# Sugarbeet Response to Plant Population, Nitrogen Rate, Row Spacing, and Starter Fertilizer Strategies

**Seth Purucker[1], and Kurt Steinke[1]**

[1]Dept. of Plant, Soil, and Microbial Sciences, Plant and Soil Sciences Building, 1066 Bogue Street, Michigan State University, East Lansing, MI 48824

Corresponding author: Kurt Steinke (ksteinke@msu.edu)

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## ABSTRACT

**Michigan sugarbeet growers question how intensive management strategies involving greater plant densities, nitrogen (N) rates, and narrower row spacing may improve yield, quality, and profitability. As row spacings narrow, the use of starter N subsurface banded 5 cm beneath and 5 cm beside the furrow (5x5) has decreased. Two field studies were established to investigate 1) two plant populations (123,552 and 148,260 seeds ha-1), four N rates (0, 89, 179, and 269 kg N ha-1), and with or without 45 kg N ha-1 starter N applied at-planting, and 2) two row spacings (56 and 76 cm) with at-plant subsurface banded starter N or broadcast N both at 45 kg N ha-1. Across tested N rates, 179 kg N ha-1 produced optimal root yield, quality, and expected net return, but peak recoverable sucrose averaged 27 kg N ha-1 lower than optimal root yield N rates across years. Compared to 76 cm rows, narrower row spacing (i.e., 56 cm) increased root yield by 14.5 and 23.8 Mg ha-1 in 2018 and 2019, respectively, and 5x5 starter N increased root yield by 4.3 Mg ha-1 compared to broadcast N placement in 2018 during dry May-June soil conditions. Data suggest 5x5 starter N placement may still benefit row closure in 56 cm rows and should not be abandoned simply due to less distance between rows.**

**Additional Key Words:** intensive management, sub-surface banded N, starter, narrow row, fertilizer

Michigan sugarbeets (*Beta vulgaris* L.) accounted for 12.9 and 13.7% of total U.S. production in 2018 and 2019, respectively (NASS, 2018, 2019). Production occurs on approximately 59,084 hectares of non-irrigated, predominately low organic matter (< 3%) land located within the Great Lakes watershed basin (NASS, 2019). Although mean root yields increased by 14% across the state since 2009, sucrose concentrations declined by 11% (NASS, 2019). Increased climate variability including excessive rainfall events later in the season may explain a portion of the decreased sucrose concentrations (Märländer et al., 2003; Chatterjee et al., 2018). Greater root yields and fluctuating commodity prices have increased grower interest in adaptive, focused intensive production practices including narrower row spacings (Grove et al., 2005), increased plant populations (Sogut and Arioglu, 2004), and variable N rates (DeBruyn et al., 2017), but negative effects on recoverable sucrose can occur from these practices (Yonts and Smith, 1997; Chatterjee et al., 2018).

Water quality concerns and proximity within the Great Lakes watershed have growers considering N fertilizer strategies that promote sugarbeet quality while simultaneously addressing environmental sustainability (Steinke and Bauer, 2017). Below optimal N rates risk reduced root yield and recoverable sucrose per hectare while over applying N may increase root impurities, production costs, and risk environmental contamination (Hergert, 2010; Chatterjee et al., 2018). Nitrogen guidelines for Michigan sugarbeet production following corn (*Zea mays* L.) or wheat (*Triticum aestivum* L.) suggest rates near 179 kg N ha-1 with 45 kg N ha-1 applied as starter N at planting with the remainder sidedressed near the 2-4 leaf growth stage (Steinke and Chomas, 2018). Steinke and Chomas (2018) found 179 kg N ha-1 produced the highest recoverable sucrose per hectare and root yield when comparing N rates between 0 and 269 kg N ha-1 following corn. As N rates increase, sucrose concentrations (g kg-1) typically decrease due to increased water retention by the taproot resulting in decreased root dry matter (Draycott, 2006). Excessive N may also reduce the amount of extractable sugar due to increased concentrations of soluble N compounds (Draycott and Christenson, 2003). In the Red River Valley region of North Dakota and Minnesota, Chatterjee et al. (2018) found 213 kg N ha-1 reduced sucrose concentration compared to 0 and 112 kg N ha-1 likely due to increased N compounds associated with greater rates of N application. Since N application rates are positively correlated with root yield but negatively correlated with recoverable sucrose per Mg, optimum N rates should consider both yield and percentage sugar as grower payments are calculated from both factors (Van Eerd et al., 2012; DeBruyn et al., 2017).

Continued adoption of 4R nutrient stewardship (i.e., right rate, source, placement, and time) has prompted Michigan sugarbeet growers to consider applying a portion of N in a band 5 cm below and 5 cm laterally from the furrow at planting (i.e., starter N) (DeBruyn et al., 2019). Starter N applied in a 5x5 promotes early season plant biomass, quicker canopy closure, and can improve root quality compared to pre-plant incorporated N (Clark et al., 2010). Due to sugarbeet seed sensitivity to fertilizer salts as compared to other rotational field crops, growers who utilize starter N at planting often apply the remainder of total N as an early-vegetative sidedress application (i.e., 2-4 leaf growth stage) (Steinke and Bauer, 2017). Current university and Michigan Sugar Company (MSC) recommendations suggest starter N should consist of 45-56 kg N ha-1 in a 5x5 at planting (Warncke et al., 2009; MSC, 2020; Steinke and Bauer, 2017). Sugarbeet producers that utilize 45 kg N ha-1 in a 5x5 starter N application may be able to decrease overall N rates while simultaneously increasing root yield, recoverable sucrose per hectare, and expected net return on investment.

Plant population is an important and controllable factor affecting sugarbeet root yield and quality (Cakmakci et al., 1998). Maintaining higher plant populations (>172,000 seeds ha-1) through field harvest can be difficult when utilizing 76 cm row spacings due to greater inter-plant competition from reduced spacing between individual plants (Yonts and Smith, 1997) and may be more attainable in narrower row spacings than 76 cm (DeBruyn et al., 2017). Michigan Sugar Company recommends a final plant stand of 86,000 seeds ha-1, however not all seeds planted will produce sugarbeet roots due to germination issues, soil crusting, and seedling disease (MSC, 2020). In Michigan, Groulx et al. (2010) found plant population between 99,000 and 124,000 seeds ha-1 produced the greatest root yield and recoverable sucrose per hectare when utilizing 76 cm row spacings. In Nebraska, Yonts and Smith (1997) found plant populations between 40,000 and 100,000 seeds ha-1 produced the highest recoverable sucrose per ha-1. Plant population typically has a greater impact on recoverable sucrose per hectare rather than root yield which may in turn influence optimal overall N rates needed to achieve maximum expected net return (DeBruyn et al., 2017).

Greater root yield and sucrose concentration in sugarbeets planted to narrower row spacings (i.e., 56 cm) as compared to wider (i.e., 76 cm) row spacings is not new (Dillon and Schmehl, 1971; Yonts and Smith, 1997). In 2010, MSC set a goal to reach 19% mean grower sucrose concentration which prompted more growers to utilize narrower row spacings (Flegenheimer, 2010). Estimated 2019 percentage of sugarbeet acres with 51 cm, 56 cm, 71 cm, and 76 cm row spacings were 23%, 28%, 16%, and 33%, respectively (Michigan Sugar Co., personal communication, 12 Feb. 2020). Recently, MSC set a new goal for Michigan growers to increase average recoverable sucrose per Mg to 150 kg Mg-1 while maintaining 67 Mg ha-1 root yields which may continue to include 56 cm row spacing (Flegenheimer, 2019). The use of narrower 56 cm row spacings may allow sugarbeet growers to increase plant populations without producing under-sized roots which can occur with greater plant populations in 76 cm rows due to the reduced inter-plant spacing (Grove et al., 2005). Narrower (e.g., 56 cm) row spacing may offer quicker row closure which may be a tool in managing weed pressure (Armstrong and Sprague, 2010). However utilizing 76 cm row spacings may allow greater wind movement between rows resulting in less disease occurrence (Palti, 1981). Growers also question whether benefits from starter fertilizer (e.g., increased early season biomass; faster row closure) are needed when utilizing reduced row spacing. Additionally, corn is typically grown in rotation with sugarbeet and utilizes 76 cm row spacing which may allow growers to maintain a standard row width for sharing equipment between crops (Yonts and Smith, 1997).

The objectives of this study were to 1) evaluate plant population, N rate, and starter N on sugarbeet root yield and quality, expected net return, and total N tissue concentration, and 2) determine the effects of sugarbeet row spacing and N placement on root yield and quality, expected net return, and row closure.

## Materials and Methods

Field trials were established during the 2018-2019 growing seasons at the Saginaw Valley Research and Extension center near Richville, MI (43°23'57.3"N, 83°41'49.7"W) on a Tappan-Londo loam (fine-loamy, mixed, active, calcareous, mesic Typic Epiaquoll). Located in Northeastern Michigan, the site is non-irrigated, tile-drained, and contains soils representative of sugarbeet production throughout the region. Fields were previously cropped to corn and autumn plowed followed by spring field cultivation (0-10 cm depth). Pre-plant soil characteristics (0-20 cm) followed standard methods and included 8.0-8.2 pH (1:1 soil/water), 24 g kg-1 soil organic matter (loss-on-ignition), 15-34 mg kg-1 P (Olsen sodium bicarbonate extraction), and 137-227 mg kg-1 K (ammonium acetate method) (Table 1) (Brown, 2015). Prior to planting, soil samples (0-30 cm) for nitrate-N (NO3-N) analysis were air-dried and ground to pass through a 2 mm sieve resulting in pre-plant concentrations of 2.2 and 2.6 mg NO3-N kg-1 soil (nitrate electrode method) in 2018 and 2019, respectively (Gelderman and Beegle, 1998). Monthly precipitation and temperature data were collected and recorded throughout the growing season from Michigan State University Enviro-weather (http://mawn.geo.msu.edu) Michigan State University, East Lansing, MI).

**Table 1.** *Soil physical and chemical properties including mean nitrate-nitrogen (NO3-N) (0-30cm), phosphorus (P) (0 – 20 cm), and potassium (K) soil test (0 – 20 cm) nutrient concentrations obtained prior to sugarbeet planting, Richville, MI, 2018-2019.*

| Year | Soil description | Soil test† | | | | |
|---|---|---|---|---|---|---|
| | | $NO_3$-N | P | K | pH | OM |
| | | ----------mg $kg^{-1}$------------ | | | | g $kg^{-1}$ |
| 2018 | Tappan-Londo Loam | 2.2 | 34 | 227 | 8.0 | 24 |
| 2019 | Tappan-Londo Loam | 2.6 | 15 | 137 | 8.2 | 24 |

*†P phosphorus (Olsen sodium bicarbonate extraction); K potassium (ammonium acetate extractable K).*

## Experimental Procedures for Population, N Rate, and Starter N Study

Plots measured 4.5 m in width by 10.7 m in length utilizing 76 cm row spacing. Trial consisted of 16 treatments arranged as a randomized complete-block split-plot design with four replications. Main plots consisted of seeding rate while subplots were N rate and starter N. The two seeding rates were one seed every 8.9 cm (148,260 seeds ha-1) or 10.4 cm (123,552 seeds ha-1). Four N rates were 0, 89, 179, and 269 kg N ha-1 total N. Starter N included 45 kg N ha-1 applied 5 cm below and 5 cm laterally from the seed at planting or no application. Sidedress N application rates were reduced by 45 kg N ha-1 in treatments containing starter fertilizer, but total N rates remained the same at either 0, 89, 179, and 269 kg N ha-1 total N. Nitrogen source for all treatments was urea ammonium nitrate (UAN, 28N-0P2O5-0K2O). Treatments received remainder of total N (i.e., minus starter N) injected to 12.7 cm depth and halfway between the rows at 2-4 leaf growth stage on 30 May 2018 and 4 June 2019 using UAN.

Trials were planted on 30 April 2018 and 25 April 2019 utilizing variety 'Crystal G675' (ACH Seeds, Inc., Eden Prairie, MN) with a Monosem planter (Monosem Inc., Kansas City, KS). Plant emergence was counted 20-30 days after planting to confirm actual plant population equaled targeted plant population. Percent ground coverage was determined utilizing digital images taken every 10-14 days from each plot starting at the 2-4 leaf growth stage and lasting through canopy closure (Patrignani and Ochsner, 2015). The uppermost fully developed and extended leaf and petiole were collected from 10 plants plot-1 at the 6-8 leaf growth stage. Plant tissue samples were dried at 60°C, mechanically ground to pass through a 1-mm mesh screen, and analyzed for total N using a micro-Kjeldahl digestion method and colorimetric analysis with a Lachat rapid flow injector autoanalyzer (Nelson and Sommers, 1973; Bremner, 1996). Roots from the center two rows of each plot were harvested on 17 October 2018 and 14 October 2019 with a mechanical plot harvester and weighed. Root subsamples were collected from each plot (10-12 roots plot-1) analyzed for sucrose concentration, extraction percentage, and recoverable sucrose at the Michigan Sugar Co. laboratory (Bay City, MI).

## Experimental Procedures for Row Spacing and N Placement Study

Plots measured 4.5 m in width by 10.7 m in length and consisted of four treatments arranged as a randomized complete-block split-plot design with four replications. Main plots consisted of row spacing while subplots were at-plant N strategy. The row spacings were 56 and 76 cm while the two N strategies were 45 kg N ha-1 surface applied after planting (PRE) with urea (46-0-0 N-P-K) or 45 kg N ha-1 applied 5 cm below and 5 cm laterally from the seed (5x5) with UAN (28-0-0 N-P-K). The PRE N rate coincided with the 5x5 N rate to measure the impact of starter N and not differences in total N rate or timing. Treatments containing the PRE strategy included a urease inhibitor (UI) (N-(n-butyl)-thiophosphoric triamide (NBPT) [2.09 ml kg-1 urea]; Koch Agronomic Services LLC, Wichita, KS) to prevent surface N volatilization as the 5x5 N was applied subsurface where minimal volatilization occurs. All treatments received 134 kg N ha-1 using urea (46-0-0 N-P-K) with a UI at the 2-4 leaf growth stage on 30 May 2018 and 4 June 2019.

Trials were planted on 30 April 2018 and 25 April 2019 utilizing variety 'Crystal G675' (ACH Seeds, Inc., Eden Prarie, MN) with a Monosem planter (Monosem Inc., Kansas City, KS) at a rate of one seed every 14.4 cm for 56 cm rows and every 10.4 cm for 76 cm rows (123,552 seeds ha-1). Plant emergence was counted 20-30 days after planting to validate plant populations. Percent ground coverage was determined utilizing digital images taken every 10-14 days from each plot starting at the 2-4 leaf growth stage and lasting through canopy closure using the software Canopeo (Patrignani and Ochsner, 2015). Roots from the center two rows of each plot were harvested on 17 October 2018 and 14 October 2019 with a mechanical plot harvester and weighed. Root subsamples were collected from each plot (10-12 roots plot-1) and analyzed for sucrose concentration, extraction percentage, and recoverable sucrose at the Michigan Sugar Co. laboratory (Bay City, MI).

Expected economic net return was calculated using both root yield and recoverable sucrose (kg Mg-1) in addition to MSC's average payment standard (2018-2019) (Michigan Sugar Company, Bay City, MI) for 2018. Expected net return was based on US$45.1 Mg-1 (fresh weight) for sugarbeet roots which was later adjusted based on a ratio of observed recoverable sucrose (kg Mg-1) to average Michigan Sugar Company's recoverable sucrose (kg Mg-1) value of 119 kg Mg-1. Michigan Sugar Company 2019 payment standards were calculated using adjustment factors based on harvest date to determine amount of sugar delivered (kg ha-1). Adjustment factors used were 1.07 for root yield and recoverable sucrose (kg ha-1) and then multiplied by US$0.08 kg-1 to equal total payment ha-1. Variable costs of N fertilizer (US$0.97 kg-1) and trucking (US$4.13 Mg-1) were subtracted from expected net return across years.

Data were analyzed in SAS 9.4 (SAS Institute, 2012) using the GLIMMIX procedure (SAS Institute, 2012). Year, population, N rate, and starter N were considered fixed effects and replication as random for the population, N rate, and starter N study. Year, row spacing, and N placement were considered fixed effects and replication as random for the row spacing study. Data were analyzed separately after being determined to be significantly different by year for both studies ($P \leq 0.10$). Dunnett's test was used to compare the untreated control relative to all treatments receiving N to verify N responsive locations (Dunnett, 1955). The UNIVARIATE procedure in SAS was used to examine the normality of residuals ($P \leq 0.05$). Squared and absolute values of residuals were examined with Levene's Test to confirm homogeneity of variances ($P \leq 0.05$). Least square means were separated using the LINES option of the slice statement when ANOVA indicated a significant interaction ($P \leq 0.10$). A linear plateau model was developed to investigate the response of root yield and recoverable sucrose per hectare to N rate for the population, N rate, and starter N study. Pearson product-moment correlations were generated using the REG procedure of SAS to investigate the relationships between root yield and recoverable sucrose per ha-1 with 6-8 leaf tissue N concentration.

## Results and Discussion

### Environmental Conditions

Total growing season (April-September) precipitation deviated -4% and +13% from the 30-yr mean during 2018 and 2019, respectively (Table 2). However, May-June total precipitation was 43% below and 88% above the 30-yr mean in 2018 and 2019, respectively, while August precipitation was 140% above and 68% below the 30-yr mean in 2018 and 2019, respectively. This precipitation pattern created contrasting dry early/wet late and wet early/dry late seasons between 2018 and 2019, respectively. Dry August 2019 soil conditions from deficit precipitation likely limited sugarbeet bulking and concomitantly decreased overall root yield. Except for April 2018, monthly growing season air temperatures were near the 30-yr mean. A late April 2018 planting date resulted in little impact on sugarbeet emergence or growth from cool air temperatures.

**Table 2.** *Mean monthly and 30-yr precipitation† and temperature for the sugarbeet growing season, Richville, MI, 2018 - 2019.*

| Year | Apr. | May | Jun. | Jul. | Aug. | Sept. | Total |
|---|---|---|---|---|---|---|---|
| | | | | ----------cm---------- | | | |
| | | | | ----------°C---------- | | | |
| | | | | ----------cm---------- | | | |
| | | | | ----------°C---------- | | | |
| | | | | ----------cm---------- | | | |
| | | | | ----------°C---------- | | | |
| 2018 | 7.1 | 5.4 | 3.8 | 5.0 | 20.1 | 4.9 | 46.3 |
| 2019 | 5.8 | 12.8 | 17.7 | 6.0 | 2.7 | 9.6 | 54.6 |
| 30-yr‡ avg. | 7.3 | 8.6 | 7.6 | 6.6 | 8.4 | 9.7 | 48.2 |
| | | | | ----------°C---------- | | | |
| 2018 | 3.6 | 17.6 | 19.7 | 22.1 | 21.8 | 17.8 | -- |
| 2019 | 7.4 | 12.8 | 18.4 | 22.6 | 19.9 | 17.9 | -- |
| 30-yr avg. | 7.8 | 14.1 | 19.6 | 21.7 | 20.4 | 16.3 | -- |

*†Precipitation and air temperature data were collected from Michigan State University Enviro-weather (https://enviroweather.msu.edu/).*

*‡30-yr means were obtained from the National Oceanic and Atmospheric Administration (https://www.ncdc.noaa.gov/cdo-web/datatools/normals).*

### Effects of Population, N Rate, and Starter N on Root Yield, Quality, and Expected Net Return

An interaction between total N rate and starter N fertilizer influenced root yield ($P < 0.01$) and recoverable sucrose per hectare ($P < 0.01$) in 2018 (Table 3). When utilizing subsurface banded starter

N, a total N rate of 179 kg N ha-1 produced the greatest root yield at 80.7 Mg ha-1. However when subsurface banded starter N was not utilized, a total N rate of 269 kg N ha-1 was required to achieve a similar root yield. At the 179 kg N ha-1 rate, starter N increased root yield 13.4 Mg ha-1 compared to no starter N. Total N rate of 179 kg N ha-1 also produced maximum recoverable sucrose per hectare (8691-10371 kg ha-1) with and without starter N. Starter N increased recoverable sucrose per hectare 10 and 20% at 89 and 179 kg N ha-1, respectively, compared to no starter N. Limited May-June precipitation in combination with cool April air temperatures leading into plant emergence may have limited early season (May-June) vegetative growth where starter N was absent thus providing opportunities for starter N to increase root yield and recoverable sucrose per hectare. Starter N increased canopy coverage 10-17% (data not shown) throughout the growing season which may have translated into increased light interception, root yield, and recoverable sucrose per hectare as compared to no starter N at the 179 kg N ha-1. Starter N may promote quicker vegetative growth compared to no starter N during dry soil conditions by providing N near developing roots from the seed which may increase light interception and translate into season-long vigor and greater root sucrose (Hergert, 2011; Gehl and Boring, 2011). The primary purpose of starter N is to accelerate early season sugarbeet growth rates to achieve maximum development at an earlier point in the season (Clark et al., 2010; Overstreet and Cattanach, 2010). Results agree with Clark et al. (2010) who found 56 kg N ha-1 in a starter N application increased root yield and recoverable sucrose per hectare 13.5 Mg ha-1 and 910 kg ha-1, respectively, compared to no starter N. Current data also suggest application of starter N may provide opportunities for growers to produce optimal root yield and recoverable sucrose per hectare at decreased N rates.

**Table 3.** *Starter nitrogen (N) fertilizer and total N rate interaction on sugarbeet root yield (Mg ha-1) and recoverable sucrose (kg ha-1), Richville, MI, 2018.*

| Total N | **Root yield** | | | **Recoverable sucrose** | | |
|---|---|---|---|---|---|---|
| Rate | Starter | No Starter | ***P > F*** | Starter§ | No Starter | ***P > F*** |
| | --------Mg ha$^{-1}$-------- | | | --------kg ha$^{-1}$-------- | | |
| 0 | 51.6 c†A‡ | 53.8 bA | 0.74 | 6777 cA | 7073 cA | 0.55 |
| 89 | 69.5 bA | 62.8 bA | 0.12 | 9253 bA | 8440 bB | 0.06 |
| 179 | 80.7 aA | 67.3 bB | <0.01 | 10371 aA | 8691 abB | <0.01 |
| 269 | 76.2 aA | 76.2 aA | 0.86 | 9398 bA | 9249 aA | 0.74 |
| ***P > F*** | <0.01 | <0.01 | | <0.01 | <0.01 | |

*†Means in the same column following by the same lowercase letter are not significantly different at P ≤ 0.10.*

*‡Means in the same row following by the same uppercase letter are not significantly different at $P \leq 0.10$.*

*§Sidedress N application rates were reduced by 45 kg N ha-1 in treatments containing starter fertilizer, but total N rates remained the same at either 0, 89, 179, and 269 kg N ha-1 total N.*

Nitrogen rate influenced root yield ($P < 0.01$) and recoverable sucrose per hectare ($P < 0.01$) in 2019 (Table 4). A linear plateau model was best fit across all treatments and suggested maximum root yield occurred at 145 and 170 kg N ha-1, but recoverable sucrose per hectare was maximum at 115 and 146 kg N ha-1 in 2018 and 2019, respectively. Across 2019 tested N rates, a total of 179 kg N ha-1 produced optimal root yield and recoverable sucrose per hectare. Nitrogen rates for peak sucrose per hectare averaged 27 kg N ha-1 lower than N rates required for peak root yield across years. Optimal N rates required to achieve maximum root yield and recoverable sucrose were greater in 2019 (i.e., early wet/ late dry) than 2018 (early dry/late wet) likely due to an 88% increase in May-June 2019 rainfall from 30-year means (Table 2). Data from this study provides support to both the university and MSC's total N recommendation for sugarbeet following corn in Michigan (Warncke et al., 2009; MSC, 2020). Previous research from both Michigan and Ontario found optimal root yields with N rates between 157 and 168 kg N ha-1 following corn (Clark et al., 2010; DeBruyn et al., 2017). Clark et al. (2010) suggested greater amounts of N may be needed to satisfy sugarbeet N requirements when heavy corn residues are present, however application of a 5x5 starter N at planting may negate needs for greater N rates due to N placement beneath the residue layer. Nitrogen can immobilize in high C:N ratio residue (e.g., corn) decomposition resulting in period of N unavailability until decomposition is complete (Green and Blackmer, 1995). Michigan Sugar Company N rate recommendations following corn are typically greater compared to soybean (*Glycine max* L. Merr.) or dry bean (*Phaseolus vulgaris* L.) due to greater C:N ratios from corn residue compared to leguminous crops (MSC, 2020). Optimal N rates should account for both economic net return and reducing potential N losses rather than solely relying upon root yield (DeBruyn et al., 2017). Root yield was not influenced by starter N in 2019 likely due to excessive May-June rainfall which may have hindered root establishment limiting root access to starter N (Finch et al., 2014). Results suggest starter N may provide a greater benefit under dry early season (i.e., May-June) conditions by promoting early season root and above ground growth which may translate into longer-term root and sucrose yield gains.

**Table 4.** *Population, total nitrogen (N) rate, and starter N fertilizer main effects on sugarbeet root yield, recoverable sucrose (kg ha-1 and kg Mg-1), sucrose concentration, and extraction, Richville, MI, 2019.*

| Treatment | Root yield | Recoverable sucrose | | Sucrose | Extraction |
|---|---|---|---|---|---|
| | --Mg ha$^{-1}$-- | --kg ha$^{-1}$-- | --kg Mg$^{-1}$-- | --%-- | --%-- |
| Population, seeds ha$^{-1}$ | | | | | |
| 123552 | 57.4a | 8095a | 141a | 20.6a | 97.0a |
| 148260 | 57.8a | 8264a | 141a | 20.5a | 97.1a |
| ***P > F*** | 0.92 | 0.68 | 0.79 | 0.74 | 0.17 |
| N Rate, kg N ha$^{-1}$ | | | | | |
| 0 | 41.9c | 5898c | 140b | 20.2b | 97.2a |
| 89 | 54.2b | 8030b | 145a | 20.8a | 97.2a |
| 179 | 66.4a | 9473a | 143ab | 21.0a | 97.0b |
| 269 | 67.9a | 9317a | 137c | 20.2b | 96.8b |
| ***P > F*** | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 |
| Starter N | | | | | |
| Starter | 58.5a | 8297a | 142a | 20.7a | 97.1a |
| No Starter | 56.5a | 8062a | 141a | 20.4b | 97.0a |
| ***P > F*** | 0.27 | 0.36 | 0.65 | 0.02 | 0.72 |

*†Means in the same column following by the same lowercase letter are not significantly different at $P \leq 0.10$.*

Nitrogen rate significantly affected recoverable sucrose per Mg ($P$ < 0.01) and sucrose concentration ($P$ < 0.01) in 2018 and 2019, while only affecting extraction percentage in 2019 ($P$ < 0.01) (Table 4, 5). Starter N affected sucrose concentration ($P$ < 0.02) in 2019. Among N treatments, recoverable sucrose per Mg was optimal at 89 kg N ha-1 while N rates ≥ 179 kg N ha-1 reduced recoverable sucrose per Mg and sucrose concentration similarly in 2018 and 2019. Extraction percentages decreased at 179 and 269 kg N ha-1 in 2019, however differences were minimal and likely did not affect recoverable sucrose or sucrose concentration. Starter N increased sucrose concentration 0.3% compared to no starter in 2019. Nitrogen fertilizer application often has an inverse relationship with recoverable sucrose per Mg and sucrose concentration due to increased water retention by the taproot associated with increased growth rates from applied N (Draycott and Christenson, 2003; Draycott, 2006). In 2019, higher N rates were required to decrease recoverable sucrose per Mg than 2018 due to August precipitation being 68% below the 30-yr mean which likely limited overall water absorption and therefore N. In 2019, starter N increased canopy coverage 6.8% at 60 days after planting (DAP) (data not shown) compared to no starter which likely translocated more sucrose into the root due to greater light interception from increased above ground leaf biomass (Draycott, 2006). Despite the inverse relationship between N rate and both recoverable sucrose per Mg and sucrose concentration, the direct relationship between N rate and root yield requires both yield and quality consideration when contemplating overall changes in expected net return (DeBruyn et al., 2017)

**Table 5.** *Population, total nitrogen (N) rate, and starter N fertilizer main effects on sugarbeet recoverable sucrose (kg Mg-1), sucrose concentration, and extraction, Richville, MI, 2018.*

| Treatment | Recoverable sucrose | Sucrose | Extraction |
|---|---|---|---|
| | ---kg $Mg^{-1}$--- | ---%--- | ---%--- |
| Population, seeds $ha^{-1}$ | | | |
| 123552 | 129a† | 19.8a | 96.3a |
| 148260 | 130a | 19.9a | 96.3a |
| ***P > F*** | 0.42 | 0.48 | 0.75 |
| N Rate, kg N $ha^{-1}$ | | | |
| 0 | 133a | 20.2a | 96.4a |
| 89 | 134a | 20.4a | 96.5a |
| 179 | 130b | 19.8b | 96.4a |
| 269 | 123c | 18.8c | 96.2a |
| ***P > F*** | <0.01 | <0.01 | 0.21 |
| Starter N | | | |
| Starter | 130a | 19.9a | 96.3a |
| No Starter | 129a | 19.8a | 96.4a |
| ***P > F*** | 0.51 | 0.47 | 0.26 |

*†Means in the same column following by the same lowercase letter are not significantly different at $P \leq 0.10$.*

An interaction between N rate and starter N fertilizer influenced expected net return ($P < 0.02$), expected net return minus N costs ($P < 0.03$), and expected net return minus N and trucking costs ($P < 0.01$) in 2018 (Table 6). The 179 kg N ha-1 rate produced the greatest expected net return with or without starter N (US$ ha-1) in 2018. However when N or trucking costs were taken into consideration, 89 kg N ha-1 maximized expected net return with and without starter N. Starter N provided a 20-21% increase in expected net return, expected net return minus N costs, and expected net return minus N and trucking costs at the 179 kg N ha-1 rate compared to no starter N in 2018. Main effects of N rate influenced expected net return, expected net return minus N costs, and expected net return minus N and trucking costs ($P < 0.10$) in 2019 (Table 7). In 2019, total N rates of 179 kg N ha-1 maximized expected net return across all economic variables. Data did not show yield or profitability benefits when applying above university recommended N rates (179 kg N ha-1). Yield loss from underapplication of N is often perceived as a greater risk than reductions in sucrose concentration and recoverable sucrose from overapplying N, but greater root yields may not offset increased production costs resulting in greater expected net returns at lower yield potentials (Mourtzinis et al., 2017; Rutan and Steinke, 2017; Chatterjee et al., 2018). Results suggest that starter N improved overall 2018 profit by promoting plant growth during dry early season soil conditions (i.e. May-June precipitation deficits) which correspondingly decreased the overall N rate required to achieve maximum root yield. Greater emphasis upon optimal recoverable sucrose per hectare should be the main objective when implementing management practices to maximize expected net return as the current payment structure rewards growers based solely off recoverable sucrose per hectare rather than previous payment structures (e.g., pre-2019) which rewarded growers based upon root yield and recoverable sucrose per Mg incentives.

**Table 6.** *Starter nitrogen (N) fertilizer and total N rate interaction on sugarbeet expected net return, expected net return minus N costs, and expected net return minus N and trucking costs, Richville, MI, 2018.*

| | Expected net return[§] | | | Expected net return minus N costs | | | Expected net return minus N and trucking costs | | |
|---|---|---|---|---|---|---|---|---|---|
| N Rate | Starter | No Starter | ***P > F*** | Starter | No Starter | ***P > F*** | Starter | No Starter | ***P > F*** |
| | US$ ha$^{-1}$ | | | | | | | | |
| 0 | 2572c[‡]A[‡] | 2654cA | 0.64 | 2575cA | 2654bA | 0.64 | 2360cA | 2436bA | 0.63 |
| 89 | 3499bA | 3193bA | 0.23 | 3413abA | 3106aA | 0.23 | 3128abA | 2841aA | 0.22 |
| 179 | 3929aA | 3287abB | <0.01 | 3756aA | 3114aB | <0.01 | 3425aA | 2834aB | <0.01 |
| 269 | 3553bA | 3511aA | 0.69 | 3294bA | 3252aA | 0.69 | 2980bA | 2933aA | 0.62 |
| ***P > F*** | <0.01 | <0.01 | | <0.01 | <0.01 | | <0.01 | <0.01 | |

*†Means in the same column following by the same lowercase letter are not significantly different at P ≤ 0.10.*

*‡Means in the same row following by the same uppercase letter are not significantly different at P ≤ 0.10.*

*§Expected net returns based upon US$45.1 Mg-1 base payment with volume and quality incentives, an N price of $0.97 kg-1, and trucking costs of $US$4.13 Mg-1.*

**Table 7.** *Population, total nitrogen (N) rate, and starter N fertilizer main effects on sugarbeet expected net return, expected net return minus N costs, and expected net return minus N and trucking costs, Richville, MI, 2019.*

| Treatment | Expected net return ‡ | Expected net return minus N costs | Expected net return minus N and trucking costs |
|---|---|---|---|
| | -----------------------------US$ ha$^{-1}$ | ----------------------------- | |
| Population, seeds ha$^{-1}$ | | | |
| 123552 | 3496a | 3366a | 3128a |
| 148260 | 3569a | 3439a | 3197a |
| ***P > F*** | 0.68 | 0.68 | 0.68 |
| N Rate, kg N ha$^{-1}$ | | | |
| 0 | 2547c | 2547c | 2374c |
| 89 | 3468b | 3381b | 3152b |
| 179 | 4091a | 3917a | 3643a |
| 269 | 4021a | 3763a | 3482a |
| ***P > F*** | <0.01 | <0.01 | <0.01 |
| Starter N | | | |
| Starter | 3584a | 3453a | 3211a |
| No Starter | 3482a | 3351a | 3115a |
| ***P > F*** | 0.36 | 0.36 | 0.36 |

*†Means in the same column following by the same lowercase letter are not significantly different at P ≤ 0.10.*

*‡Expected net returns based upon harvest date adjustment factor for recoverable sucrose (kg ha-1) and then multiplied by US$0.08 to determine final payment, an N price of $0.97 kg-1., and trucking costs of US$4.13 Mg-1.*

## Effect of Population, N Rate, and Starter N on Tissue N Concentration

An interaction between N rate and starter N influenced 6-8 leaf total N concentration ($P$ < 0.01) in 2018 (Table 8), while only main effects of plant population ($P$ < 0.09), N rate ($P$ < 0.01) and starter N ($P$ < 0.02) influenced 6-8 leaf tissue N concentration in 2019 (Table 9). Six to eight leaf total N concentration was maximized at 179 kg N ha-1 in 2018 and 2019. At 89 and 179 kg N ha-1, 6-8 leaf total

N concentration increased 0.4 and 0.5%, respectively, with starter N application in 2018. In 2019, 6-8 leaf total N concentration increased 0.3% in the low seeding rate (123,552 seeds ha-1) compared to the high seeding rate (148,260 seeds ha-1). Six-eight leaf total N concentration increased 0.3% without starter N in 2019 as compared to including starter N. With dry May-June conditions, starter N was likely accessed by the root soon after root emergence which facilitated sufficient early canopy growth and diluted N concentrations but is suggested for optimal N management in rainfed sugarbeet production systems (Hergert, 2011; Steinke and Bauer, 2017). At the low seeding rate, individual plants were likely able to uptake more applied N due to less interplant competition resulting in an increase in 6-8 leaf total N concentration (Suhre et al., 2014). Although differences occurred between treatments in both years, all 6-8 leaf tissue N concentrations exceeded the minimum N sufficiency range (i.e., 3.0%) for sugarbeet (Vitosh et al., 1988) suggesting differences did not affect root yield or quality. Pearson product-moment correlations suggested a weak positive relationship between 6-8 leaf tissue N concentration and root yield ($r$ = 0.49, $P$ < 0.01) or recoverable sucrose per ha-1 ($r$ = 0.49, $P$ < 0.01). Although optimal N rates were similar for tissue concentration and root yield, tissue N may be an unreliable predictor for overall optimum N rate due to variable precipitation patterns throughout the growing season and the inverse effects of N on sugarbeet quality (Hergert et al., 2011; Sharma and Bali, 2018).

**Table 8.** *total nitrogen (N) rate and starter N fertilizer interaction on sugarbeet 6-8 leaf growth stage tissue total N concentration, Richville, MI 2018.*

| | Total N | | |
|---|---|---|---|
| N Rate | Starter | No Starter | ***P > F*** |
| | -----------%----------- | | |
| 0 | 3.7c[†]B[‡] | 3.9bA | 0.07 |
| 89 | 4.3bA | 3.9bB | <0.01 |
| 179 | 4.5aA | 4.0aB | <0.01 |
| 269 | 4.4aA | 4.1aA | <0.01 |
| ***P > F*** | <0.01 | 0.07 | |

*†Means in the same column following by the same lowercase letter are not significantly different at P ≤ 0.10.*

*‡Means in the same row following by the same uppercase letter are not significantly different at P ≤ 0.10.*

**Table 9.** *Population, total nitrogen (N) rate, and starter N fertilizer main effects on sugarbeet 6-8 leaf growth stage tissue total N concentration, Richville, MI 2019.*

| Treatment | Total N† |
|---|---|
| | ---%--- |
| Population, seeds ha$^{-1}$ | |
| 123552 | 4.4a‡ |
| 148260 | 4.1b |
| ***P > F*** | 0.09 |
| N Rate, kg N ha$^{-1}$ | |
| 0 | 3.6c |
| 89 | 4.2b |
| 179 | 4.7a |
| 269 | 4.6a |
| ***P > F*** | <0.01 |
| Starter N | |
| Starter | 4.1b |
| No Starter | 4.4a |
| ***P > F*** | 0.02 |

*†Uppermost fully developed and extended leaf and petiole samples from 10 plants per plot.*

*‡Means in the same column following by the same lowercase letter are not significantly different at $P \leq 0.10$.*

## Effect of Row Spacing and N Placement on Root Yield, Quality, and Expected Net Return

Nitrogen placement significantly affected root yield in 2018 ($P < 0.08$) while row spacing significantly affected root yield in 2018 ($P < 0.09$) and 2019 ($P < 0.02$) (Table 10). Row spacing at 56 cm increased root yield 14.5 and 23.8 Mg ha-1 compared to 76 cm rows in 2018 and 2019, respectively. Roots grown in narrower rows have greater intra-plant spacing and due to less interplant competition often utilize nutrients and moisture more efficiently (Yonts and Smith, 1997; Grove et al., 2005). Total August 2019 rainfall was 68% below the 30-yr mean (Table 2), and the larger yield increase from 56 cm rows, compared to 2018, suggests dry soil conditions had a greater impact on the wider row spacing perhaps due to evaporative moisture losses from bare soil due to greater distance and less shading between rows (Bhattacharya, 2019).

**Table 10.** *Row spacing and starter nitrogen (N) fertilizer placement effects on sugarbeet root yield, recoverable sucrose (kg ha-1 and kg Mg-1), sucrose concentration, and extraction, Richville, MI, 2018-2019.*

| Treatment | Root yield | Recoverable sucrose | | Sucrose | Extraction |
|---|---|---|---|---|---|
| | | | 2018 | | |
| | --Mg ha$^{-1}$-- | --kg ha$^{-1}$-- | --kg Mg$^{-1}$-- | ---%--- | ---%--- |
| Row Spacing | | | | | |
| 56 cm | 75.8a | 8759a | 116b | 18.2b | 95.2b |
| 76 cm | 61.3b | 7516a | 122a | 19.1a | 95.9a |
| ***P > F*** | 0.09 | 0.16 | 0.07 | 0.07 | 0.07 |
| N Placement | | | | | |
| 5x5 | 70.7a | 8413a | 119a | 18.7a | 95.6a |
| PRE | 66.4b | 7862a | 119a | 18.6a | 95.5a |
| ***P > F*** | 0.08 | 0.16 | 0.84 | 0.82 | 0.95 |
| | | | 2019 | | |
| | --Mg ha$^{-1}$-- | --kg ha$^{-1}$-- | --kg Mg$^{-1}$-- | ----%---- | ----%---- |
| Row Spacing | | | | | |
| 56 cm | 80.7a | 9980a | 123b | 19.4a | 96.2a |
| 76 cm | 56.9b | 7801b | 137a | 19.9a | 96.5a |
| ***P > F*** | 0.02 | 0.05 | <0.01 | 0.14 | 0.50 |
| N Placement | | | | | |
| 5x5 | 69.2a | 8843a | 129a | 19.6a | 96.4a |
| PRE | 68.4a | 8938a | 132a | 19.7a | 96.3a |
| ***P > F*** | 0.85 | 0.89 | 0.18 | 0.48 | 0.70 |

*†Means in the same column following by the same lowercase letter for each year are not significantly different at P ≤ 0.10.*

Greater yield with narrower row spacing has been documented previously with similar row spacing comparisons (Cattanach and Schroeder, 1980; Dillon and Schmehl, 1971; Yonts and Smith, 1997, Groulx et al., 2010). However, the question many growers ask is whether starter N still benefits at the narrower row spacing. In 2018, 5x5 N placement increased root yield 4.3 Mg ha-1 compared to PRE N placement with a urease inhibitor. Nitrogen placed close to the seed using 5x5 applications allows the plant easier access to soluble N especially in sugarbeet where limited ability for lateral seedling root movement exists (Weaver, 1926; Stevens et al., 2007). During soil moisture stress, N is more readily available from subsurface (5x5) placement as compared to surface (PRE) placement (Stevens et al., 2007). Though use of a urease inhibitor likely limited N volatilization potential of the surface applied PRE N treatment, the dry May-June 2018 soil conditions likely limited N movement from PRE placement into the rhizosphere providing opportunities for root yield increases from 5x5 N placement due to closer N proximity. Results highlight one of the risk factors to surface-applied N applications which is greater potential for positional unavailability during dry soil conditions. No differences were observed between N placements in 2019 likely due to excessive May-June rainfall inhibiting root establishment thus restricting benefits of N placed closer to the seed or sufficient moisture to distribute N throughout the rootzone regardless of placement (Finch et al., 2014). Benefits of PRE placement include ease and quickness of application, but potential exists for volatilization and surface-runoff N losses. Additionally, disadvantages of 5x5 placement (i.e., soil disturbance, slower planting speeds, delayed planting dates due to moist soils) may be outweighed by the consistency of increased vegetative and root growth offered from subsurface N placement but results will depend upon season long climatic conditions.

Row spacing significantly affected recoverable sucrose per Mg ($P <$ 0.07), sucrose concentration ($P < 0.07$) and extraction ($P < 0.07$) in 2018 but only recoverable sucrose per Mg ($P < 0.01$) and recoverable sucrose per hectare ($P < 0.05$) in 2019 (Table 10). Sucrose concentration and extraction increased 0.9 and 0.7%, respectively, with 76 cm rows in 2018. Recoverable sucrose increased 6 and 14 kg Mg-1 with 76 cm rows in 2018 and 2019, respectively. Although recoverable sucrose per Mg was greater from 76 rows, recoverable sucrose per hectare increased 28% with 56 cm rows in 2019 likely due to the large observed root yield increase. Sugarbeet grown in 56 cm rows may have produced larger individual roots that absorbed more moisture due to less inter-plant competition within a row which lowered the concentration of sucrose in 2018 (Hills, 1972; Alford et al., 2003). Data suggest increases in sucrose concentration and extraction percentage likely translated into an increase in recoverable sucrose per Mg from 76 cm rows in 2018, as recoverable sucrose per Mg is calculated using the two parameters (Tarkalson et al., 2012). In 2019, dry August conditions may have limited moisture availability within 76 cm rows due to greater evapotranspiration from bare soil between plants and rows which likely decreased sugarbeet root water tissue thus concentrating recoverable sucrose per Mg. An advantage of utilizing 56 cm rows is the ability to increase intra-row spacing to reduce interplant competition. However 76 cm rows may produce comparable root and sucrose yields with sufficient August rainfall while also allowing more room for air movement between rows to reduce risk of disease (Clark et al., 2010; Palti, 1981).

Row spacing significantly affected expected net return ($P < 0.05$) and expected net return minus trucking costs ($P < 0.05$) in 2019 (Table 11). Expected net return and expected net return minus trucking costs increased 27-28% with 56 cm rows. Before 2019, MSC awarded grower payment based upon a base payment with volume and quality incentives, however current payment structure emphasizes the importance of maximizing recoverable sucrose per hectare instead of root yield or recoverable sucrose per Mg individually. Greater expected net return in 2019 from 56 cm rows was directly influenced by the increase of recoverable sucrose per hectare observed. This study did not reflect other factors, such as equipment, which may impact overall farm efficiency and profitability. Growers should be cognizant of associated costs when considering row spacings and the impact of changing to a narrow or wide row spacing on other rotational crops, such as corn or soybean, when sharing planting equipment between cropping systems.

**Table 11.** *Row spacing and starter N fertilizer placement effects on sugarbeet expected net return and expected net return minus trucking costs, Richville, MI, 2018-19.*

| Treatment | Expected Net Return ‡ | Expected Net Return Minus trucking costs |
|---|---|---|
| | **2018‡** | |
| | --------------------US$ $ha^{-1}$-------------------- | |
| Row Spacing | | |
| 56 cm | 3312a† | 2999a |
| 76 cm | 2842a | 2589a |
| ***P > F*** | 0.16 | 0.17 |
| N Placement | | |
| 5x5 | 3182a | 2889a |
| PRE | 2973a | 2543a |
| ***P > F*** | 0.16 | 0.17 |
| | **2019§** | |
| | --------------------US$ $ha^{-1}$-------------------- | |
| Row Spacing | | |
| 56 cm | 4310a | 3976a |
| 76 cm | 3369b | 3134b |
| ***P > F*** | 0.05 | 0.05 |
| N Placement | | |
| 5x5 | 3819a | 3533a |
| PRE | 3860a | 3578a |
| ***P > F*** | 0.89 | 0.87 |

*†Means in the same column following by the same lowercase letter are not significantly different at P ≤ 0.10.*

*‡Expected net returns based upon US$45.1 Mg-1 base payment with volume and quality incentives and trucking costs of $US$4.13 Mg-1.*

*§Expected net returns based upon harvest date adjustment factor for recoverable sucrose (kg ha-1) and then multiplied by US$0.08 to determine final payment, an N price of $0.97 kg-1., and trucking costs of US$4.13 Mg-1.*

## Effect of Row Spacing and N placement on Row Closure

An interaction between row spacing and N placement influenced canopy coverage 37 and 51 DAP ($P < 0.01$) in 2018 (Table 12). Within 56 cm rows, 5x5 N placement increased canopy coverage 3.0 and 15.1% at 37 and 51 DAP compared to PRE N with no differences observed at the wider row spacing. At both 37 and 51 DAP however, PRE N placement resulted in a 1.5 and 7.2% increase in canopy coverage with 76 cm rows as compared to the narrower 56 cm rows while 5x5 placement appeared to have a greater impact on the 56 cm rows at 51 DAP. Limited May-June 2018 precipitation likely hindered N movement from PRE placement into the root zone and canopy coverage differences at 37 and 51 DAP between row spacings was likely due to plants in 76 cm rows utilizing greater area between rows for canopy growth (Stebbing et al., 2000). Nitrogen within the 5x5 N placement was likely accessed by the plant soon after root emergence which promoted above ground growth and resulted in an increase in canopy coverage (Hergert, 2011; Steinke and Bauer, 2017). Increase in row closure at 51 DAP with 5x5 N was likely due to less distance between rows in 56 cm rows compared to 76 cm. Sugarbeet growth rates are slower at 37-51 DAP compared to 90-100 DAP (De et al., 2019), and starter N applications may promote early season above ground biomass and provide an advantage for the remainder of the growing season (Stevens et al., 2007). As the growing season progressed (e.g., 70-90 DAP), differences in canopy coverage diminished between row spacing and N placement (data not shown) with both row spacings completing maximum row closure near the same day across years. Lack of canopy coverage differences at complete row closure indicate that despite having greater distance between rows, 76 cm rows can close row near similar dates as 56 cm rows. Data suggest 5x5 N placement still offers canopy coverage benefits in 56 cm rows and that 5x5 N should not be abandoned in row spacings narrower than 76 cm simply due to less distance between rows.

**Table 12.** *Sugarbeet percent canopy coverage as affected by a nitrogen rate and starter N fertilizer interaction at 37 and 51 days after planting (DAP), Richville, MI 2018.*

| Row Spacing | 37 DAP | | | 51 DAP | | |
|---|---|---|---|---|---|---|
| | 5x5 | PRE | ***P > F*** | 5x5 | PRE | ***P > F*** |
| | -------% canopy------- | | | -------% canopy------- | | |
| 56 cm | 6.1a†A‡ | 3.1bB | <0.01 | 42.2aA | 27.1bB | <0.01 |
| 76 cm | 4.6aA | 4.6aA | 0.99 | 37.3bA | 34.3aA | 0.24 |
| ***P > F*** | 0.11 | 0.08 | | 0.07 | 0.02 | |

*†Means in the same column following by the same lowercase letter are not significantly different at $P \leq 0.10$.*

*‡Means in the same row following by the same uppercase letter are not significantly different at $P \leq 0.10$.*

## Conclusions

In the current environment, tested plant populations did not affect root yield or quality in either year. Optimal N rates should incorporate maximizing expected net return, root yield, and sugar quality and not one component individually. Across tested N rates, 179 kg N ha-1 resulted in the best combination among root yield, quality, and expected net return further supporting university and MSC recommended N rates when following high residue crops such as corn or wheat. A linear plateau model suggested peak recoverable sucrose per hectare averaged 27 kg N ha-1 lower than peak root yield across years. Limited May-June precipitation may have limited early season plant growth where starter N was absent thus providing opportunities for 5x5 starter N to increase root yield and recoverable sucrose per hectare. Although excessive May-June 2019 precipitation hindered root development and reduced benefits from starter N, root yield or quality was not decreased by this fertilizer strategy. Advantages of starter N fertilizer may outweigh potential disadvantages by providing opportunities to increase N efficiency and decrease overall N rates by addressing early-season variable weather patterns.

Row closure was completed near the same date with both row spacings. Data suggest 5x5 starter N placement still offered row closure benefits in 56 cm row, and this fertilizer strategy should not be abandoned in row spacings narrower than 76 cm simply due to less distance between rows. Narrow (56 cm) rows increased root yield while wide (76 cm) rows increased recoverable sucrose per Mg across both years with narrower row spacing increasing recoverable sucrose per hectare in 2019. With the 2019 MSC payment structure, recoverable sucrose per hectare should be a primary factor for sugarbeet growers when making agronomic management decisions such as population, 5x5 starter N, overall N rate, and row spacing to increase expected net return. Growers should consider field conditions, soil texture, harvest date, sugar prices, and input costs prior to adopting broadly implemented management strategies such as plant population, N management, and row spacing.

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