

Intensive Nutrient Management Strategies to Improve Sugarbeet Root Yield, Recoverable Sugar and Profitability

LANE S. BEARSS¹, AND KURT STEINKE¹

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 (*Beta vulgaris*) nutrient management guidelines suggest 157-179 kg N ha⁻¹ (140-160 lbs. N A⁻¹) which may include an initial 44.8 kg N ha⁻¹ (40 lbs. N A⁻¹) applied at planting for a yield potential of 67.2 Mg ha⁻¹ (30 tons A⁻¹). While individually added inputs associated with yield gaps were previously investigated, nutrient interactions from added inputs when combined with a standard N program (SN) have not been explored. This study investigated sugarbeet response to SN combined with various nutrients or soil amendments across varying levels of management intensity. In 2022, SN treatment averaged 90.1 Mg ha⁻¹ (40.2 T A⁻¹), 148.4 kg Mg⁻¹ (296.8 lbs. T⁻¹) and 13,327.9 kg ha⁻¹ (11,890.9 lbs. A⁻¹). The addition of in-furrow P negatively impacted average root yield and recoverable sugar by -15.5 Mg ha⁻¹ (-6.9 T A⁻¹) and -2,325.7 kg ha⁻¹, (-2,074.9 lbs. A⁻¹) respectively. In 2023, pre-plant broadcast lime, in-furrow P, and intensive management increased average root yield by 13.7 (6.1), 11.9 (5.3), and 13.2 (5.9) Mg ha⁻¹ (T A⁻¹), respectively. The intensive management and pre-plant broadcast lime increased average recoverable sugar per Mg by +7.1 (+14.2) and +8.4 (+16.8) kg Mg⁻¹ (lbs. T⁻¹), respectively, while also improving average recoverable sugar per hectare by +2,329.8 (+2,078.6) and +2,278.0 (+2,032.4) kg ha⁻¹ (lbs. A⁻¹), respectively. All fertilizer treatments increased average treatment costs relative to SN in 2022 (USD 27.9–2,150.0 ha⁻¹; USD 11.3–870.1 A⁻¹) and 2023 (USD 27.9–1,671.8 ha⁻¹; USD 11.3–676.6 A⁻¹). However,

agricultural lime and in-furrow P increased the 2023 average potential profit by USD 1,109.1 ha⁻¹ (USD 448.8 A⁻¹) and USD 1,078.2 ha⁻¹ (USD 436.3 A⁻¹), respectively. These findings demonstrate that the agronomic and economic benefits of added nutrient inputs in sugarbeet production depend on site-year conditions, reinforcing the need for site-specific management to close yield gaps and maximize profitability.

Additional Key Words: starter fertilizer, nitrogen, phosphorus, lime, sulfur, boron, potassium, *Beta vulgaris*

Introduction

In 2022, Michigan sugarbeet (*Beta vulgaris* L.) production decreased 25% from 4.8 million Mg (5.3 million T.) to 3.6 million Mg (4.0 million T.) with an average yield of 64.5 Mg ha⁻¹ (28.8 T. A⁻¹) which was lower than the national average of 70.6 Mg ha⁻¹ (31.5 T. A⁻¹) (NASS, 2021; NASS 2022). To obtain more sugar on equal or fewer hectares while simultaneously addressing climate variabilities, soil spatial differences, and lack of predictability for disease occurrence, growers are increasingly exploring intensive nutrient management strategies including combinations of lime (Clark et al., 2015), phosphorus (P) applications (Steinke and Bauer, 2017), supplementary potassium (Milford et al., 2000), sulfur (Kastori et al., 2000), and foliar boron (B) (Armin and Asgharipour, 2012). Intensive management involves adjusting agronomic inputs to reduce yield gaps while

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accounting for site-specific yield variability (Harms et al., 1989).

Lime provides both direct and indirect benefits to soil-crop systems. Direct effects include neutralizing soil acidity (Olsson et al., 2019), improving nutrient availability (Holland et al., 2018), and reducing heavy metal solubility (Olego et al., 2021). Indirect effects include greater yields (DeSutter and Godsey, 2010), improved soil structure (Valzano et al., 2001), and enhanced biological activity (Holland et al., 2018). In Michigan sugarbeet production, agricultural lime is often replaced with precipitated calcium carbonate (PCC), a sucrose-processing byproduct, that is Ca-rich (35%) with a high calcium carbonate equivalence (CCE) (84.3%) (Clark et al., 2015). Although lime is generally not required in Michigan's neutral to alkaline soils, PCC is applied to recycle byproduct material, supply nutrients (Sims et al., 2010) and reduce seedling damping-off diseases caused by *Aphanomyces cochlioides* (Windels et al., 2007). Field studies report benefits of PCC, including yield and sucrose gains in Michigan (Clark et al., 2015), increased bicarbonate-extractable P in Idaho (Tarkalson et al., 2024), and reduced *Aphanomyces* soil index values in North Dakota (Windels et al., 2007). However, excessive PCC applications can increase soil pH and reduce both phosphate availability (Haynes, 1982) and micronutrient solubility (Fageria and Baligar, 2008) thus posing risks of nutrient deficiencies.

Nitrogen (N) is critical for sugarbeet production. In Michigan, the recommended N rate is 157–179 kg N ha⁻¹ (140–160 lbs. A⁻¹) with 44.8 kg N ha⁻¹ (40 lbs. A⁻¹) that may be applied at planting to promote canopy closure (Purucker and Steinke, 2022; Warncke et al., 2009). Sub-optimal N reduces root yield and recoverable sugar while excessive N increases root impurities (Carter and Traveller, 1981; Draycott and Christenson, 2003). Beyond rate, placement and timing strongly influence N uptake. Banded N application (5 cm × 5 cm) at planting increased root yield and recoverable sugar (Purucker and Steinke, 2022). In contrast, late N applications often increase plant N concentrations and canopy size but may have minimal effects on root or sugar yield as late N often increases top dry matter rather than root dry matter (Malnou et al., 2008; Wiesler et al., 2002).

Phosphorus (P) is essential for root establishment (Lynch and Brown, 2008), rapid germination, (Grant et al., 2001) and early plant growth (Nadeem et al., 2013). Positive responses in root yield and sugar production were observed with both individual P applications and when combined with other nutrients across soil textures. In sandy soils (e.g., pH 8.1; soil P 4.8–6.1 mg kg⁻¹), applying 15–30 kg P₂O₅ ha⁻¹ (13–26 lbs. A⁻¹) with foliar B and Mg increased root yield and sugar content (Makhlouf et al., 2020), while in clay soils (e.g., pH 8.1–8.5; soil P 9.2 mg kg⁻¹), 30 kg P₂O₅ ha⁻¹ (26 lbs. A⁻¹) maximized root biomass, sugar yield, and quality (Mahmoud et al., 2014). Application methods

also strongly influence P efficiency. In-furrow ammonium polyphosphate (10-34-0) enhanced stand count and canopy growth but had little effect on root yield under soils with moderate P availability (pH 7.8–8.0; Bray P1 32–41 mg kg⁻¹) (Steinke and Bauer, 2017). Similarly, banding N and P together in single band (5 cm × 5 cm) produced comparable results to dual-row banding in sorghum (pH 6.9; Bray P1 12 mg kg⁻¹) (Gordon and Whitney, 2000). These findings suggest that the positive response to localized P fertilization often reflects low pre-plant soil P and improved P availability enhancing plant uptake.

Potassium (K) is an essential nutrient for plant growth and development, with its role in agriculture well established (Römheld and Kirkby, 2010; Sardans and Peñuelas, 2021). Field studies demonstrate that K fertilizer supports the transport of photosynthates and nutrients enhancing root yield and sugar production (Hadir et al., 2020; Jákli et al., 2018). In Michigan, the recommended K rate is approximately 74 kg K₂O ha⁻¹ (66 lbs. A⁻¹) for a yield potential of 44.8 Mg ha⁻¹ (20 tons A⁻¹) (Warncke et al., 2009). Potassium plays a critical role in active phloem loading with K deficiencies reducing sugar translocation (Zhao et al., 2001). Limited information is available on the optimal timing of K application to maximize sugar translocation. Therefore, K fertilizer was applied mid-season, near the onset of root bulking to support translocation of sugar from aboveground biomass to the storage root.

Sulfur (S) has gained increased attention over the past decade due to reduced atmospheric deposition (Steinke et al., 2015). Sulfur is present in plants at an average ratio of about one part S to 15 parts N, is primarily a structural component of the amino acids cysteine and methionine (Droux, 2004), and supports root and seed growth as well as development of dark green foliage favorable for photosynthesis (Crusciol et al., 2013; Szulc et al., 2021). The primary plant-available form is sulfate (SO₄²⁻) which is typically present in low concentrations and may leach making S fertilization necessary (Camberato et al., 2022). Crop response to S is strongly influenced by soil texture and organic matter with lower probabilities for a yield response on heavier soils (i.e., 80% loam, 5% clay) (Hoffmann et al., 2004) or in soils with greater organic matter (i.e., 12–31 g kg⁻¹) which can supply sufficient mineralized S (Goyal et al., 2021). Nonetheless, prior research highlights a synergistic relationship between S and N with combined applications improving nutrient uptake (Salvagiotti and Miralles, 2008) and yield (Carciochi et al., 2020) across cropping systems suggesting that balanced N and S management may be more effective than supplying either nutrient individually.

Boron (B) is absorbed by plants primarily as undissociated boric acid (H₃BO₃) and borate (H₂BO₃⁻) with availability strongly influenced by soil pH (Rehman et al., 2018). Boron deficiency can reduce root yield and quality while also disrupting key metabolic functions including cell wall and

membrane integrity, metabolite transfer, and enzyme activity (Song et al., 2023; Wu et al., 2021). In sugarbeet, B may also have implications for disease management particularly against *Cercospora* leaf spot (CLS) caused by *Cercospora beticola* (Tedford et al., 2019; Thomas et al., 2025). CLS is characterized by progressive necrotic spotting and reduced leaf regrowth which diminishes photosynthetic capacity and ultimately reduces yield and sugar content (Rossi et al., 2000; Weiland and Koch, 2004). Effective CLS control requires integrated strategies including fungicide application, resistant varieties, and crop rotation with non-host species (Skaracis et al., 2010). Field-level evidence on the direct role of B in CLS management remains limited (Thomas et al., 2025).

There is limited information on the interactive effects of soil amendments associated with sugarbeet yield gaps when combined with a standard N management program (SN) (179 kg N ha⁻¹ or 160 lb A⁻¹). The objective of the current study was to investigate the sugarbeet root yield and recoverable sugar response to multiple fertilizer strategies reflecting a SN-plus treatment structure across varying levels of management intensity compared to a baseline standard N management program.

Materials and Methods

Sugarbeet trials were established in the 2022 and 2023 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*) soil. The site was non-irrigated and tile-drained on 5.2 m spacings representative of production areas in northeastern MI. The thirty-year mean annual temperature and precipitation were 9.0 °C and 86.3 cm, respectively. Fields were autumn chisel plowed (20-cm) following corn and field cultivated (10-cm) in the spring before planting. Pre-plant composite soil characteristics (0-20 cm) included 7.7-7.8 soil pH (1:1 soil/water) (Peters et al., 2015), 21-28 g kg⁻¹ soil organic matter (loss-on-ignition) (Combs and Nathan, 2015), 20 mg kg⁻¹ P (Olsen sodium bicarbonate extraction) (Frank et al., 2015), 152-171 mg kg⁻¹ K (ammonium acetate method) (Brown, 2015), 6 mg kg⁻¹ S (monocalcium phosphate extraction) (Combs et al., 2015) and 1.2- mg kg⁻¹ B (Watson, 2015). Prior to planting, pre-plant composite 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 concentrations of 5.7 and 7.0 mg NO₃-N kg⁻¹ soil (nitrate electrode method) in 2022 and 2023, respectively (Gelderman and Beegle, 1998). Monthly precipitation, air and soil 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). The 30-year average of temperature and precipitation was obtained from the National Oceanic and Atmospheric Administration (<https://www.ncdc.noaa.gov/cdo-web/datatools/normal>s).

Treatment Structure and Experimental Design

Field experiments were planted on 11 May 2022 and 27 April 2023 with a Monosem planter (Monosem Inc., Kansas City, KS). Plots measured 4.6 m in width by 10.7 m in length containing 6 rows with 76-cm spacing. Sugarbeet 'Crystal G049' (ACH Seeds, Inc., Eden Prairie, MN), a high tonnage, moderate sugar-producing variety with excellent *Cercospora* and good *Rhizoctonia* resistance (Michigan Sugarbeet Research Education Advisory Council, 2022) was planted both seasons. The experiment included eight treatments plus a check arranged in a randomized complete block design with four replications. Treatments represented SN-plus treatment structure across varying levels of management intensity from 1) a standard N (SN) baseline of 179 kg N ha⁻¹ (160 lbs. N A⁻¹) with 44.8 kg N ha⁻¹ (40 lbs. A⁻¹) as urea ammonium nitrate (UAN, 28-0-0) banded 5 cm below and 5 cm to the side of the seed (5×5 N) at planting and the remaining 135 kg N ha⁻¹ (120.4 lbs. N A⁻¹) as UAN sidedressed (1 June 2022 and 31 May 2023) at the 2-4 leaf growth stage (2-4 LF), 2) SN + P, 7.2 kg N (6.4 lbs. N A⁻¹) and 22.3 kg P₂O₅ ha⁻¹ (19.9 lbs. P₂O₅ A⁻¹) were applied in-furrow during planting using liquid ammonium polyphosphate (APP, 10-34-0), 3) SN + Lime, 4.5 Mg. ha⁻¹ (2 T A⁻¹) of agricultural lime (32% Ca) broadcast before planting, 4) SN + S, 44.8 kg N ha⁻¹ (40 lbs. N A⁻¹) from UAN at planting (5×5) with 126.1 kg N ha⁻¹ (112.5 lbs. N A⁻¹) (UAN), 8.2 kg N ha⁻¹ (7.3 lbs. N A⁻¹) and 17.8 kg S ha⁻¹ (15.9 lbs. S A⁻¹) from ammonium thiosulfate (ATS, 12-0-0-26S) at 2-4 LF, 5) SN + B, consisting of a total of 2.2 kg B ha⁻¹ applied as sodium borate (16.5% B), diluted and applied weekly as a foliar treatment during July 2022 (8, 14, 19, and 22 July) and July 2023 (7, 14, 19, and 27 July) at a spray volume of 140 L ha⁻¹ (15 gallons A⁻¹). 6) SN + K, 112 kg K₂O ha⁻¹ (100 lbs. K₂O A⁻¹) from Monty's® LiquidK2O® (Monty's Plant Food, Louisville, KY) surface banded at 20 LF (05 July 2022 and 07 July 2023), 7) SN + Late N, 44.8 kg N ha⁻¹ (40 lbs. N A⁻¹) was applied 2 weeks after the initial side-dress of 89.6 kg N ha⁻¹ (80 lbs. N A⁻¹) (UAN) at 2-4 LF (14 June 2022 and 14 June 2023), 8) intensive management including all treatment combinations, and 9) check (no fertilizer added). Foliar boron was sprayed using a CO₂-powered backpack sprayer equipped with four TJ 8002XR nozzles (76-cm spacing) calibrated at 140 L ha⁻¹ (15 gal. A⁻¹). Side-dress N applications were made using a tractor-mounted coulter injection cart placing fertilizer 10 cm below ground directly between sugarbeet rows. Surface band applications of liquid K₂O were made using a backpack sprayer equipped with orifice body nozzles and short drop hoses to place fertilizer 5-10 cm laterally from sugarbeet rows. Rates of applied fertilizer, placements, and timings are summarized in Table 1.

Measurements

Plant emergence was recorded from two linear meters per plot 20-30 days after planting (DAP). The uppermost ful-

ly developed and extended leaf and petiole were collected from 20 plants per plot at the 6-8 and > 20 LF growth stages. Total nitrogen was determined using the Dumas combustion method while mineral nutrients were measured using Inductively Coupled Argon Plasma (ICAP) analysis by an external laboratory. Final stand counts were recorded prior to harvest from two linear meters per plot. Sugarbeets from the center two rows were harvested on 24 October 2022 and 24 October 2023 using a mechanical plot harvester. After weighing the plot root weight, ten sugarbeet roots per plot were collected from the harvested sample and analyzed for sucrose concentration, extraction percentage, and recoverable sugar at the Michigan Sugar Co. (MSC) Laboratory in Bay City, MI. Recoverable white sugar per ton (RWST) is based on sugar content and clear juice purity. Recoverable white sugar per acre (RWSA) is calculated by multiplying the RWST by the actual root yield per acre. Both RWST and RWSA were converted to recoverable white sugar kg Mg^{-1} and kg ha^{-1} , respectively.

Partial Economic Profitability Analysis

Economic return was calculated using Michigan Sugar Company's average payment standard (2022-2023) which considers root yield (Mg ha^{-1}) and recoverable sugar (kg Mg^{-1}). The potential economic profitability (USD ha^{-1}) was calculated from each treatment as follows: $\text{PEP} = [(Y \times S \times \text{St})] - [(Cf + Cfa) + (Y \times T)]$, where Y is the observed root yield (Mg ha^{-1}) from the treated treatment, S is the recoverable sugar (kg Mg^{-1}), and St is the price of sugar (USD kg^{-1}). The abbreviations Cf stands for fertilizer cost (USD ha^{-1}), Cfa for fertilizer application cost (USD ha^{-1}), and T for trucking cost (USD Mg^{-1}). Net return in this economic analysis excludes specific grower management practices such as direct and fixed costs and focuses solely on expenses affected by treatments. In 2022, gross economic return was based on $\text{USD } 0.40 \text{ kg}^{-1}$ sugar delivered while in 2023 the price was $\text{USD } 0.55 \text{ kg}^{-1}$ sugar delivered. Fertilizer costs were obtained from local fertilizer vendors while application costs were estimated using the Michigan State University Extension Custom Machine and Work Rate Estimates for 2022 and 2023, respectively. Trucking from field to processor was $\text{\$}4.13 \text{ Mg}^{-1}$ for both years. The prices of sugar and agronomic inputs applied are summarized in Table 2.

Statistical Analyses

Analyses for in-season measurements (plant emergence, pre-harvest stand count) and leaf tissue nutrient concentrations (6-8 and > 20 leaf stages) were conducted using the PROC MIXED procedure in SAS (SAS 9.4) (SAS Institute Inc., 2017). Each site year was analyzed individually due to significant treatment-by-year interactions. Fertilizer treatment was considered a fixed effect while block was a random effect. The normality assumption was checked by examining the residuals' histogram and normal probability plots. Unequal variance assumption was assessed by visual inspection of the side-by-side box plots of the

residuals followed by Levene's test for unequal variances. Since Levene's test results indicated that the equal variance assumption might be violated, unequal variance analyses were conducted using the REPEATED /GROUP= statement of PROC MIXED. Models with homogeneous and heterogeneous variances were compared using AIC criteria (Milliken and Johnson, 2009). The model that resulted in the lowest AIC and BIC values was selected for further analysis. These were analyzed using Analysis of Variance and compared using Least Significant Difference (LSD) at $\alpha = 0.10$. Root yield, recoverable sugar (RSWT and RSWA), and potential economic profitability were analyzed using planned single degree of freedom contrasts at $\alpha = 0.10$ with SN (Treatment 1) compared to remaining fertilizer treatments (Treatment 2 – 8) to evaluate the individual input effects.

Results

Sugarbeet Root Yield and Recoverable Sugar

Root yields ranged from $39.9 - 101.6 \text{ Mg ha}^{-1}$ ($17.8 - 45.3 \text{ T A}^{-1}$) across site years with yields ranging from $41.8 - 101.6 \text{ Mg ha}^{-1}$ ($18.6 - 45.3 \text{ T A}^{-1}$) in 2022 and from $39.9 - 97.9 \text{ Mg ha}^{-1}$ ($17.8 - 43.7 \text{ T A}^{-1}$) in 2023. In 2022, the mean root yield from the SN treatment was 90.1 Mg ha^{-1} (40.2 T A^{-1}) with in-furrow P the only treatment to significantly impact root yield (-15.5 Mg ha^{-1}) (-6.9 T A^{-1}) (Table 3). All fertilizer treatments yielded above the 2022 state root yield average of 82.9 Mg ha^{-1} (37 T A^{-1}) except for in-furrow P treatment (74.6 Mg ha^{-1}) (33.3 T A^{-1}). In 2023, the mean root yield from SN was 78.0 Mg ha^{-1} (34.8 T A^{-1}) with pre-plant broadcast lime, in-furrow P, and intensive treatments all significantly increasing root yield by 13.7 (6.1), 11.9 (5.3), and 13.2 (5.9) Mg ha^{-1} (T A^{-1}), respectively (Table 3). All fertilizer strategies except for the check surpassed the 2023 state root yield average of 64.6 Mg ha^{-1} (28.8 T A^{-1}).

Across all treatments, the average recoverable sugar in 2022 was 148.4 kg Mg^{-1} ($296.8 \text{ lbs. T}^{-1}$) and $12,433.4 \text{ kg ha}^{-1}$ ($11,092.8 \text{ lbs. A}^{-1}$) as compared to 134.2 kg Mg^{-1} ($268.4 \text{ lbs. T}^{-1}$) and $10,536.4 \text{ kg ha}^{-1}$ ($9,400.4 \text{ lbs. A}^{-1}$) in 2023. The 2022 SN treatment averaged 148.4 kg Mg^{-1} ($296.8 \text{ lbs. T}^{-1}$) and $13,327.9 \text{ kg ha}^{-1}$ ($11,890.9 \text{ lbs. A}^{-1}$) (Table 3). No treatments impacted recoverable sugar per Mg in 2022, but in-furrow P reduced recoverable sugar per hectare by $-2,325.7 \text{ kg ha}^{-1}$ ($-2,074.9 \text{ lbs. A}^{-1}$) (Table 3). The 2023 average recoverable sugar from SN was 130.1 kg Mg^{-1} ($260.2 \text{ lbs. T}^{-1}$) and $10,160.4 \text{ kg ha}^{-1}$ ($9,064.9 \text{ lbs. A}^{-1}$) (Table 3). The all-inclusive intensive management treatment and pre-plant broadcast lime increased recoverable sugar per Mg by $+7.1$ ($+14.2$) and $+8.4$ ($+16.8$) kg Mg^{-1} (lbs. T^{-1}), respectively, while also improving recoverable sugar per hectare by $+2,329.8$ ($+2,078.6$) and $+2,278.0$ ($+2,032.4$) kg ha^{-1} (lbs. A^{-1}), respectively (Table 3). In-furrow P increased sugar per hectare by $2,186.3 \text{ kg ha}^{-1}$ ($1,950.6 \text{ lbs. A}^{-1}$) but had no impact on sugar per Mg (Table 3).

Economic Impact

In the current study, the SN treatment was used as a primary reference to gauge potential economic profitability across all treatments excluding the check. In 2022, mean treatment costs (fertilizer and application) and potential economic profitability (PEP) of SN were 510.8 USD ha⁻¹ (206.7 USD A⁻¹) and 4,380.9 USD ha⁻¹ (1,772.9 USD A⁻¹), respectively (Table 4). All fertilizer treatments increased the treatment costs (27.9 – 2,150.0 USD ha⁻¹) (11.3 – 870.1 USD A⁻¹) as expected with intensive management having the highest additional cost (2,150.0 USD ha⁻¹) (870.1 USD A⁻¹) followed by banded K (SN + K) (1,673.6 USD ha⁻¹) (677.3 USD A⁻¹). Consequently, intensive management and SN + K significantly reduced the PEP by 2,431.3 USD ha⁻¹ (983.9 USD A⁻¹) and 1,705.8 USD ha⁻¹ (690.3 USD A⁻¹), respectively. Due to a significant decrease in root yield and recoverable sugar per hectare, in-furrow P (SN + P) reduced PEP by 937.9 USD ha⁻¹ (379.6 USD A⁻¹) (Table 4).

In 2023, SN treatment costs and potential economic profitability (PEP) were 274.8 USD ha⁻¹ (111.2 USD A⁻¹) and 4,981.7 USD ha⁻¹ (2,016.0 USD A⁻¹), respectively (Table 4). All fertilizer treatments increased treatment costs by 27.9 – 1,671.8 USD ha⁻¹ (11.3 – 676.6 USD A⁻¹) with both intensive management and SN + K again having the highest additional costs at 1,671.8 USD ha⁻¹ (676.6 USD A⁻¹) and 1,295.1 USD ha⁻¹ (524.1 USD A⁻¹), respectively. Banded K was the only treatment significantly reducing PEP by 1,554.7 USD ha⁻¹ (629.2 USD A⁻¹). Across fertilizer strategies, early-season treatment applications including agricultural lime and in-furrow P increased PEP by 1,109.1 USD ha⁻¹ (448.8 USD A⁻¹) and 1,078.2 USD ha⁻¹ (436.3 USD A⁻¹), respectively.

Discussion

Comparative Effects of Baseline N and Late-season Nitrogen on Sugarbeet Root Yield and Recoverable Sugar

Except for the in-furrow P treatment, applying the university and MSC recommended N program (SN) provided comparable root yield and recoverable sugar across fertilizer strategies in 2022. However in 2023, the SN treatment root yield and recoverable sugar were significantly less than the intensive management, in-furrow P, and pre-plant broadcast lime treatments (Table 3). Increased rainfall in May (+68%) and June (+45%) 2022 as compared to May and June 2023 (Table 5) may have moved N to the developing roots leading to sufficient tissue N concentrations in 2022 (4.3-5.0%) (Mills and Jones, 1996) (6-8 LF 4.3-6.7%, avg. 5.6%; 20-22 LF 3.7-6.1%, avg. 5.2%). In an N-fertilized environment, the presence of precipitation and developing roots are vital since sugarbeet primarily absorbs nitrate (NO₃⁻) (Varga et al., 2022). Decreased May and June 2023 precipitation may have caused limited early

root development and hindered N uptake causing tissue N deficiency at the 6-8 leaf stage (3.2-4.8%, avg. 3.9%). Early-season drought conditions can affect developing fibrous roots leading to severely limited canopy expansion and radiation interception (Brown et al., 1987). Conversely in July 2023, increased precipitation (+93% compared to 30-year avg.) may have caused later movement of N to the developing root resulting in sufficient tissue N levels at 22-24 leaf stage (4.0-5.0%, avg. 4.6%). Further, it is important to emphasize that intensive management included additional inputs, such as P and lime, which may have improved nutrient availability under those site-year conditions compared with N alone in the SN treatment.

Alternatively, the later-applied N treatment (14 June 2022, 34 DAP and 14 June 2023, 48 DAP) was applied during the growth phase where sugarbeet was still developing canopy coverage. Limited data are available for Michigan on later nitrogen application timings as growers are concerned about potential reductions in recoverable sugar and aim to avoid disrupting the possibility of early harvest which is a Michigan-centric issue. Across both years, late applied N did not significantly influence root yield or recoverable sugar.

Sugarbeet Yield and Recoverable Sugar Response to Fertilizer Strategies

Agricultural Lime

Broadcast applying agricultural lime at 4.5 Mg ha⁻¹ (2 T A⁻¹) before planting significantly increased root yield and recoverable sugar in 2023 (Table 3). Across both years, pre-plant soil pH was 7.7-7.8 a common characteristic for the highly calcareous soils of this region. Reports vary on the impacts of sugarbeet lime application on alkaline soils. Christenson et al. (2000) reported no negative effects on root or sugar yield by lime application on a silty clay to loam soil with a pH of 7.7, but Mn and Zn tissue concentrations decreased with increasing lime rate as expected. Similarly, Hubbell et al. (2001) found that recoverable sugar and quality were not significantly affected by the multiple lime rates at a soil pH of 8.0. Both Christenson et al. (2000) and Hubbell et al. (2001) were Michigan-focused studies concluding that lime may be applied up to 5 Mg ha⁻¹ once every three years on alkaline soils without adverse effects on sugarbeet.

In both 2022 and 2023, leaf Ca, Mg, and Mn concentrations were sufficient across fertilizer strategies for all sampling stages including check (Ca 0.5-1.5%; Mg 0.3-1.0%; Mn 21-150 ppm) (Mills and Jones, 1996) (2022: Ca 0.4-2.0%, avg. 0.9%; Mg 0.4-1.8%, avg. 1.0%; Mn 44-220 ppm, avg. 82 ppm; 2023: Ca 1.0-2.4%, avg. 1.6%; Mg 0.9-3.1%, avg. 2.0%; Mn 105-238 ppm, avg. 166 ppm).

Calcium is absorbed primarily by young root tips while other cations are absorbed along the entire length of the root (Clarkson et al., 1968). Further, basic cations (i.e.,

Na⁺, K⁺ and Mg²⁺) and CaCO₃ dominate in the pH range 7.0–8.5 (Tavakkoli et al., 2015). Since the pre-plant soil pH was slightly alkaline (i.e., 7.7–7.8), it is possible that developing young root tips absorbed soluble Ca²⁺ from soil reserves due to sufficient May 2022 precipitation (4.2 cm or 1.7 inch). The reduced rainfall during May 2023 (-71% compared to 30-yr. May avg., Table 5) likely reduced Ca uptake from the soil exchangeable Ca pool and acquired Ca from freshly-applied pre-plant broadcast lime resulting in increased root yield and recoverable sugar.

Phosphorus

Precipitation shortly after planting strongly influenced root yield and recoverable sugar with APP application (7 kg N and 22 kg P₂O₅ ha⁻¹) (6.2 lb N and 19.6 lb P₂O₅ A⁻¹). In 2022, limited May precipitation reduced emergence and harvest stand counts by 19% and 15%, respectively (Table 6) decreasing root yield and recoverable sugar per hectare (Table 3). Because in-furrow P is placed close to the seed, low soil moisture likely increased salt injury risk. In contrast, rainfall in early May 2023 (1.4 cm [0.6 in.]) prevented early-season seed damage, resulting in comparable stand counts (Table 6) and greater root yield and recoverable sugar per hectare (Table 3). These results suggest that both the timing and amount of rainfall positively influenced sugarbeet response to in-furrow P likely reducing APP salinity effects.

Pre-plant soil test P concentrations impact P fertilizer strategies. The critical Bray P1 soil test value for sugarbeet is 25 ppm (Warncke et al., 2009). When soil test P exceeds 30 ppm, sugarbeets are unlikely to respond to additional P fertilizer unless moisture becomes limiting. However, if a grower still chooses to include P as starter fertilizer, the application rate should remain below crop removal, which is approximately 33.6 kg P₂O₅ ha⁻¹ (30 lb P₂O₅ A⁻¹) (Warncke et al., 2009). Across years, pre-plant soil P concentrations were slightly above critical thresholds nearing 30 ppm Bray P1. As soil pH increases, phosphate availability decreases increasing the likelihood of sugarbeet response to P fertilizer. In 2022, it was only at the 6–8 leaf stage (0.5–0.8%, avg. 0.7%) that all plots, including the check, exhibited sufficient tissue P levels (0.5–1.1%) (Mills and Jones, 1996) while at the 20–22 leaf stage plant tissues were deficient (0.3–0.6%, avg. 0.4%). In 2023, tissue P concentrations for all fertilizer strategies including check were deficient across sampling dates (6–8 LF 0.1–0.3%, avg. 0.2%; 22–24 LF 0.2–0.4%, avg. 0.3%). Among individual added inputs, only in-furrow P increased tissue P concentrations by 0.05% compared to SN at the 22–24 leaf stage ($P = 0.0448$). Examples of deficient tissue P in both 2022 and 2023 cropping years highlight the impact that soil pH can have on soil P availability and plant P uptake. In soil pH > 7.5, base cations become more soluble increasing availability in the soil solution thus providing more opportunities for

soil labile P interaction leading to the precipitation of Ca phosphates (Penn and Camberato, 2019).

Potassium

Pre-plant soil critical K concentrations are 100 and 120 ppm for coarse and fine-textured soils, respectively (Culman et al., 2020). In both 2022 and 2023, the pre-plant soil K levels were above critical thresholds (> 120 ppm K) thus little reason to expect a positive yield or sugar response to applied K₂O fertilizer (Table 3). Further, tissue K levels were sufficient (2.0–6.0%) (Mills and Jones, 1996) throughout all sampling stages across both the 2022 and 2023 cropping seasons (2022 K 3.6–7.3%, avg. 5.0%; 2023 K 3.4–6.5% avg. 5.0%). Previous studies demonstrated that sugarbeet had a higher K demand per unit root length and was more effective in removing available soil K compared to small grains. De et al. (2019) found that K had the highest mean total accumulation at harvest with 529 kg ha⁻¹ (472 lbs. A⁻¹) as compared to N and P with 268 (239) and 69 (61.6) kg ha⁻¹ (lbs. A⁻¹), respectively. El Dessougi et al. (2002) also reported that sugarbeet had 7–10 times higher K influx than small grains.

Sulfur

Ammonium thiosulfate (ATS, 12-0-0-26S) was applied at sidedress to supply 8.2 kg ha⁻¹ N (7.3 lbs. A⁻¹) and 17.8 kg ha⁻¹ S (15.9 lbs. A⁻¹) with the S treatment during the 2-4 leaf stage. In both 2022 and 2023 cropping seasons, the addition of sidedress ATS did not significantly influence root yield or recoverable sugar (Table 3). Tissue S levels were sufficient in all plots including the check during 2022 (0.2–5%) (Vitosh et al., 2006) (6–8 LF 0.2–0.4%, avg. 0.3%; 20–22 LF 0.4–0.5%, avg. 0.4%). In 2023, at 6–8 leaf stage ($P < 0.001$), intensive management and pre-plant broadcast lime increased leaf S levels by 0.2% and 0.1% respectively, compared to SN (0.2%) resulting in the only treatments with sufficient leaf S concentrations. The likely explanation behind sufficient tissue S levels of intensive management and pre-plant broadcast lime at 6–8 leaf stage was enhanced initial canopy and root growth promoting uptake of available soil S. All plots including check had adequate leaf S concentrations at 22–24 leaf stage (0.3–0.4% avg. 0.4%).

Although ATS has been found to be a reliable source of S, ATS needs to be broken down first to tetrathionate (Camberato et al., 2022). The conversion of tetrathionate to sulfate is critical for plant S absorption (Camberato et al., 2022). Deficit precipitation in May (-71%) and June (-55%) 2023, compared to 30-yr. avg., (Table 5) may have delayed the conversion of tetrathionate to sulfate. This delay could potentially explain the lack of influence of sidedress ATS application (31 May 2023) at the 6–8 leaf stage. Alternatively, precipitation in July 2023 (+93%, Table 5) could accelerate tetrathionate to sulfate conversion leading to increased 22–24 leaf S concentrations on ATS-applied plots.

Sugarbeet also has deep-rooting characteristics that may

better exploit soil resources. Michigan has a diverse cropping system including rotation of sugarbeet with corn and winter wheat both of which tend to be S responsive. Corn and winter wheat require 17 (15.1) and 28 (25.0) kg $\text{SO}_4^{2-} \text{ha}^{-1}$ (lbs. A^{-1}), respectively (Camberato et al., 2022). Hence, continuous S application may result in S accumulation at deeper soil depths with later absorption by more deeply rooted sugarbeet.

Boron

Pre-plant critical soil B concentration is 0.7 ppm (Warncke et al., 2009). In 2022, the pre-plant soil B concentration was above critical at 0.8 ppm. In Michigan, modern sugarbeet varieties may not require supplemental B under fine-textured soils eliminating the need for B fertilizer (Warncke et al., 2009). Sodium tetraborate (16.5% B, total 2.2 kg B ha^{-1}) was applied as a weekly foliar spray application in July 2022 and July 2023 as a B source under SN + B treatment. In both 2022 and 2023 cropping seasons, the application of foliar B did not significantly influence root yield or recoverable sugar (Table 3). Over the years, tissue B concentrations remained > 26 ppm indicating sufficiency (26-80 ppm) (Mills and Jones, 1996) (2022 B range: 20-66 ppm avg. 35 ppm; 2023 B range: 33-62 ppm avg. 41 ppm)

Cercospora leaf spot is one of the most destructive foliar pathogens impacting sugarbeet production worldwide (Weiland and Koch, 2004). CLS is a polycyclic disease, with several rounds of infection occurring in a single growing season weather permitting (Franc, 2010). Relative humidity is vital to CLS infection where > 87% exacerbates the CLS infection (Khan et al., 2007). In both 2022 and 2023 cropping seasons, monthly relative humidity was < 87% thus reducing CLS infection. Hence the reduced disease pressure may have limited the observed effects of foliar B on root yield and recoverable sugar. Due to the detrimental impact of CLS on root yield and sugar quality, farmers should use integrated pest management (IPM) practices to minimize fungicide resistance. In this study, CLS control relied heavily on weekly standard fungicide applications while foliar B was included as a supplementary but complementary approach with the potential to enhance the protective effect of fungicides on leaf tissue.

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Conclusion

Results demonstrate the inconsistent responses intensive management may have on sugarbeet root yield, recoverable sugar, and economic benefit to the producer. Root yield and recoverable sugar were only increased by intensive management in 2023 but would be considered not profitable due to high treatment costs. Conversely, the early-season added fertilizers (in-furrow P or pre-plant agricultural lime) increased root yield and recoverable sugar; thereby improving the potential profitability. Spring weather and pre-plant soil conditions played significant roles in successful early season fertilizer strategies. Precipitation (1.4 cm or 0.55 inch.) and residual soil P level (Olsen P 20 mg kg^{-1}) due to pre-plant alkaline soil conditions had a positive influence on the effects of in-furrow P in 2023. Conversely, 2022 lacked rainfall after the in-furrow P application which may have reduced stand count emergence thereby decreasing root yield and recoverable sugar. Under slightly alkaline soil conditions, the limited influence of pre-plant broadcast agricultural lime on root yield and recoverable sugar demonstrates the variable impacts of lime applications.

Despite having only two years of data, the contrasting growing seasons in this study provide valuable insight into treatment performance under different environmental conditions. This highlights the need for additional multi-year research to further validate these findings. Results also appear to provide continued support for current nutrient use guidelines, the planting of disease-resistant varieties, and recognizing areas of the field where water may accumulate or drain from as this will impact on critical soil test nutrient thresholds. Disease outbreak modeling tools such as the BEETcast™ may be used to monitor Disease Severity Values (DSV's) and help determine the risk factor of sugarbeet fields for CLS.

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Table 1. Overview of treatment names, fertilizer source, grade, rate, placement, and timings applied to sugarbeet, Richville, MI, 2022-2023.

Treatment Name ^c	Fertilizer	Fertilizer grade	Amount –ha ⁻¹ – (A ⁻¹)	Placement	Timing
Standard N (SN)	Urea ammonium nitrate (UAN)	28-0-0	124.4 L. (13.3 gal)	5cm. × 5 cm. Side-dress (SD)	Planting 2-4 leaf (LF)
	UAN	28-0-0	374.2 L. (40 gal)		
SN + P	Ammonium polyphosphate (APP)	10-34-0	46.8 L. (5 gal)	In-furrow	Planting
SN + Lime	Agricultural lime	32% Ca	4.5 Mg. (2 T)	Broadcast	Pre-planting
SN + S	UAN	28-0-0	350.8 L. (37.5 gal)	SD	2-4 LF
	Ammonium thiosulfate (ATS)	12-0-0-26S	52.4 L. (5.6 gal)	SD	2-4 LF
SN + B	Sodium tetraborate	16.5% B	2.2 kg. (2.0 lb.)	Foliar	Weekly in July
SN + K	K ₂ O Liquid	0-0-28	288.1 L. (30.8 gal)	Band	Early July
SN + Late N	UAN	28-0-0	249.8 L. (26.7 gal)	SD	2-4 LF
	UAN	28-0-0	124.4 L. (13.3 gal)	SD	2WASD ^a
Intensive (all treatments)	Agricultural lime	32% Ca	4.5 Mg. (2 T)	Broadcast	Pre-planting
	UAN	28-0-0	124.4 L. (13.3 gal)	5cm. × 5 cm.	Planting
	APP	10-34-0	46.8 L. (5 gal)	In-furrow	Planting
	UAN	28-0-0	226.4 L. (24.2 gal)	SD	2-4 LF
	ATS	12-0-0-26S	52.4 L. (5.6 gal)	SD	2-4 LF
	UAN	28-0-0	124.4 L.	SD	2WASD
	Sodium tetraborate	16.5% B	2.2 kg. (2.0 lb.)	Foliar	Weekly in July
	K ₂ O Liquid	0-0-28	288.1 L. (30.8 gal)	Band	Early July
Check	No fertilizer added	NA ^b	NA	NA	NA

^a 2WASD, 2 weeks after sidedress at 2-4 leaf stage; ^b NA, not applicable; ^c N, nitrogen, P, phosphorus, Lime, agricultural lime, K, potassium, S, sulfur, B, boron

Table 2. Estimates of sugarbeet input costs per kilogram and sugar prices received used for potential economic profitability, Richville, MI, 2022-2023. †

Yield	Prices (USD)	
	2022	2023
Sugar ^a	0.40 kg ⁻¹	0.55 kg ⁻¹
Fertilizer	Unit Price (USD kg ⁻¹)	
UAN (28-0-0) ^b	0.74	0.37
Ammonium polyphosphate (10-34-0) ^c	1.16	0.90
Agricultural lime (32% Ca) ^d	0.003	0.003
Ammonium thiosulfate (12-0-0-26S) ^e	0.74	0.39
Sodium tetraborate (16.5% B) ^f	0.81	0.81
	Unit Price (USD L ⁻¹)	
Liquid K ₂ O (0-0-28) ^g	4.40	4.40

^a Michigan Sugar Company

^b 675 USD ton⁻¹, 3.61 USD gal⁻¹ (2022) 340 USD ton⁻¹, 1.82 USD gal⁻¹ (2023)

^c 1,050 USD ton⁻¹, 6.14 USD gal⁻¹ (2022) 818 USD ton⁻¹, 4.78 USD gal⁻¹ (2023)

^d 13 USD ton⁻¹ including trucking cost

^e 670 USD ton⁻¹, 3.64 USD gal⁻¹ (2022) 350 USD ton⁻¹, 1.91 USD gal⁻¹ (2023)

^f 739 USD ton⁻¹

^g 16.65 USD gallon⁻¹

† 5 cm by 5 cm application 7.36 USD ha⁻¹ in both 2022 and 2023. Liquid side-dress 27.92 USD ha⁻¹. Foliar spray 18.56 USD ha⁻¹. MSU Extension Farm Business (2021) https://www.canr.msu.edu/farm_management/uploads/files/MSU%20Custom%20Work%20Rates%202021.pdf.

Table 3. Fertilizer strategy impact on sugarbeet root yield and recoverable sugar, Richville, MI, 2022 - 2023. Mean sugarbeet root yield and recoverable sugar of standard nitrogen treatment (SN) displayed. All other treatments display change in sugarbeet root yield and recoverable sugar using a single degree of freedom contrasts §.

Treatment ^a	Root yield		Recoverable sucrose†			
	2022	2023	2022	2023	2022	2023
	Mg ha ⁻¹ (T A ⁻¹)		kg ha ⁻¹ (RSWA)		kg Mg ⁻¹ (RSWT)	
Standard N (SN)	90.1 (40.0)	78.0 (34.8)	13,327.9 (11,890.9)	10,160.4 (9,064.9)	148.4 (296.8)	130.1 (260.2)
SN + P	-15.5** (-6.9)	+13.7** (+6.1)	-2,325.7** (-2,074.9)	+2,186.3** (+1,950.6)	-0.8 (-1.7)	+4.7 (+9.4)
SN + Lime	+4.0 (+1.8)	+11.9** (+5.3)	+438.8 (+391.5)	+2,278.0** (+2,032.4)	-1.8 (-3.6)	+8.4** (+16.8)
SN + S	+1.8 (+0.8)	+4.3 (+1.9)	+465.4 (+415.2)	+849.0 (+757.5)	+1.7 (+3.4)	+3.8 (+7.7)
SN + B	-4.0 (-1.8)	-3.8 (-1.7)	-474.6 (-423.4)	-136.1 (-121.4)	+0.9 (+1.8)	+5.2 (+10.5)
SN + K	-2.2 (-1.0)	-5.2 (-2.3)	-105.1 (-93.8)	-511.7 (-456.5)	+1.6 (+3.3)	+2.0 (+4.1)
SN + Late N	-2.0 (-0.9)	-2.5 (-1.1)	-81.9 (-73.1)	-35.2 (-31.4)	+2.3 (+4.6)	+4.1 (+8.2)
Intensive	-3.8 (-1.7)	+13.2** (+5.9)	-750.7 (-669.8)	+2,329.8** (+2,078.6)	-2.8 (-5.6)	+7.1* (+14.2)
Check	55.1 (24.6)	49.5 (22.1)	8,111.0 (7,236.5)	6,584.7 (5,874.7)	147.8 (295.6)	131.6 (263.3)

§ Asterisks indicate thresholds of significance (*, P < 0.10; **, P < 0.05; ***, P < 0.001). Check is not included in the analysis.

† RSWA, recoverable white sugar per acre, RSWT, recoverable white sugar per ton

^a N, nitrogen, P, phosphorus, Lime, agricultural lime, K, potassium, S, sulfur, B, boron

Table 4. Fertilizer treatment costs and potential sugarbeet economic profitability, Richville, MI, 2022- 2023. Mean treatment costs and potential economic profitability of standard nitrogen treatment (SN) displayed. Changes in potential profitability for all other treatments were evaluated using single-degree-of-freedom contrasts. §.

Treatment	2022		2023	
	Treatment Cost USD ha ⁻¹ (USD A ⁻¹)	Potential Profitability USD ha ⁻¹ (USD A ⁻¹)	Treatment Cost USD ha ⁻¹ (USD A ⁻¹)	Potential Profitability USD ha ⁻¹ (USD A ⁻¹)
Standard N (SN)	510.8 (206.7)	4,380.9 (1,772.9)	274.8 (111.2)	4,981.7 (2,016.0)
SN + In-furrow P	+83.2 (+33.7)	-937.9** (-379.6)	+66.5 (+26.9)	+1,078.2** (+436.3)
SN + PPI Ag. lime	+93.9 (+38.0)	+62.7 (+25.4)	+93.9 (+38.0)	+1,109.1** (+448.8)
SN + SD ATS	+78.4 (+31.7)	+98.6 (+39.9)	+43.2 (+17.5)	+405.7 (+164.2)
SN + Foliar B	+74.3 (+30.1)	-244.8 (-99.1)	+74.3 (+30.1)	-132.4 (-53.6)
SN + Band K	+1,673.6 (+677.3)	-1,705.8*** (-690.3)	+1,295.1 (+524.1)	-1,554.7** (-629.2)
SN + Late N	+27.9 (+11.3)	-51.1 (-20.7)	+27.9 (+11.3)	-36.3 (-14.7)
Intensive	+2,150.0 (+870.1)	-2,431.3*** (-983.9)	+1,671.8 (+676.6)	-445.9 (-180.4)
Check	0.0 (0.0)	2,975.4 (1,204.1)	0.0 (0.0)	1,380.3 (558.6)

§ Asterisks indicate thresholds of significance (*, P < 0.10; **, P < 0.05; ***, P < 0.001). Check is not included in the analysis. a N, nitrogen, P, phosphorus, Lime, agricultural lime, K, potassium, S, sulfur, B, boron

Table 5. Mean monthly[†] air and soil temperatures, precipitation, and 30-year averages during the sugarbeet growing season in Richville, MI, 2022–2023.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct
Mean Monthly Air Temperature, °C (°F)							
2022		16.6 (61.9)	20.4 (68.7)	21.9 (71.4)	21.2 (70.2)	17.3 (63.1)	10.3 (50.5)
2023	8.9 (48.0)	14.3 (57.7)	19.9 (67.8)	21.9 (71.4)	19.2 (66.6)	17.5 (63.5)	12.0 (53.6)
30-yr. avg.‡	7.7 (45.9)	14.6 (58.3)	20.2 (68.4)	22.2 (72.0)	21.1 (70.0)	17.1 (62.8)	10.6 (51.1)
Mean Monthly Soil Temperature, °C (°F)							
2022		14.7 (58.5)	21.1 (70.0)	23.7 (74.7)	23.3 (73.9)	19.8 (67.6)	12.2 (54.0)
2023	9.5 (49.1)	14.8 (58.6)	21.1 (70.0)	24.0 (75.2)	21.8 (71.2)	ND	ND
15-yr. avg.	7.4 (45.3)	14.3 (57.7)	20.3 (68.5)	23.9 (75.0)	23.1 (73.6)	19.3 (66.7)	12.7 (54.9)
Monthly Precipitation, cm (inch)							
2022		4.2 (1.7)	5.5 (2.2)	5.9 (2.3)	7.9 (3.1)	6.5 (2.6)	5.0 (2.0)
2023	1.4 (0.6)	2.5 (1.0)	3.8 (1.5)	13.9 (5.5)	15.0 (5.9)	3.4 (1.3)	5.5 (2.2)
30-yr. avg.	7.6 (3.0)	8.5 (3.3)	8.5 (3.3)	7.2 (3.0)	9.7 (3.8)	7.4 (2.9)	7.4 (2.9)

† 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>).

∨ ND, no data due to the soil temperature sensor malfunctioned and was not operational from September through October 2023.

Table 6. Sugarbeet emergence and harvest stand counts in response to fertilizer strategies, Richville, MI., 2022-2023. §

Treatment ^a	2022		2023	
	Emergence —————%—————	Pre-harvest	Emergence —————%—————	Pre-harvest
Standard N (SN)	75.2a	75.4	66.3	65.4
SN + P	56.0c	60.2	61.9	59.4
SN + Lime	77.3a	74.5	65.5	66.1
SN + S	75.0a	74.0	67.0	66.5
SN + B	75.6a	74.0	70.5	68.0
SN + K	76.4a	76.0	67.3	65.4
SN + Late N	75.6a	71.1	64.2	60.0
Intensive	63.7b	68.1	65.8	68.6
<i>P > F</i>	0.0027	0.2464	0.6254	0.5138
Check	77.6	78.1	64.8	58.1

Check is not included in the analysis. a N, nitrogen, P, phosphorus, Lime, agricultural lime, K, potassium, S, sulfur, B, boron