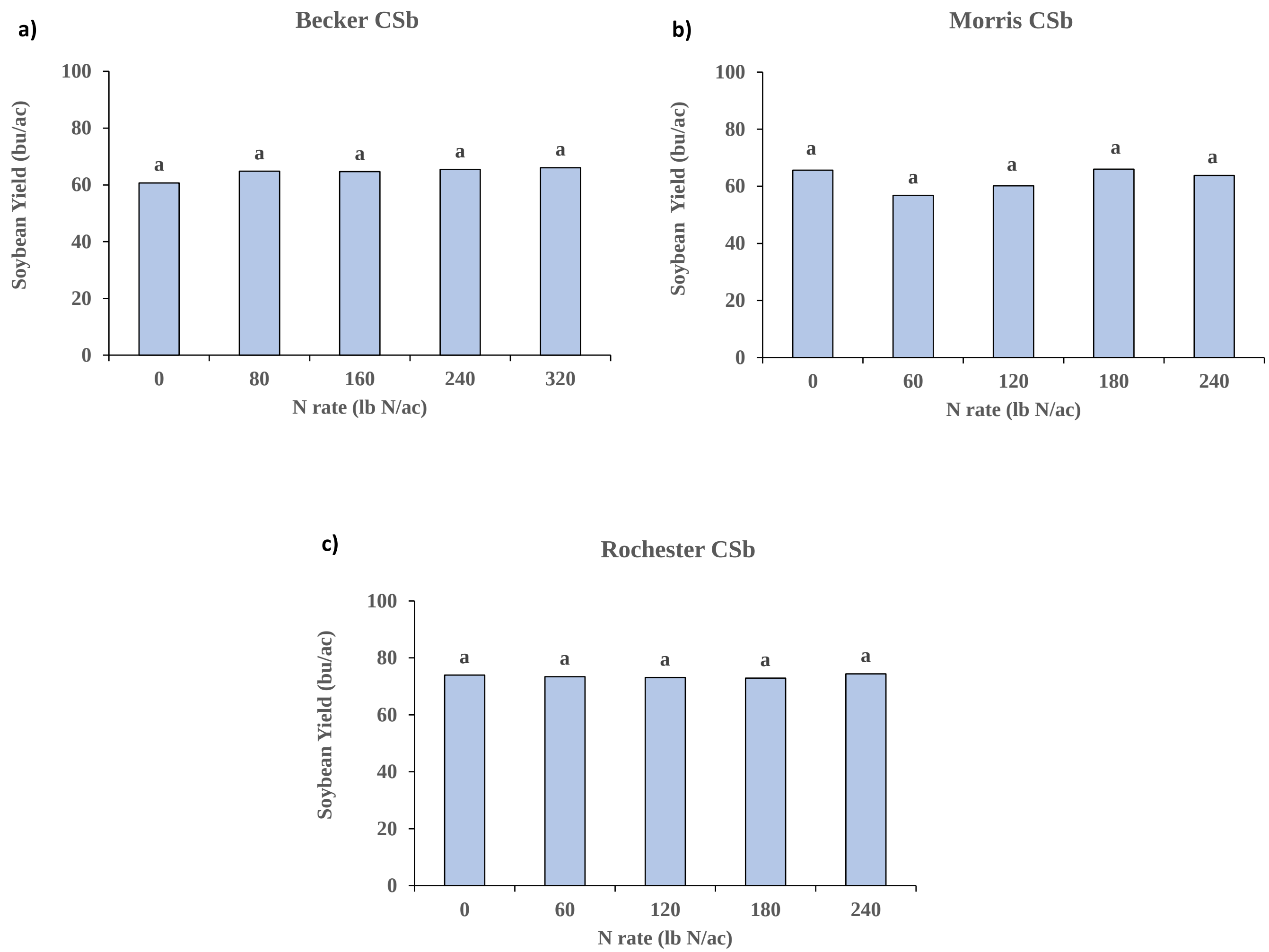

Figure 2. Soybean yield in response to residual N rates applied on the corn phase at Becker (a), Morris (b) and Rochester (c). Bars with same letters are not statistically different at P=0.05.

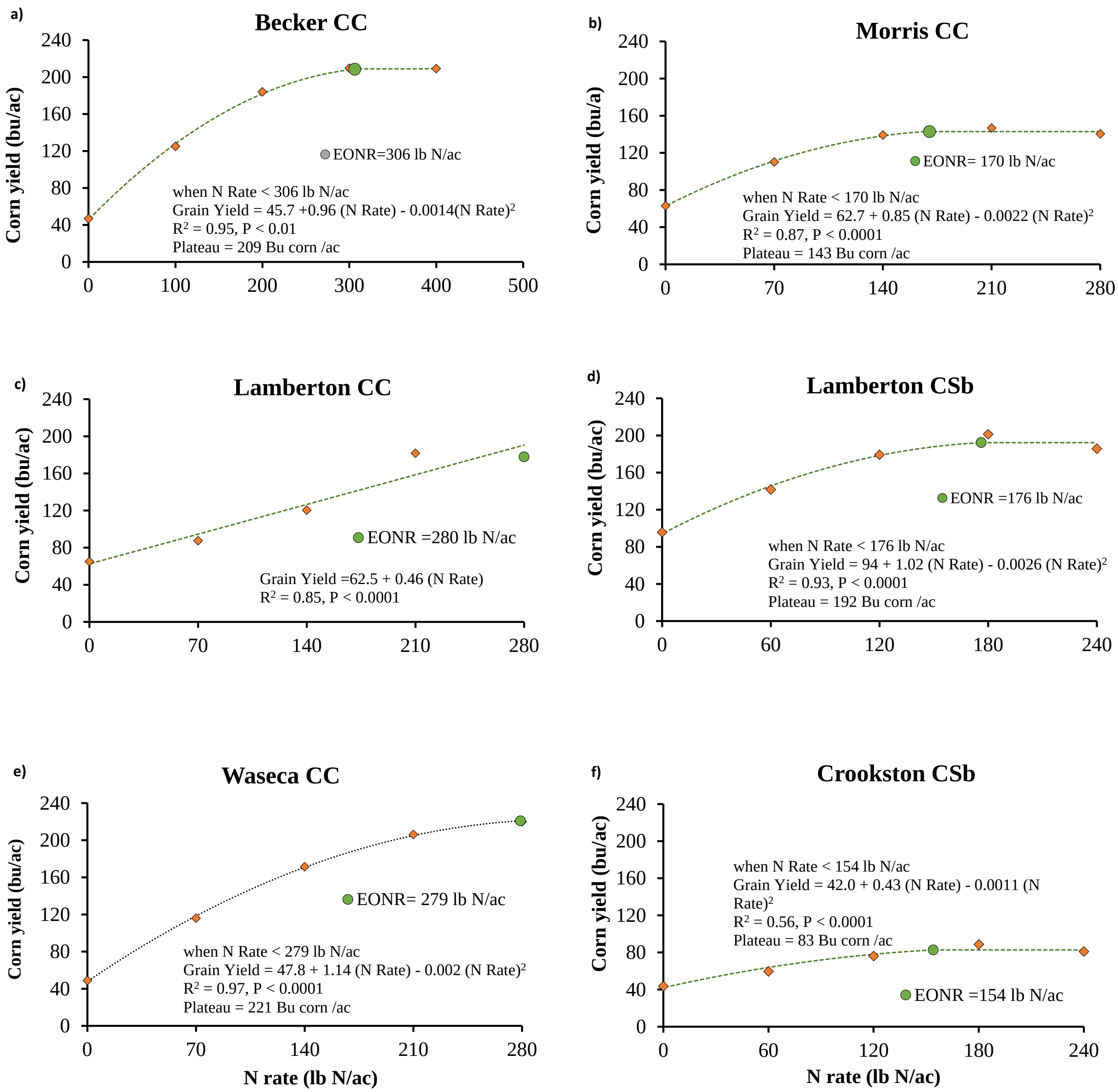

Figure 3. Corn grain yield response to N application averaged across all subplots, and calculation of the economic optimum N rate (EONR) and yield at the EONR with a 0.1 N to corn price ratio for continuous corn (CC) at Becker (a), Lamberton (b), Morris (d) and Waseca (e), and for corn after soybean (CSb) at Lamberton (c) and Crookston (f).

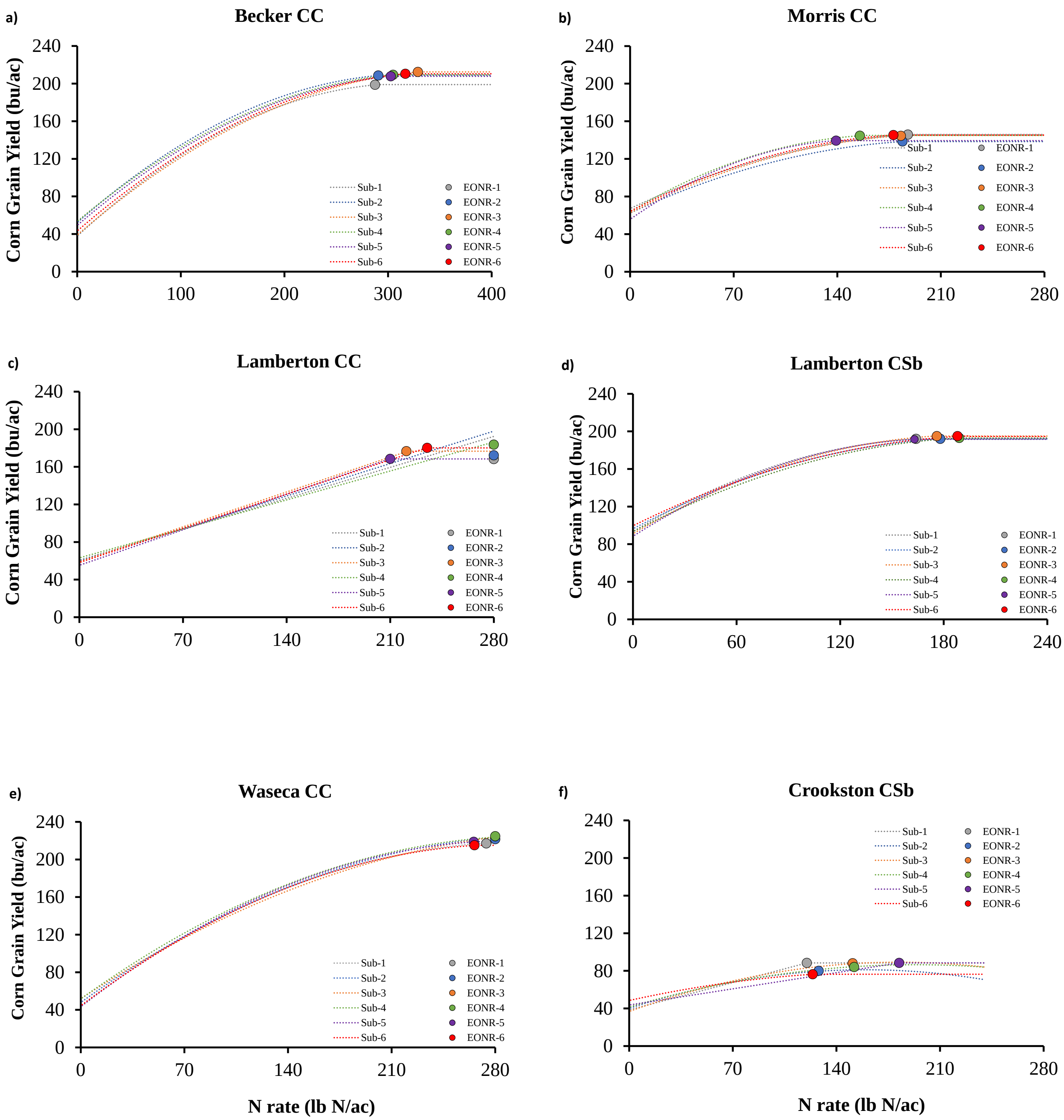

Figure 4. Corn grain yield and economic optimum N rate (EONR) variability at Becker (a), Lamberton (b), Morris (d), and Waseca (f) in continuous corn (CC), and at Lamberton (c) and Crookston (g) in corn-soybean (CSb). Each EONR was calculated for each sub-plot with four replications using a 0.1 N to corn price ratio.

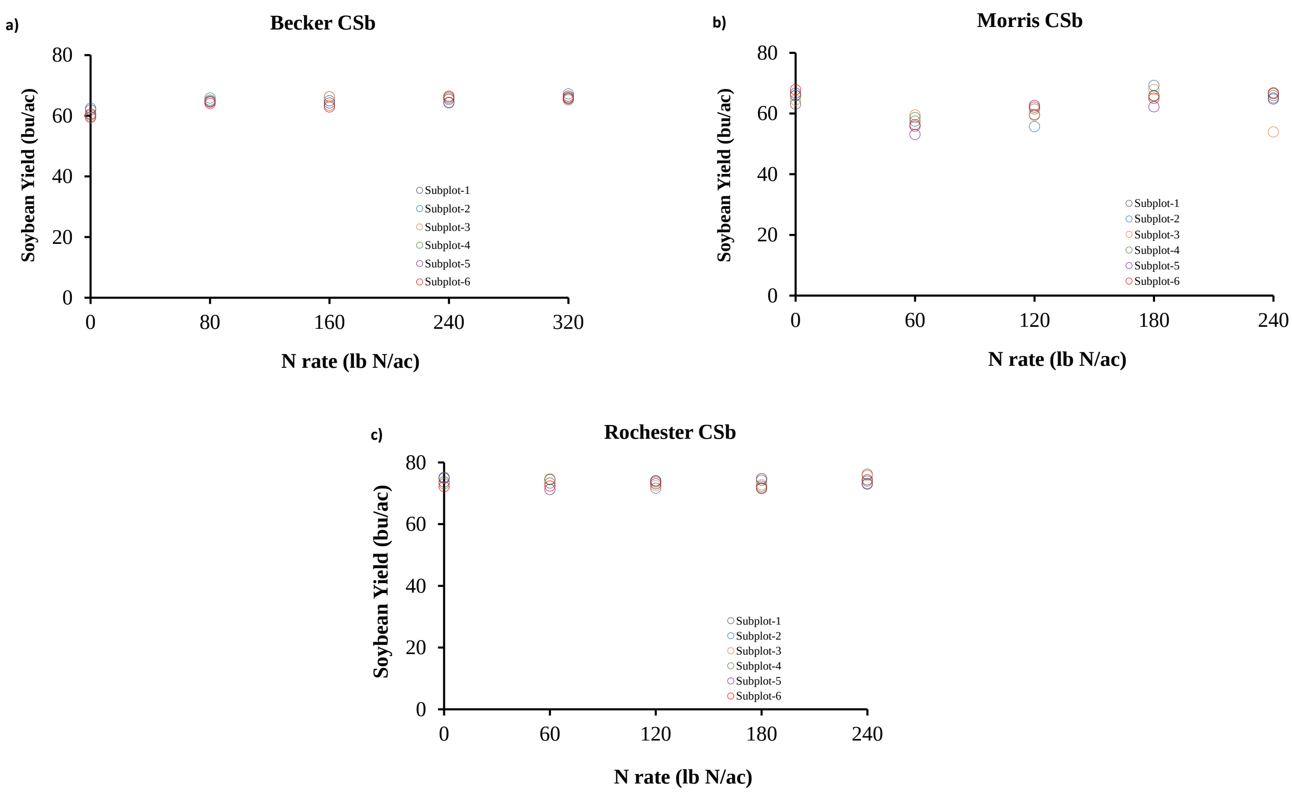

Figure 5. Soybean yield variability at Becker (a), Morris (b) and Rochester (c) in the corn-soybean (CSb) cropping system.