# EVALUATION OF NITROGEN FERTILIZER TECHNOLOGIES AND FERTILIZER TIMING FOR SUGAR BEET PRODUCTION

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**Justification**: Nitrogen is the single most researched nutrient for sugar beet as nitrogen is the nutrient most likely to limit production. Numerous trials in Minnesota and North Dakota have been conducted studying nitrogen rate and the impact of residual nitrate on sugar beet yield and quality. The majority of these studies have included spring nitrogen rates usually applied as urea. Nitrogen suggestions assume the same amount of N is required for fall versus spring application on N if best management practices are followed. As nitrogen is applied in the fall in some cases, more research needs to be conducted to determine if fall application of nitrogen can continue to be an acceptable practice.

While spring application of nitrogen is generally suggested for most crops to limit the potential for spring N losses, wet springs present challenges to plant crops at optimal times in the midst of getting fertilizer applied and fields prepared for planting. Fall application of all fertilizer is advantageous to limit the number of field operations which must be completed prior to planting. Current nitrogen best management practices for much of the sugar beet growing regions in Minnesota maintain fall nitrogen application as an acceptable practice. Anhydrous ammonia is the source of nitrogen encourages for use in the fall due to the impacts anhydrous ammonia has on soil nitrifying bacteria. Fall application of urea has been considered acceptable in Western and Northwestern Minnesota but the practice is being increasingly questioned due to increased rainfall in areas presenting a greater risk for nitrogen loss.

Urea and anhydrous ammonia when applied to the soil both result in the accumulation of ammonia and ammonium in the soil. Urea differs in that it must be hydrolyzed by the enzyme urease before ammonium is forms. The urease enzyme is ubiquitous in soils and hydrolysis of urea can be rapid if the appropriate conditions exist in the soil. Since urea does not impact soil microorganisms the same as anhydrous ammonia the conversion of urea can be quicker presenting greater risks for nitrate loss while shallow application can present volatility issues also representing a potential loss for the product. More recent data collected from multiple locations in Western Minnesota has shown a significant yield penalty for identical rates of nitrogen applied to corn in the fall versus in the spring. The corn yield penalty is greater when corn follows corn which could be partially due to immobilization of nitrogen by the corn residue. With typical rotations of sugar beet following corn a comparison of fall versus spring nitrogen applied as urea is needed to determine the efficiency of fall versus spring application or urea to determine if changes to nitrogen best management practices are warranted, or if sugar beet differs enough where fall urea can still be an acceptable practice even if it is not suggested for corn.

Nitrification inhibitors are currently available to be used for urea which could limit the potential for nitrate accumulation in the soil profile. Research with N-serve applied with anhydrous ammonia has demonstrated that nitrapyrin is an effective nitrification inhibitor. The primary nitrification inhibitor for urea historically was dicyandiamide (DCD). Mobility of the DCD molecule has led to inconsistent results with this product. More recently Dow has released Instinct which is an encapsulated nitropyrin product for use with urea. Research has shown no overall benefit for Instinct applied with broadcast urea for corn, but the product is still sold to growers with a promise of reducing nitrogen loss from fall urea applications. Inhibitor research is needed in sugar beet production to determine if the additional cost of the products justifies their use for fall application.

Polymer coated urea is available in Minnesota as the product ESN. Polymer coated urea differs from inhibitors as the polymer coating provides a barrier which slows the release of nitrogen to the soil. Water moves into the polymer coating dissolving urea which then diffuses through the coating into the soil. The rate of release of urea through the polymer coating is related to soil moisture and temperature. Cool or dry soils can limit release subsequently resulting in a deficiency of nitrogen for the plant even through there may be adequate nitrogen in the soil for the crop. The lack of predictability of release and higher cost of the product has resulted in polymer coated urea suggested for application as a blend rather than 100% of the nitrogen required applied as ESN. However, ESN has been demonstrated as being effective at limiting nitrogen loss in high loss environments and thus may be better suited for fall application than urea treated with an inhibitor. Data reporting fall application of polymer coated products on sugar beet is scare and is needed to determine if this practice is better and what the optimal blend rate may be.

**Objectives:**

1. Evaluate nitrogen fertilizer requirement for sugar beet.
2. Compare the efficiency of fall versus spring application of urea for the southern and northern growing region through impacts on root yield and sugar content.
3. Determine if polymer coated urea (ESN) blends with urea results in greater root yield and recoverable sugar per acre when applied in the fall.
4. Determine if root yield and recoverable sugar are greater when commercially available nitrification and/or urease inhibitors marketed for use with urea when applied in the fall.

**Materials and Methods**: Two field locations were established in Fall 2020 (Table 1). One of the field trials will be located in the northern growing region at the Northwest Research and Outreach Center at Crookston following wheat, and the second will be located on an on-farm trial location in the southern growing region following corn near Hector. There are two separate studies at each location.

Study 1 consists of six N rates at Crookston (0 to 200 lbs) and eight in the southern region (0 to 210 lbs). All N is applied as urea in the fall and in the spring. Trials consist of a split plot design where main plots consist of N rate and sub-plots within each main plot will be N timing such that the same rate can be applied side by side for comparison. Fall application are targeted to the end of October or when the soil has stabilized below 50ºF and incorporated as soon as possible after application. Spring application are made just prior to and incorporated before planting (Table 2).

Study 2 consists of multiple fertilizer sources applied at a sub-optimal N rate applied in fall and spring. The target rate was 45 lbs of N only which, including the four-foot nitrate test, the total N should account for roughly two-thirds to three quarters of the suggested N needed for sugar beet production. The 45 lb rate was not meant to represent an optimal rate of N applied to sugarbeet. Rather, the 45 lb N rate should be on the more responsive part of the N response curve allowing for easier detection of smaller differences related to N availability from the sources used. A split plot design is used for the source trial where main plots will consist of N source and sub-plots will be time of application.

N sources consist of:

1. 0 N control
2. Urea only
3. 33% ESN/66% urea
4. 66% ESN/33%urea
5. 100% ESN
6. Super U [NBPT (urease inhibitor) +DCD (nitrification inhibitor)]
7. Agrotain (urease inhibitor) – 0.45 qt/ton (low rate similar to the NBPT rate in Super U)
8. Anvol (urease inhibitor) – 1.5 qt/ton
9. Instinct (nitrification inhibitor) – 24 oz/ac

10. Ammonium sulfate

Initial site-composite soil samples were collected from each study at each location to a depth of four feet. A summary of soil test information is given in Table 2. Stand counts were taken early in the growing season to assess phytotoxicity of the urea rates and sources. In season plant tissue samples are collected towards the end of June to early July depending on planting date. Leaf blade and petiole samples are collected, and extractable nitrate-N is determined in Dr. Kaiser's lab following extraction with water or 2% acetic acid. Petiole and leaf blade samples are additionally sent out to a private lab for total N analysis by dry combustion. The uppermost fully developed leaf blade and petiole were sampled which is consistent with what is suggested for petiole nitrate analysis. Plots were harvested at the end of the growing season and root samples will be analyzed for quality parameters.

A single variety is planted at each location and differed by location. All practices, weed and disease control, planting, and tillage will be consistent with common practices for the growing regions. Additional P, K, and S is applied as needed based on current fertilizer guidelines.

**Results**

A summary of main effect significance is given in Table 3 for the urea rate trial and Table 4 for the urea source trial. Figures 1 through 5 summarize sugar beet response to N at the two trial locations for the rate trials only. Data are summarized across all rate or treatments when the statistical analysis indicated no N rate or source by time interaction for a given locations. The summary of the main effect of time for the rate and source trials is given in Table 5. Since this report represents the first year of a multiple year study no conclusions will be drawn at the end of this report.

An application error resulted in the loss of all fall treatments for the urea source trial at Crookston. The spring treatments were applied as planned and the source main effect at Crookston only summarizes the spring treatments. The fall treatments were all applied as planned for the rate trial at Crookston and both trials at Hector.

Sugar beet emergence was significantly impacted by N rate at both locations and the rate by time interaction was significant at both sites (Table 3 and Figure 1). In both cases, sugar beet emergence was less as the rate of N applied as spring urea increased. Fall urea had a slight impact on sugarbeet emergence at Crookston while there generally was no impact of fall urea on sugrbeet emergence at Hector. When decreased, sugarbeet emergence decreased linearly as fertilizer rate increased.

Urea source impacted emergence at both locations (Table 6). All sources reduced emergence at Crookston while emergence was greater for most urea sources compared to the control at Hector. Due to the differences in response between the two locations, the ranking of sources generally differed except for urea treated with instinct which resulted in the lowest emergence of all treatments. More data will be required to achieve a better understanding of how the urea sources impact emergence over time.

Sugar beet root yield as impacted by N application rate at Hector but not at Crookston and time was not significant at either site (Table 4). Root yield responded to 130 lbs of total N (applied N plus nitrate-N in a four-foot soil sample) at Hector (Figure 2). Dry soils at Crookston resulted in less and more variable root yield. If root yield did vary by N rate the likely would not have been any additional yield produced passed around 120 lbs of total N at Crookston. The fact that timing of application did not impact root yield likely resulted from the dry soils and a lack of potential for leaching of nitrate.

Root yield varied by urea source only at Hector (Table 6). Almost all urea sources increased root yield over the non-fertilized control. The greatest yield was produced with the 33% ESN, urea plus Anvol, and urea plus Agrotain treatments. Anvol and Agrotain are urease inhibitors which slow volatility of ammonia by reducing the rate of hydrolysis of the urea. Super-U also contains NBPT, the active ingredient in Agrotain, but at a lower rate that what is applied with the suggested application rate of Agrotain. Issues with coating of the fertilizer resulted in a NBPT rate applied that was roughly 2x that of the amount of NBPT in Super-U (Agrotain rate was targeted to supply the same NBPT rate as in Super-U). It should be noted that this dataset is limited in that it is one site-year total. The addition of more site-years of data is needed to make a conclusion of the optimal urea source.

The decrease in plant population did not impact sugar beet root yield at either location. The loss of population was compensated by the sugar beet plants which increased the mass of roots per plant (not shown). While higher rates of N as spring urea could reduce yield the effect on root yield should be minimal if the variety planted can compensate by growing larger roots. A reduction in emergence without a resulting decrease in yield was also seen in 2020.

Recoverable sucrose per ton was affected by urea rate and timing at both locations, but the time by rate interaction was not significant. Fall urea application resulted in 3% more recoverable sucrose at both locations. Urea rate resulted in a general decrease in recoverable sucrose at both locations (Figure 3). In both cases increasing urea rate decreased recoverable sucrose per ton. The decrease was relatively minor at the rate where root yield was maximized at Hector. Urea source had a relatively minor impact on recoverable sucrose (Table 6). Most sources did not differ from the non-fertilized control except for Super-U which resulted in the lowest recoverable sucrose per ton at both locations.

Recoverable sucrose per acre is summarized for the rate stud in Figure 4. Recoverable sucrose was not impacted by urea rate at Crookston while recoverable sucrose was maximized by 80 lbs of total N at Hector and did not increase or decrease beyond that point. Time of urea application did not impact recoverable sucrose per acre (Table 5). For the source trial there was no impact of urea source on recoverable sucrose per acre at Crookston, but recoverable sucrose was increased by urea sources at Hector (Table 6). Most sources were similar, but 100% ESN produced slightly less recoverable sucrose than the other urea sources.

Petiole nitrate concentrations were determined following sampling in early to mid-July. Samples from 2021 have yet to be analyzed so the data are not included in this report.

Petiole nitrate concentration was regressed with relative yield from previous studies and the data are given in Figure 6. Data indicate that 100% of maximum root yield was achieved with a petiole nitrate concentration near 850 ppm. However, relative root yield for plots ranged from 50-110% for petiole nitrate concentration less than 850 ppm. The high range in relative yield levels for petiole nitrate concentration does present some issues for using petiole nitrate concentration to assess nitrate sufficiency to direct supplemental application of N for sugar beet. The range in relative yield values is similar to what is seen with other tests such as the corn basal stalk N test. While we could say that 850 ppm would be a sufficient petiole nitrate concentration for sugar beet what to do if you concentration is below that level is more difficult to determine. As we continue the nitrogen work, we will add more data to the dataset. One item of note is that root yield at Lake Lillian did not respond to nitrogen and yield levels were 40+ tons similar to Wood Lake, yet many of the petiole nitrate concentration were less than 850 ppm. Past research has also not been able to calibrate the petiole nitrate test. The petiole nitrate test may work to help manage nitrogen at specific locations, but it may not be possible to determine which locations it may work until yield data is available at a given location.

## Acknowledgments

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Table 1. Location, planting and sampling information and dominant soil series for each location.

| Location | Date of | | | | | Soil | | |
|---|---|---|---|---|---|---|---|---|
| | Urea Application | | Planting | Tissue Sampling | Harvest | Series | Texture† | Classification‡ |
| Crookston | 29-Oct | 4-May | 4-May | 8-Jul | 14-Sept | Wheatville | FSL | Ae. Calciaquoll |
| Hector | 6-Nov | 30-Apr | 30-Apr | 12-Jul | 29-Sept | Canisteo-Glencoe | CL | T. Endoaquoll |

† CL, clay loam; FSL, fine sandy loam.

‡Ae, aeric; T, typic

Table 2. Summary of soil test results for 2021 locations.

| Location | 0-6" Soil Test | | | | Soil Test Nitrate-N | |
|---|---|---|---|---|---|---|
| | Olsen P | Ammonium Acetate K | pH | SOM | 0-2' | 2-4' |
| | ----------ppm---------- | | | ----%---- | --------------------lb/ac-------------------- | |
| | | | | Urea Rate Trials | | |
| Crookston | 9 | 159 | 8.2 | 3.0 | 25 | 43 |
| Hector | 8 | 168 | 7.3 | 5.4 | 21 | 39 |
| | | | | Urea Source Trials | | |
| Crookston | 12 | 140 | 8.2 | 2.3 | 39 | 70 |
| Hector | 7 | 151 | 7.6 | 4.0 | 25 | 68 |

Table 3. Summary of analysis of variance for main effects of nitrogen application rate (N rate) and time of application (Time) and their interaction at Crookston (CRX) and Hector (H), MN in 2021.

| | Emergence | | Petiole N | | Yield | | Recoverable Sugar (ton) | |
|---|---|---|---|---|---|---|---|---|
| Effect | CRX | H | CRX | H | CRX | H | CRX | H |
| | ------------------------------------------------------------*P*>F------------------------------------------------------------ | | | | | | | |
| N rate | *** | 0.10 | na | na | 0.50 | ** | 0.10 | * |
| Time | *** | *** | na | na | 0.66 | 0.88 | ** | ** |
| N ratexTime. | *** | *** | na | na | 0.13 | 0.90 | 0.25 | 0.46 |

†Asterisks represent significance at *P*<0.05,*; 0.01, **; and 0.001, ***.

Table 4. Summary of analysis of variance for main effects of urea source (Source) and time of application (Time) and their interaction at Crookston (CRX) and Hector (H), MN in 2021.

| | Emergence | | Petiole N | | Yield | | Recoverable Sugar (ton) | |
|---|---|---|---|---|---|---|---|---|
| Effect | CRX | H | CRX | H | CRX | H | CRX | H |
| | ------------------------------------------------------------*P*>F------------------------------------------------------------ | | | | | | | |
| Source | *** | ** | na | na | 0.18 | ** | | * |
| Time | na | 0.58 | na | na | na | 0.26 | na | 0.63 |
| SourcexTime. | na | 0.55 | na | na | na | 0.62 | na | 0.95 |

†Asterisks represent significance at *P*<0.05,*; 0.01, **; and 0.001, ***.

Table 5. Summary of the main effect of in-urea timing or source for selected variables at Crookston (CRX) and Hector (H), MN in 2021. Letters indicating least significant difference are only listed in the table when the main effect of timing was significant. Data are given separately for the urea rate and source trials at each location. Fall treatments for the Crookston source trial were not included in this dataset.

| | Emergence | | Petiole N | | Yield | | Rec. Sugar (ton) | | Rec Sugar (acre) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Time | CRX | H | CRX | H | CRX | H | CRX | H | CRX | H |
| | ------%------ | | ----ppm---- | | --tons/ac-- | | ---lb/ton--- | | ----lb/ac---- | |
| | | | | | Urea Rate Trial | | | | | |
| Fall | 79a | 86a | na | na | 19.4 | 39.5 | 326a | 246a | 6340 | 9690 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Spring | 72b | 74b | na | na | 19.1 | 39.6 | 316b | 240b | 6027 | 9479 |
| | | | | | Urea Source Trial | | | | | |
| Fall | -- | 84 | -- | na | -- | 33.9 | -- | 261 | -- | 8587b |
| Spring | -- | 83 | -- | na | -- | 34.6 | -- | 260 | -- | 8859a |

†Numbers followed by the same letter are not significantly different at the $P \leq 0.10$ probability level.

Table 6. Summary of the main effect of urea source for selected variables at Crookston (CRX) and Hector (H), MN in 2021. Letters indicating least significant difference are only listed in the table when the main effect of timing was significant.

| | Emergence | | Petiole N | | Yield | | Rec. Sugar (ton) | | Rec Sugar (acre) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Source | CRX | H | CRX | H | CRX | H | CRX | H | CRX | H |
| | ------%------ | | ----ppm---- | | --tons/ac-- | | ---lb/ton--- | | ----lb/ac---- | |
| None | 86.4a | 78.6cd | na | na | 18.1 | 29.9f | 345.6a | 261.5ab | 6259 | 7092d |
| Urea | 69.7ef | 88.1a | na | na | 16.7 | 31.6def | 336.2ab | 261.9ab | 5612 | 8639abcd |
| AMS | 78.9bc | 86.6a | na | na | 19.5 | 36.7abc | 325.1bc | 270.1a | 6339 | 9768ab |
| 33% ESN | 73.7de | 85.6ab | na | na | 15.7 | 39.0a | 329.0b | 263.5ab | 5163 | 9839a |
| 66% ESN | 77.1bcd | 80.1bcd | na | na | 18.5 | 30.7ef | 329.9b | 260.1b | 6104 | 8094bcd |
| 100% ESN | 80.8b | 88.5a | na | na | 19.6 | 34.2bcde | 332.1b | 262.0ab | 6510 | 7596cd |
| Instinct | 68.4f | 75.2d | na | na | 17.9 | 34.0bcde | 329.2b | 257.1b | 5909 | 8412abcd |
| Super-U | 74.1cde | 84.8ab | na | na | 19.0 | 33.1cdef | 314.8c | 246.0c | 5965 | 8922abc |
| Agrotain | 77.3bcd | 84.6abc | na | na | 18.7 | 37.6ab | 327.7b | 259.8b | 6145 | 8909abc |
| Anvol | 72.5def | 80.4bcd | na | na | 18.9 | 35.5abcd | 333.4b | 259.4b | 6282 | 9955a |

†Numbers followed by the same letter are not significantly different at the P<0.10 probability level.
Na, data are not available

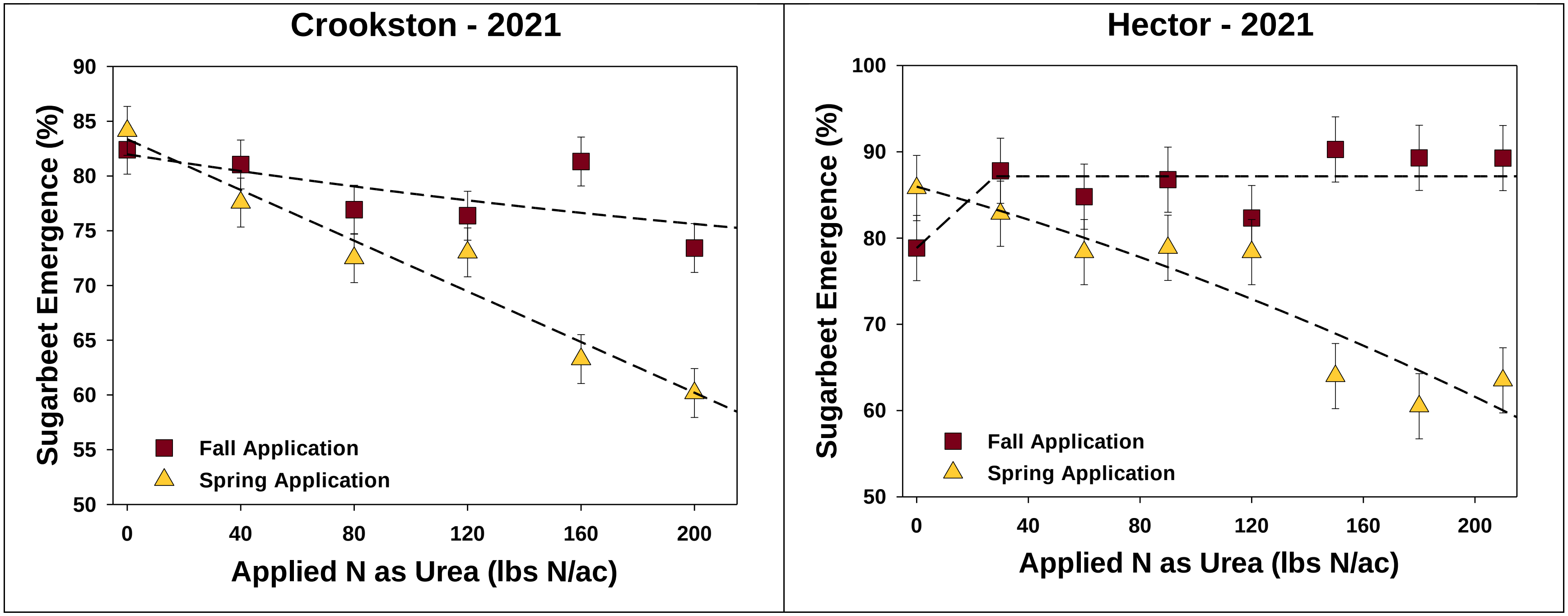


Figure 1. Effect of nitrogen applied as fall or spring urea (data averaged for both timings) on sugar beet emergence at two Minnesota locations during the 2021 growing season.

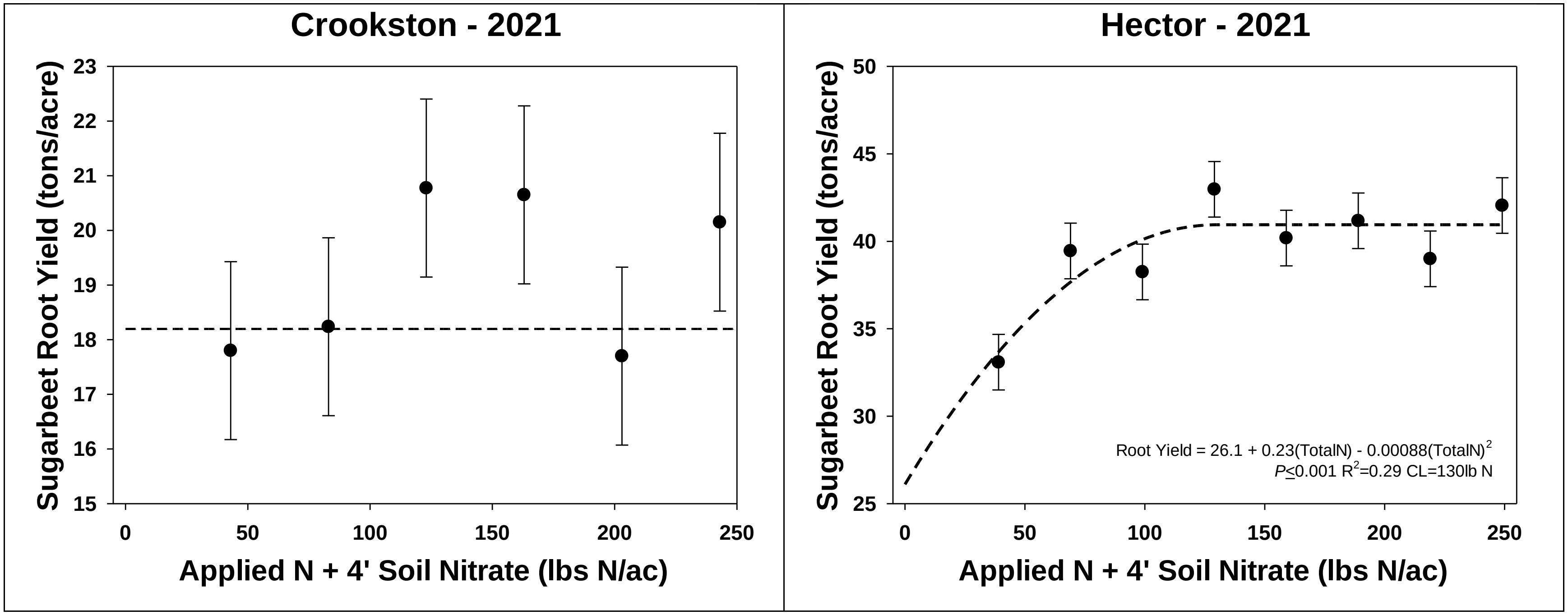


Figure 2. Effect of nitrogen applied as fall or spring urea (data averaged for both timings) plus the nitrate in a four-foot on sugar beet root yield at two Minnesota locations during the 2021 growing season.

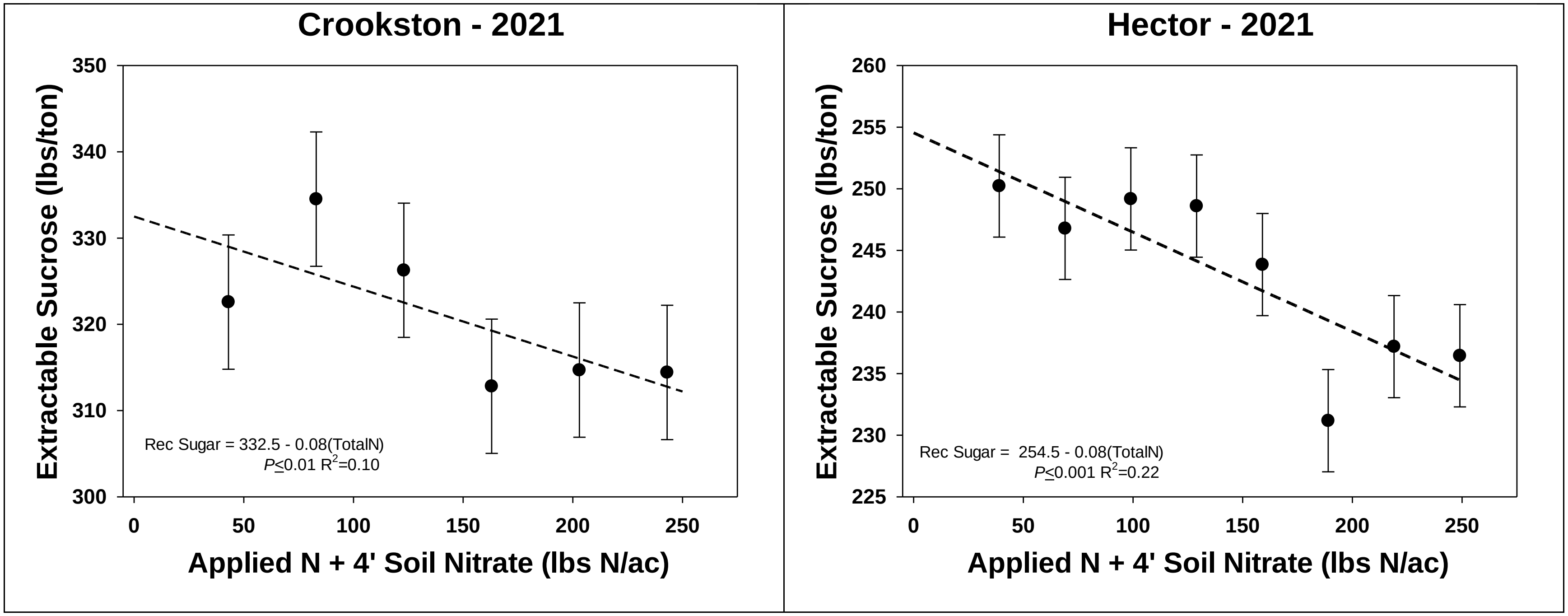


Figure 3. Effect of nitrogen applied as spring urea plus the nitrate in a four-foot on sugar beet extractable sucrose per ton at two Minnesota locations during the 2021 growing season.

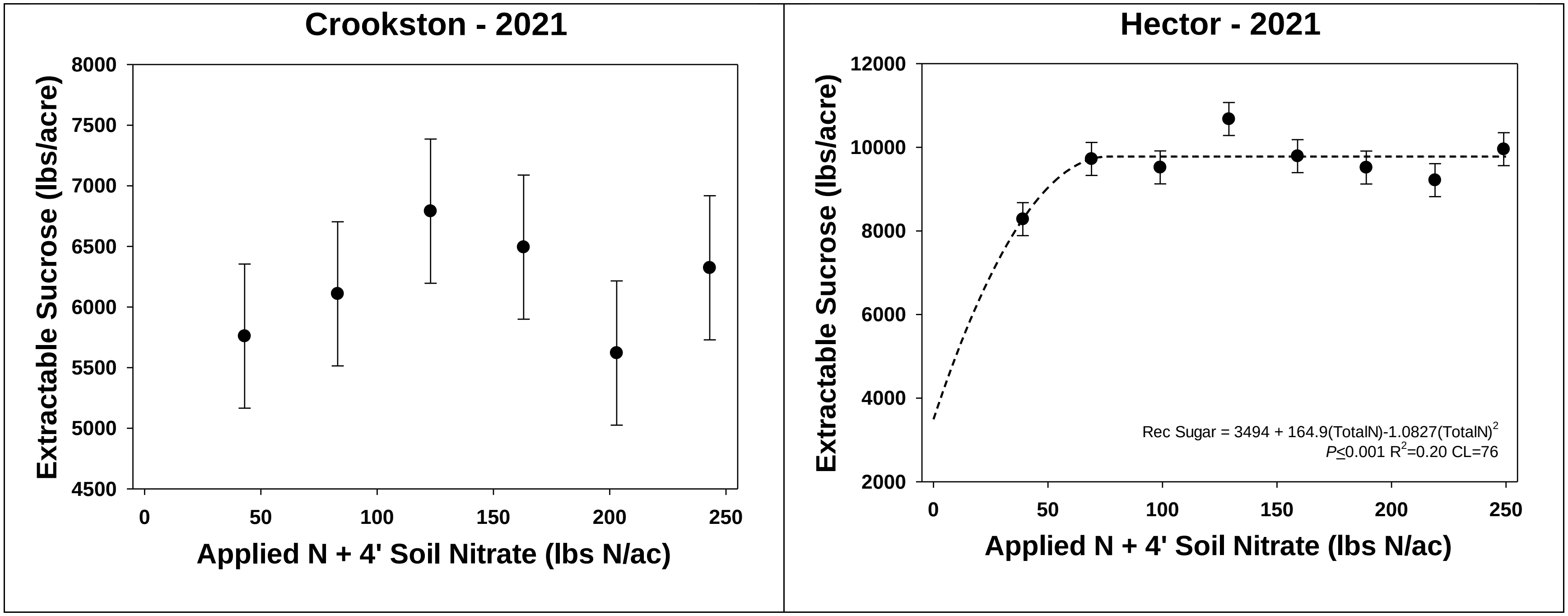


Figure 4. Effect of nitrogen applied as fall or spring urea (data averaged for both timings) plus the nitrate in a four-foot on sugar beet total extractable sucrose per acre at two Minnesota locations during the 2021 growing season.

| | |
|---|---|
| Data not available | |

Figure 5. Effect of nitrogen applied as fall or spring urea (data averaged for both timings) plus the nitrate in a four-foot on sugar beet early to mid-July petiole nitrate measured from the newest fully developed leaf at two Minnesota locations during the 2021 growing season. Samples were collected but had not been analyzed at the time of this report.

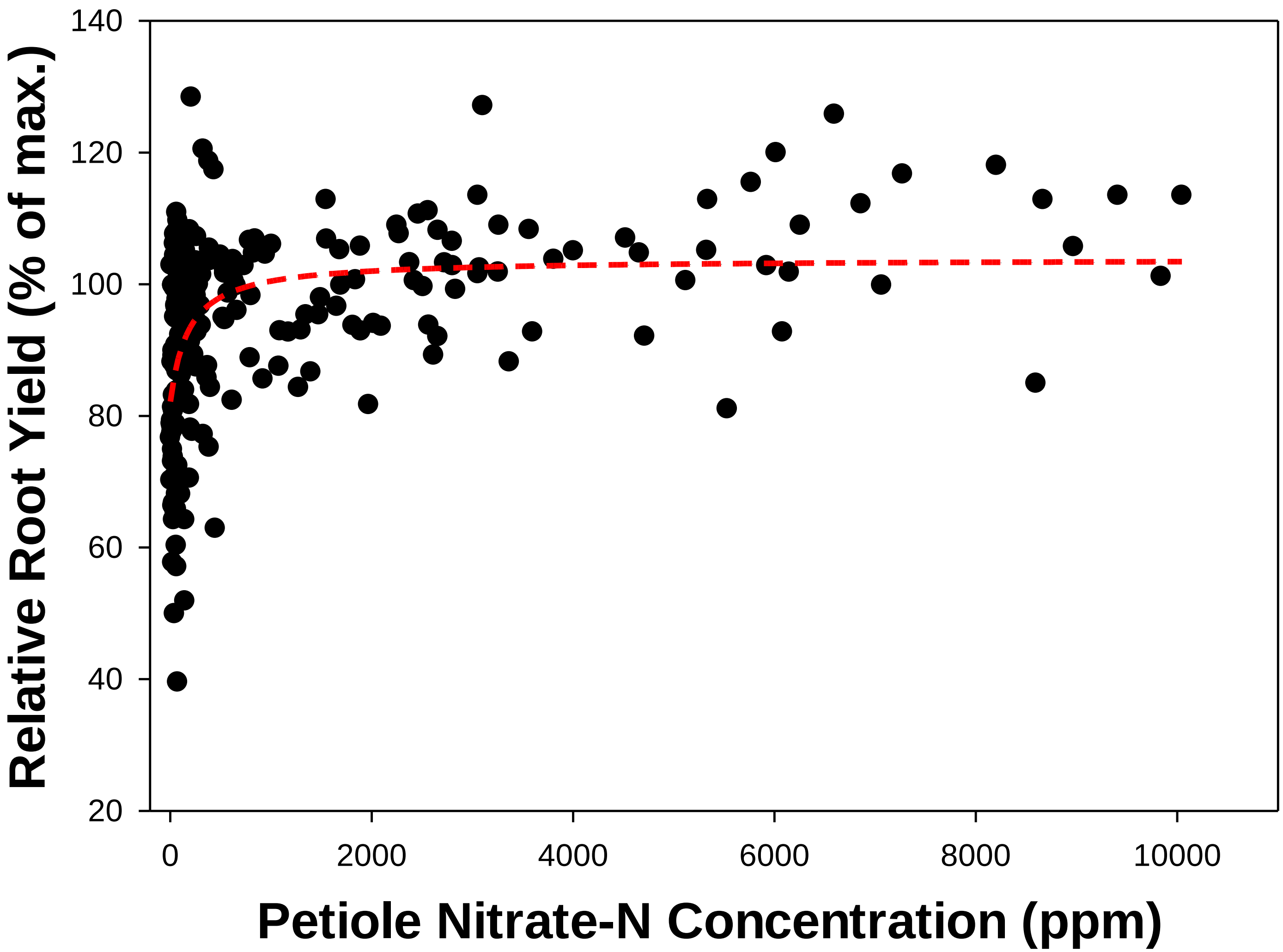


Figure 6. Relationship between relative sugar beet root yield (% of site maximum yield) and nitrate concentration in the uppermost fully developed petiole sampled in early- to mid-July.