EFFECT OF SOIL AND FOLIAR APPLICATION OF SULFUR, MAGNESIUM, BORON, AND ZINC ON ROOT YIELD AND SUGAR QUALITY IN CONVENTIONAL TILL AND NO TILL SUGAR BEET

Charlemagne Lim*, Chengci Chen, Bill Franck, Calla Kowatch-Carlson, Thomas Gross, and Ronald Brown
Eastern Agricultural Research Center, Sidney, MT
Montana State University

ABSTRACT

Field experiment was conducted at the Eastern Agricultural Research Center in Sidney, MT, to determine the effect of S, Mg, B, and Zn on beet yield and sugar quality under conventional and no-till system. Split-plot design was used with 3.6 x 9.1 m experimental plots and four replicates. Tillage was main plot and micronutrient fertilizer was sub-plot. Tillage treatments included conventional and no-till. Fertilizer treatments included SUL4R-PLUS® (Ca & S), SUL4R-PLUS®B+Zn (Ca, S, B, & Zn), MAX-IN®BORON (B), EDTA-Magnesium (Mg), EDTA-Zinc (Zn), and nontreated check. Field soil samples within 2-ft profile were collected and initial nutrients status was determined. For SUL4R-PLUS® and SUL4R-PLUS®B+Z treatments, their respective products were separately mixed with base fertilizers (Urea and P_2O_5) at 112 kg ha^{-1} and soil-incorporated by irrigation before planting. MAX-IN®BORON, EDTA-Mg, and EDTA-Zn were foliar applied at 1.75, 1.12, and 0.9 kg or L ha^{-1}, respectively. Data were collected for emergence, final stand, root yield, and sugar quality parameters. Conventional tillage had 19% more final stand (plants ha^{-1}) and 7% more root yield (ton ha^{-1}) compared with no-till, but did not differ in sugar content or percent sucrose extract. Micronutrient fertilizer had no effect on response variables regardless of tillage, except for SUL4R-PLUS® and MAX-IN®BORON which have had differential effects on percent sucrose extract between two tillage treatments but did not translate into differences in sucrose yield (ton ha^{-1}). Lower sugar and extractable sucrose yield in no-till compared to conventional was due to difference in final stand. Residue management maybe critical for seedling establishment in no-till sugar beet depending on soil environment and climatic conditions. Further study needed to confirm results.

INTRODUCTION

Sugar beet is a valuable crop that contributes largely to the economies of the sugar beet growing regions in the Upper Midwest (MN, ND), the North West (ID, OR, WA), California, the Great Lakes (MI), and the Great Plains (CO, MT, NE, WY) of the United States. Cash receipts from marketing and sale of sugar beets by US farmers were $1.184 and $1.098 billion in 2019 and 2020, respectively (Sowell et al., 2020). Locally, it is a reliable cash crop following wheat rotation in the furrow- and sprinkler-irrigated farms of northeastern MT and northwestern ND. In 2020, a total 38,000 acres of sugar beet was harvested in Montana with an average yield of 31.3 tons/ac (Montana Annual Bulletin, 2021). Cash receipts from marketing of sugar beet in Montana was $42.4 million in 2020 (Sowell et al., 2020). Despite the viability of sugar beet as a cash crop in the region for many decades, its sustainability is always undermined by the increasing crop production costs, unpredictable weather, damages by resilient pest and diseases, and yearly fluctuation in the commodity price. However, many have shown over the years that sugar beet production with reduced tillage practices have no yield disadvantage compared to its conventional counterpart (Evans et al., 2010; Al-Kaisi and Licht, 2004; Tarkalson et al., 2012; Miyazawa et al., 2004; Jabro et al., 2010; Stevens et al., 2010). Other studies suggested that reduced tillage could maintain sugar beet yields with no compromise to pest control practices and nitrogen fertility programs (Wenninger et a., 2019; Khan and McVay, 2014; Stevens et al., 2010). Reduced tillage systems present an alternative way to minimize cost and maximize net profit by cutting down fuel, time, and labor expenses to the minimum, at the same time offer an opportunity to improve soil microbial activity, increase water infiltration and retention in the soil, and reduce soil erosion to wind and surface runoff without risk of yield drawbacks for preference over conventional sugar beet production system (Lafond et al., 2006; Zenter et al., 2004; Alvarez and Steinbach, 2009; Reeves, 1997). Micronutrients play a huge role in sugar beet growth and development. Studies have shown that soil and foliar applications of Zn, B, Mo, Fe, and Mn in addition to the macronutrients improved sugar beet root yield and sugar quality due to enhanced root and shoot growth (Yarnia et al., 2008; Zewail et al., 2020; Gobarah et al., 2014; Gharib and El-Henawy, 2011). Micronutrients has also been shown to boost plant defenses against sugar beet pathogens. In repeated greenhouse and field studies, micronutrient applications of Zn, Cu, Fe, Mg, Bo, and S not only improved root yield and sugar quality but also reduced the severity of powdery mildew and cercospora leaf spot in sugar beet due to the increased activity of enzymes responsible for the breakdown of free radicals (Shabrawy and Abd Rabboh, 2020; Ghazy et al., 2020). Integration of micronutrient fertilizers into current sugar beet fertilizer program may prove beneficial to sugar beet growers. However, information is limited as to the effect of no-till system compared to conventional in conjunction with micronutrient fertilizer application in sprinkler-irrigated sugar beet. The ultimate goal is to maximize net farm profits through improved sugar beet yield and minimized production costs. We hypothesized that no-till system approach could be a viable alternative to sugar beet production without risking yield and that micronutrient fertilizer application could help improve sugar yield and quality in a sprinkler-irrigated sugar beet. This study aimed to determine the effects of conventional tillage and no-till system in conjunction micronutrient fertilizer application on sugar beet yield and sugar quality.

METHODOLOGY

The field experiment was conducted at the Eastern Agricultural Research Center in Sidney, MT in 2021. The research center was located at 47.729819° latitude and -104.152406° longitude at 1950 feet (594 meters) above sea level. The field was under a linear irrigation system that was previously planted with spring wheat. The field's soil type was a Savage silty clay loam [21% sand:46% silt:33% clay] (Afshar et al., 2019). To achieve uniform Nitrogen (190.5 kg N/ha or 170 lbs N/ac) and Phosphorus (33.6 kg P/ha or 30 lbs P/ac) in all plots, Urea and P_2O_5 were soil-applied as base fertilizers. The experiment was conducted in randomized completed block in split-plot, with main plot size of 22 x 9.1m (72 x 30 ft) and a subplot size of 3.6 x 9.1m (12 x 30 ft). The experiment was replicated four times. Tillage treatment was assigned to the main plot and micronutrient fertilizer treatment was randomly assigned to the subplot. Tillage treatments included conventional (fall and spring tillage) and no-till (stubble left above ground after spring wheat harvest in the previous fall). Micronutrient fertilizer treatments included SUL4R-PLUS® (Ca & S), SUL4R-PLUS® B+Z (Ca, S, B, & Zn), MAX-IN® BORON (B), Magnesium (EDTA-Mg), Zinc (EDTA-Zn), and the untreated check (base fertilizers only). For SUL4R-PLUS® (Ca & S) and SUL4R-PLUS® B+Z (Ca, S, B, & Zn) treatments, each respective micronutrient fertilizer product was separately mixed with Urea and P_2O_5 at a rate of 112 kg ha^{-1} (100 lbs product/ac) and applied to the soil and incorporated through irrigation prior to sugar beet planting. MAX-IN® BORON, Magnesium, and Zinc were dissolved in water and foliar applied at a rate of 1.75, 1.12, and 0.9 kg or L ha^{-1}, respectively (1.5 pints/ac of Max-in Boron, 1 lb/ac of Mg, and 0.8 lb/ac of Zn), when sugar beet was at 8- to 10-true leaf stage. A CO_2 backpack sprayer fitted with four 80015 nozzles calibrated to deliver 140 L ha^{-1} (15 gal/ac) was used for all foliar micronutrient fertilizer sprays.

Prior to sugar beet planting or any micronutrient fertilizer application, composite soil samples that consisted 5 core samples from 0 to 30 cm (0 to 12 inches) and 30 to 60 cm (12 to 24 inches) soil profile depths in conventional tillage and no till plots were taken at random on March 15th, 2021. The soil samples were air dried, packaged, and sent to a soil analysis laboratory in Northwood, ND [AgVise Laboratories, 804 Highway 15 W, Northwood, ND 58267] and the initial soil nutrients status in the field was determined. The sugar beet variety Crystal S696 GEM 100 was planted with a no-till planter in all plots on April 22nd, 2021, at 2.5 cm (1 inch) seeding depth 12 cm apart (4.5 inches) with a 61 cm (24 inches) row spacing. The field received a total of 442 mm (17.4 inches) of linear irrigation from planting to harvest. The accumulated precipitation (snow and rainfall) from October of 2020 to September of 2021 was 164 mm (6.47 inches). Three applications of glyphosate at 0.95 kg ai/ha (24 fl oz roundup/ac) were applied on sugar beet to control weed flushes throughout the growing season. Disease incidence was very minimal and no chemical application for disease control was done. Monthly high temperatures averaged 18.6, 28.5, 32.3, 28.2, and 26^{O}C (65.8, 83.3, 90.3, 82.8, and 78.8^{O}F) and monthly low temperatures averaged 4.5, 11.8, 15.7, 11.8, and 7.05^{O}C (40.1, 53.4, 60.4, 53.4, and 44.7^{O}F) in May, June, July, August, and September, respectively. Sugar beet was harvested on September 20th, 2021.

Data collection and analyses. Data for crop emergence, final beet stand count at harvest, beet root yield, sugar content, and sugar quality (i.e., impurity value, percent SLM, percent extractable sugar) were determined. Seedling stand count was determined one week after crop emergence using a meter stick placed randomly in one of the four center rows of sugar beet, seedlings were counted and the process repeated twice in each plot. At harvest, final stand count and dirty weight of sugar beet harvested from a 30-ft center row in each plot were taken. A sample of 10 to 15 sugar beet roots from the harvested center row were placed in a labeled tare bag. Dirty and clean weights, beet count, and sugar content (with impurities) of the beet samples from the tare bag was determined at the Sidney Sugars laboratory. A 5-ml sample of sugar beet juice extract from the beet samples from the tare bag was collected and sent to a laboratory in Sheridan, WY [AgTerra Technologies, Inc., 212 W Burkitt St, Sheridan, WY 82801] for impurities analysis (i.e., sodium, potassium, amino-N concentration). Impurity, sugar loss to molasses (SLM), and percent sucrose extract values were determined. Extractable sucrose per hectare (or acre) was determined based on sugar beet yield, sugar content, SLM and percent sucrose extract values. All data were subjected to *type 3 split plot analysis of variance test* using *procmixed* in *SAS* (Statistical Analysis Systems®, version 9.2, SAS Institute Inc., SAS Campus Drive, Cary, NC 27513) with alpha set at 0.05. Tillage, micronutrient fertilizer, and interaction were considered fixed effects. Replication and interaction with treatment were considered random effects. *Type 3 test of fixed effects* was used to test for significance of treatment to the response variables. Where treatment effects significant, group means were separated using Fisher's LSD at $P< 0.05$. Data assumptions for normality of residuals and homogeneity of variance were met when tested with shapiro-wilk and levene's test, respectively, using *proc univariate* in *SAS*.

RESULTS AND DISCUSSION

The soil analysis results showed that the experimental field had good nutrient conditions to foster crop growth (Table 1). The CEC and OM values indicated high capacity for exchange and retention of water and nutrients in the soil, and the slightly alkaline pH indicated most soil nutrients were abundant in available forms for plant uptake. Potassium was sufficient in both conventional tillage and no till plots. However, Nitrogen was low in top 30 cm of soil for both and was much lower in the deep subsoil (30 to 60 cm depth). Phosphorus is relatively sufficient; however, literature suggests that an additional P fertilizer (P_2O_5) was needed to ensure availability for plant uptake. N and P issues were addressed when the base blend of Urea and P_2O_5 were incorporated in all plots before sugar beet was planted. Sulfur and magnesium amount in the soil were generally sufficient based on established literature on soil fertility. Soil pH indicated that most of the macronutrients and micronutrients were likely to be more available in the soil solution except for Fe, Mn, B, and Zn which could be less abundant due to the slightly alkaline soil condition but nevertheless still available for plant uptake.

Table 1. Results of soil analysis for initial nutrient status in Conventional (CT) and No till (NT) plots. Values presented were averaged from 5 composite samples taken at 0 to 30 cm and 30 to 60 cm depths.

Tillage	Soil Depth	pH	OM	NO_3-N	S	P-Olsen	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	B	CEC
	cm		%	ppm												meq/100g
CT	0-30	8.3	3.2	6.1	25	16	337	5247	767	152	0.60	6.9	2.0	1.2	1.8	34.2
NT	0-30	8.3	3.3	6.0	16	15	340	5321	705	153	0.71	7.6	1.7	1.2	1.8	33.9
CT	30-60	8.4		2.4	51											
NT	30-60	8.3		2.9	32											

Results of analysis of variance showed that neither micronutrient fertilizer nor interaction with tillage had a significant effect on sugar beet stand and yield parameters (Table 2). However, tillage had a significant effect on crop emergence, final stand count, beet root yield, sugar yield, and extractable sucrose but not on sugar concentration (Table 2). Results of the analysis of variance also showed that micronutrient fertilizer alone had no significant effect on sugar quality parameters, but interaction with tillage had a significant effect on potassium concentration, sugar loss to molasses (SLM), and percent sucrose extract from beet root samples (Table 3). Additionally, tillage had no significant effect on sugar quality parameters except for its effect on the amino-N concentration in the sugar beet roots which was significant (Table 3).

Table 2.Results of split-plot analysis of variance showing *p*-values for the effect of tillage, micronutrient fertilizer, and interaction on crop stand, beet root yield, and sugar yield parameters.

Source of variation	Crop emergence	Final stand	Beet yield	Sugar concentration	Sugar yield	Extractable sucrose yield
Tillage	**<0.01**	**<0.01**	**<0.01**	0.27	**<0.01**	**<0.01**
Fertilizer	0.33	0.98	0.97	0.26	0.91	0.90
Tillage*fertilizer	0.84	0.96	0.29	0.59	0.30	032

Table 3. Results of split-plot analysis of variance showing *p*-values for the effect of tillage, micronutrient fertilizer, and interaction on sugar quality parameters.

Source of variation	Sodium	Potassium	amino-N	Impurity Value	SLM	Sucrose extract
Tillage	0.20	0.44	**0.01**	0.19	0.10	0.11
Fertilizer	0.77	0.69	0.83	0.35	0.55	0.55
Tillage* fertilizer	0.12	**0.03**	0.56	0.68	**<0.01**	**<0.01**

Conventional tillage had significantly higher final beet stand count at 112,947 beets/ha (45,708 beets/ac) compared to no till which had 91,644 beets/ha (37,087 beets/ac) (Table 4). The considerable amount of stubble residue cover from the previous year's wheat crop may have had delayed the emergence and made it difficult for seedlings to come out of the residue cover which resulted in lower final stand count in the no-till compared to conventional tillage (Table 4). This was evident when seedlings counted in no-till plots only averaged 6.4 seedlings/m row which was lower compared to 7.6 seedlings/m row in conventional tillage one week after crop emergence (Table 4). However, the stand counts in the no-till plots in this study were considered to be normal. In this study, sugar beet seeds underwent fungicide seed treatment and disease incidence throughout the growing season was very minimal making it unlikely for pathogens to substantially compromise germination, emergence, or final stand count. Additionally, the seeds were planted with a no-till planter and sugar beet seeds were not visible on the soil surface in the no-till plots at the time of planting making it less likely a planter issue. However, the conventional tillage plots were allowed to dry up before chisel plowed with 5-6 passes in the previous fall and another 5-6 passes in the following spring to prepare the seedbed. Higher soil moisture in conservation tillage results in a wetter and cooler seedbed compared to the conventional (Deibert, 1983; Sojka et al., 1980; Overstreet, 2009; Hatfield et al., 2001). Wetter years have been shown to delay seedling emergence in sugar beet following strip tillage (Evans et al. 2010), although the response was inconsistent due to yearly variations in climatic conditions following planting (Wenninger et al., 2019). Although the appearance in top growth were visually the same throughout the growing season, beet root yield was significantly higher in conventional tillage which averaged 92.1 tons/ha (37.3 tons/ac) compared to the 85.9 tons/ha (34.8 tons/ac) in no-till. Similarly, sugar yield averaged 17.5 tons/ha (7.07 tons/ac) in conventional tillage which was higher compared to the 16.2 tons/ha (6.54 tons/ac) average sugar yield in no-till. Although, the beet root yield and sugar yield were significantly higher in conventional tillage compared to no-till, the sugar content of 18.93% (with impurities) from sugar beet samples in conventional tillage did not differ from those in no-till which was 18.77%. This indicates that the significantly increased root and sugar yield observed in conventional tillage compared to no-till was not due to the increased sugar content in sugar beet roots but was mainly a function of the final stand count that was higher in conventional tillage at the time of harvest. The amino-N (impurity) in beet root samples from conventional tillage was 17.8 ppm which was lower than the 20.5 ppm observed from sugar beet samples in no-till (Table 4). Previous studies have associated high soil nitrate levels with crop residue in reduced tillage (Wenninger et al., 2019; Zhang et al. 2016). However, other studies have also shown that no-till system had no effect on nitrogen storage in organic matter and that nitrate leaching into deeper subsoil (root zone) for plant uptake seemed dependent on soil and climatic conditions (Goss et al., 1990; Hansen and Djurhuus, 1997b; Constantin et al., 2010). Although the amino-N impurity in sugar beets from conventional tillage was lower, the percent extractable sucrose was comparable to sugar beet in no-till. On average, the percent extractable sucrose (free of impurities) in sugar beet samples from conventional tillage and no-till was 98.97% and 98.94%, respectively (Table 4). However, the average in extractable sucrose yield was significantly higher in sugar beet from conventional tillage which was at 17.3tons/ha (7.0 tons/ac) compared to 15.6 tons/ha (6.46 tons/a) in no-till (Table 4). The observed difference was again attributed to the higher stand count in the conventional tillage sugar beet compared to no-till.

Treatment	Crop Emergence	Final Stand	Root yield	Sugar content	Sugar yield	amino-N	Sucrose extract	Extractable sucrose yield
	seedlings / m row	beets/ac	ton/ac	%	ton/ac	ppm	%	ton/ac

8.93 a	7.07a	17.8b	98.97a	7.0a
8.77 a	6.54b	20.5a	98.94a	6.4b

Table 4. Effect of conventional tillage (CT) and no-till (NT) treatment on crop emergence, final stand count, beet yield, percent sugar, sugar yield, amino-N impurity, percent sucrose extract, and extractable sucrose yield. Values presented were averaged across micronutrient fertilizer treatments. Means followed by the same letter within a response variable are not significantly different at Fisher's LSD$_{(\alpha=0.05)}$.

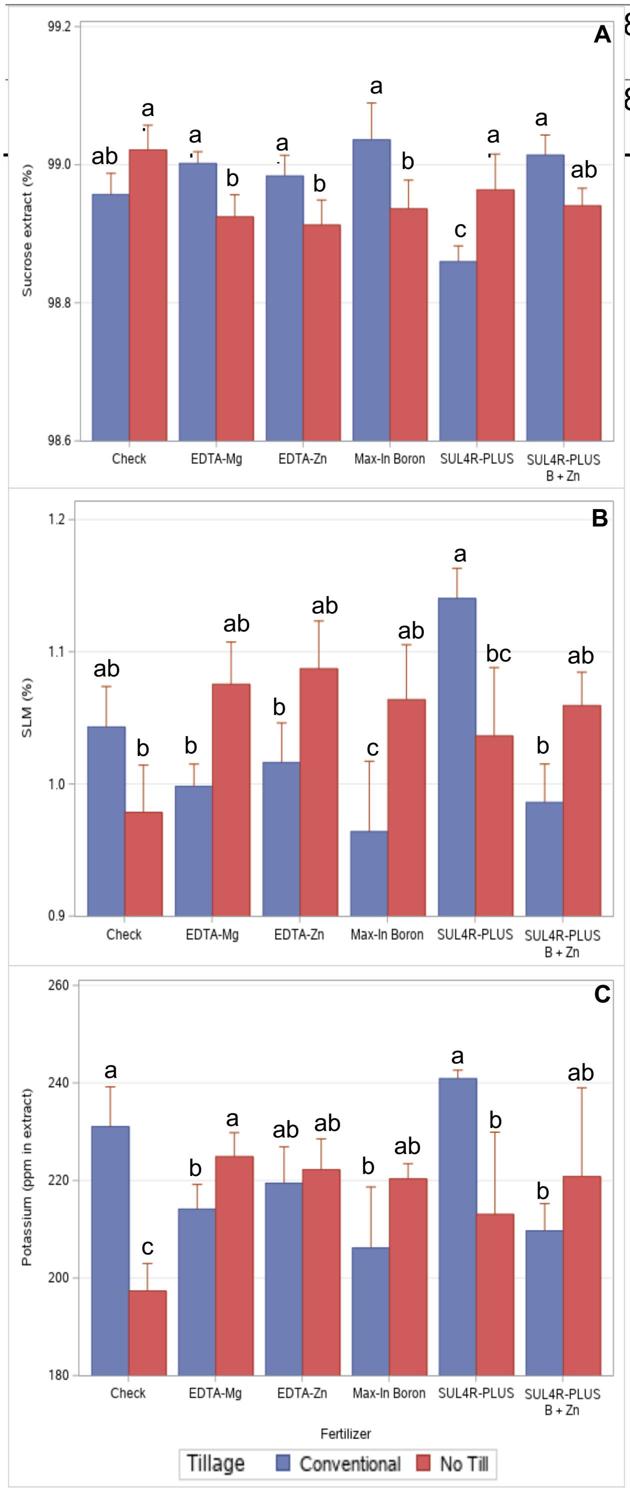

Figure 1. Effect of micronutrient fertilizer treatment on percent sucrose extract (A), sugar loss to molasses or SLM (B), and potassium concentration (C) in sugar beet as affected by conventional tillage and no-till treatment. Presented are mean values (bars) and standard error of the mean (caps). Bars with the same letter are not significantly different from each other as per Fisher's LSD$_{(\alpha=0.05)}$.

Interaction effect of tillage treatment and micronutrient fertilizer treatment was significant for potassium concentration, SLM, and percent sucrose extract (Table 3). Mean response values for each treatment combination were separated and presented in Figure 1. Percent sucrose extract, percent SLM, and potassium concentration values for sugar beet that received the same micronutrient fertilizer treatment were comparable between conventional or no-till, except for SUL4R-PLUS$^{®}$ and MAX-IN$^{®}$BORON micronutrient fertilizer treatments. Treatment of SUL4R-PLUS$^{®}$ to sugar beet in conventional tillage showed lower sucrose extract (98.85%), due to higher beet root SLM (1.14%) and potassium (241 ppm) compared to its treatment effect in no-till (98.96% sucrose extract, 1.03% SLM, and 213 ppm of potassium) [Figure 1A, 1B, 1C]. The opposite was true for MAX-IN$^{®}$BORON treatment. On average, treatment of MAX-IN BORON to sugar beet in conventional tillage resulted in higher sucrose extract (99.94%) due to lower beet root SLM (0.96%) when compared to its treatment effect in no-till (99.03% sucrose and 1.06% SLM) [Figure 1A, 1B].

Relative to in conventional tillage, treatment of SUL4R-PLUS® in no-till produced lower potassium and SLM levels, that produced higher sucrose extract in the roots. Conversely, treatment of MAX-IN®BORON in no-till sugar beet produced higher potassium and SLM levels that produced lower sucrose extract in the beet roots, relative to its treatment effect in conventional tillage. However, a *two-tailed pairwise t-test* revealed that the differential effect of CT*SUL4R-PLUS® and NT*SUL4R-PLUS® on sugar beet percent sucrose extract did not translate into a difference in extractable sucrose yield tons per hectare (p=0.26, data not shown), even though the average final stand count between two treatment combinations did not differ from each other (p=0.07, data not shown). The same can be said about MAX-IN®BORON treatment as revealed after the *t-test* (p=0.16 for sucrose yield/ha and p=0.11 for final stand count, data not shown). This suggests that sucrose yield on a per hectare basis will be comparable for sugar beet treated with SUL4R-PLUS® regardless of tillage practice. The same response from sugar beet will be expected following MAX-IN®BORON application.

In this study, the lower root yield (tonnage) in no-till was due to the difference in stand count despite having a normal plant density, however, sugar content and quality were comparable regardless of the tillage practice used. Although the actual cause for the difference in stand counts is not clear, residue management maybe critical for seedling establishment in no-till sugar beet system and could be specific to soil environment and climatic conditions. Micronutrient application using the fertilizer products seemed to have had no effect on yield and sugar quality parameters except for Boron (MAX-IN®BORON) and Sulfur (SUL4R-PLUS®) which have had an effect on percent sucrose extract but did not necessarily translate into a difference in extractable sucrose yield per hectare between conventional tillage and no-till. The field soil had sufficient amounts of micronutrients for sugar beet production that the effect of micronutrient treatments may have not been detected due to the inherent abundance and availability soil residual micronutrients for plant uptake. Additionally, soil and microbial processes associated with different soil management systems can admittedly have had confounded the effects on micronutrient uptake/absorption, translocation, and metabolism. A repeat of the experiment is needed to confirm results.

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