COMBINED NITROGEN WITH MAGNESIUM OR ZINC EFFECTS ON SUGARBEET YIELD SUCROSE CONCENTRATION UNDER CONVENTIONAL AND NO-TILL SYSTEMS

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ABSTRACT

Sugar beet (*Beta vulgaris* L.) is an important cash crop in the Lower Yellowstone River valley. Fertility, especially nitrogen (N) fertilizer management, is critical for sugar beet yield and sucrose concentration. While farmers are switching from a conventional tillage method to a no-till system for sugar beet cultivation, nitrogen (N) fertilizer application timing might need to be adjusted. Furthermore, micronutrients may enhance sugar beet yield and sucrose concentration. A two-year study was conducted in Sydney, Montana, to investigate the effects of nitrogen rate, application timing, and combination of nitrogen with magnesium (Mg) or Zinc (Zn). The objective of this study was to 1) determine the nitrogen rate and application timing for maximal sugar beet yield and sucrose concentration under conventional tillage (CT) and no-till (NT) systems, 2) examine if foliar application of Mg and Zn in combination with N can enhance sugar beet yield and sucrose concentration, and 3) assess if fertilizer management should be adjusted while shifting from CT to NT. The field experiment was conducted on clay loam soil in a rotation with spring wheat (*Triticum aestivum* L.). The results revealed that sugar beet root yield and sucrose concentration showed no consistent differences between no-till and conventional farming practices or between spring and fall application of N. The lack of tillage management suggests farmers can achieve comparable yields and sucrose concentrations by adopting no-till practices, thereby reducing energy and labor inputs while safeguarding soil and water resources. Foliar application of Mg in combination with soil application of N tended to improve sugar beet root yield.

INTRODUCTION

Sugar beet (*Beta vulgaris* L.) growers throughout the USA commonly employ conventional tillage (CT). While the exact techniques may differ from region to region, conventional tillage for sugar beet typically involves deep plowing using a moldboard plow ripper or chisel plowing. This is followed by multiple passes of disking, mulching, and leveling to create a finely prepared seedbed. The goal is to ensure optimal seedling establishment, a robust plant stand, and a high yield (Khan & McVay, 2014). Including bedding or ridging in the operational procedures may vary depending on the irrigation systems employed. However, these intensive tillage practices have numerous adverse effects on soils and the environment. The consequences associated with CT include the depletion of soil organic matter and beneficial soil organisms, heightened soil erosion and pesticide runoff, diminished soil fertility, disruption of soil structure and porosity, surface crusting, the development of plow pans, and the release of greenhouse gases. Furthermore, implementing these practices incurs significant expenses, considering fixed and variable costs associated with tractors and implements, labor, fuel, lubricants, and other related factors. Researchers are exploring the viability of incorporating conservation tillage in sugar beet production to address these challenges. Conservation tillage, characterized by maintaining a minimum of 30% soil surface residue cover throughout the year, holds promise for carbon sequestration, improvement of soil organic matter, and erosion reduction. Moreover, these practices can substantially decrease fuel consumption and the time needed for field preparation, resulting in a lower overall production cost when compared to CT systems (Crane, 2014). Limited research has been conducted on no-till (NT) sugar beet production.

Achieving an optimal root yield and sucrose concentration in sugar beet necessitates a substantial amount of nitrogen (N) (Chatterjee et al., 2018). Inadequate fertilization hampers root yield, while excessive fertilization can diminish sucrose concentration and elevate impurities in sugar beets, thereby influencing sucrose recovery. Overapplying nitrogen (N) fertilizer can lead to contamination of surface and groundwater, as well as an escalation in production expenses. However, the optimal N application rate information is scarce, particularly under different tillage systems, especially no-till (NT).

The study aimed to achieve three objectives: 1) identify the optimal nitrogen rate and application timing for maximizing sugar beet yield and sucrose concentration in both no-till (NT) systems and conventional tillage (CT), 2) examine the potential enhancement of sugar beet yield and sucrose concentration through the combined foliar application of Mg or Zn with N, and 3) evaluate the necessity of adjusting fertilizer management when transitioning from CT to NT.

MATERIALS AND METHODS

Two field experiments were conducted in 2019 and 2020 in Sidney, MT, using a sprinkler irrigation system. The soil at the experimental site is characterized as deep, well-drained, and nearly level savage clay loam (fine, smectitic, frigid Vertic Argiustolls) with a composition of 210 g kg^{-1} sand, 460 g kg^{-1} silt, and 330 g kg^{-1} clay (Afshar et al., 2019). Initial composite soil samples were collected to assess the soil fertility status, and the results are presented in Table 1. Over the period from April to September, the site received 10.4 inches of precipitation, supplemented with 9.81 inches of irrigation water from planting to harvesting in 2019, while from April to September, the site received 5.81 inches of rainfall, supplemented with 13.2 inches of irrigation water in 2020. Notably, sugar beet trials were conducted in rotation with spring wheat at this site.

Table 1. Initial soil test results. Composite soil samples were collected from conventional tillage (CT) and no-till (NT) managements from 12 inches deep in the spring before planting sugar beet.

Tillage	pH	OM	NO_3-N	P-Olsen	K	Ca	Mg	Na	Zn	Fe	Mn	Cu	B	CEC
		(%)	(mg/kg)											(meq/100g)
2019														
NT	8.3	3.3	32	15	351	6209	614	156	0.54	8.5	5.74	1.33	1.8	37.7
CT	8.2	3.7	38	17	431	6050	615	148	0.57	8.1	6.08	1.18	1.8	37.1
2020														
NT	7.9	1.9	42	21	162	--	--	--	--	--	--	--	--	--
CT	7.9	1.8	42	21	162	--	--	--	--	--	--	--	--	--

Sugar beet (*Beta vulgaris*), Crystal S696 GEM 100 variety, was used in 2019 and 2020. The planting date was performed on April 24, 2019, and harvested on September 24, 2019. In 2020, sugar beet was sown on April 22, 2020, and replanted on May 11, 2020, due to frost damage, and harvesting was done on September 21, 2020. Sugar beet planting was done using a no-till drill. Sugar beet trials have been in rotation with spring wheat.

The experiments are laid out in a split-split plot in a randomized complete block design with four replications. The main plots were dedicated to no-till and conventional tillage management. At the same time, the sub-plots were used for two fertilizer-N application times: spring application in April 2019 and April 2020 and fall application in October 2018 and October 2019. Three N rates (120, 160, and 200 lb N/ac) and applications of Mg and Zn were implemented within the sub-sub plots. Each fertility plot had dimensions of 24 ft in width and 30 ft in length, with 5 ft alleyways between plots. The row spacing was set at 24 inches, resulting in 12 rows of sugar beets per plot. All 12 rows received fertilizer-N treatments. Three distinct rows within each N rate were dedicated to applying a single rate of Mg (1.0 lb Mg/ac) and Zn (0.8 lb Zn/ac). Chelated EDTA-Mg and EDTA-Zn liquid fertilizers served as the sources of Mg and Zn, respectively, and were applied using a CO_2 backpack sprayer when the plants reached a minimum of 8-10 leaf stage to prevent excessive fertilizer-N application. The N rates were adjusted based on the residual soil NO_3-N measured at a depth of 60 cm in the fall of the previous year. The fertilizer-P application followed Montana State University's recommended guidelines due to initial results indicating low P in the soil. Soil test K fell within the sufficiency range, eliminating the need for fertilizer-K application. While soil test Mg exceeded sufficiency levels for many agronomic crops, Zinc was not deficient but approached the borderline for deficiency in other crops. All soil-applied fertilizers were broadcast. Standard laboratory procedures were employed for the analysis of sugar content and impurities.

All data were subjected to analysis of variance using split-split-plot in a randomized complete block design after checking for homogeneity of error variances using the Levene test (Levene, 1960) and testing for normality distribution using the Shapiro and Wilk approach. The collected data were tested for the validation of assumptions underlying the combined analysis of variance by a separate analysis of each season, and a combined analysis across the two seasons was then performed if the homogeneity of individual error variances examined by the Levene test (Levene, 1960) was insignificant. The statistical analysis used GenStat 19th Edition (VSN International Ltd, Hemel Hempstead, UK).

RESULTS AND DISCUSSION

A summary of the significance of the main effects of tillage managements, N application timings, N fertilizer treatments, and their interactions for the ANOVA for the measured parameters are shown in Table 2. The coefficient of variation (CV%) was reported to be statistically acceptable for all studied traits and ranged from 0.6 for sucrose % in 2019 to 15.4% in root yield in 2019 (data not shown).

Tillage systems which included no-till (NT) and conventional tillage (CT) across different fertilizer-N application timing and rates were insignificant for root yield, sucrose % extraction, impurity value (IV), and sucrose loss to molasses (SLM) in both years except for sugar beet root yield only in 2019 ($P \leq 0.01$) (Table 2). There was no significant difference ($P \leq 0.05$) between NT and CT in sucrose %, IV, and SLM in both years (Figure 1). However, root yield varied as there was no significant difference ($P \leq 0.05$) between NT and CT in 2020, but NT and CT differed significantly in 2019, where NT increased root yield 5.98 t/ac compared to CT (Figure 1).

Fertilizer-N application timing included N application in spring and fall across tillage systems, and N rates were insignificant in root yield, sucrose %, IV, and SLM in both years

2019 and 2020 (P≤0.05), excepting root yield in 2020 (Table 2). The spring application had 2.66 tons/acre higher than fall in 2020 (Figure 2).

Fertilizer-N application rate effects were significant in root yield, sucrose %, IV, and SLM in both years except root yield in 2019 (Table 2). There was a trend of fertilizer-N application increasing sugar beet root yield both in 2019 and in 2020, even though the increase was not statistically significant in 2019, and the root yield plateaued at 160 lb N/ac. In contrast, increasing the N rate significantly reduced sucrose % in both years. Moreover, this reduction coincided with the gradual increase of the N rate to 200 kg N/ac. For example, the N rate at 160 and 200 lb/ac significantly reduced sucrose% by 2.7 and 4.5 rel.%, respectively, compared to 120 lb N/ac in 2019 (Figure 3). Impurity value (IV) and sucrose loss to molasses (SLM) behaved typically regarding the N fertilizer application rate response. Fertilizer-N application significantly increased (P≤0.05) IV and SLM in both years, coinciding with increasing N fertilizer application rate. For example, in 2019, the N rate at 160 and 200 lb/ac significantly increased IV by 13.8 and 24.6%, respectively, compared to 120 lb N/ac. However, no significant difference existed between the 160 and 200 lb/ac N rate (Figure 3).

Table 2. Analysis of variance (mean square error) of sugar beet yield and its quality influenced by tillage systems, fertilizer-N application timing, and rates and their interactions in 2019 and 2020.

Source of variation	d.f.	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
			2019		
Rep	3	36.27	0.3651	0.00051	0.00115
Tillage	1	429.4**	0.143	0.000523	0.00118
Residual	3	12.49	0.0507	0.002267	0.0051
Timing	1	5.68	0.1657	0.01223	0.02752
Tillage*Timing	1	29.69	0.118	0.000113	0.00025
Residual	6	24.06	0.0876	0.006422	0.01445
N	2	25.98	2.3653**	0.078285**	0.17614**
Tillage*N	2	15.67	0.125	0.001535	0.00345
Timing*N	2	50.63	0.1477	0.002347	0.00528
Tillage*Timing*N	2	16.03	0.154	0.003108	0.00699
Residual	24	37.06	0.1081	0.009013	0.02028
				2020	
Rep	3	83.924	0.1524	0.001679	0.003778
Tillage	1	506.901	0.9633	0.034922	0.078574
Residual	3	72.78	0.1484	0.005853	0.013169
Timing	1	84.62**	0.0147	0.000007	0.000017
Tillage*Timing	1	6.202	0.0056	0.00415	0.009338
Residual	6	1.439	0.0617	0.001188	0.002672
N	2	41.854*	0.9362*	0.0201**	0.045224**
Tillage*N	2	1.312	0.0275	0.001664	0.003745
Timing*N	2	6.581	0.1173	0.005864	0.013193
Tillage*Timing*N	2	20.126	0.0147	0.00227	0.005108
Residual	24	8.828	0.2315	0.003481	0.007831

SLM, sucrose loss to molasses. *and** indicate significant and highly significant at P≤0.05 and P≤0.01; respectively.

Applying Mg tended to improve the usage of N fertilizer at 160 and 200 lb/ac. Combined with Mg, it increased root yield by 11.2% and 10.6%, respectively, compared to the application of N alone. Moreover, even when using N at 120 lb/ac, Mag improved root yield by 1.5%. Zn effects were inconsistent; there were no differences at 120 and 160 N levels but a slight increase in the 200 N level (Table 4).

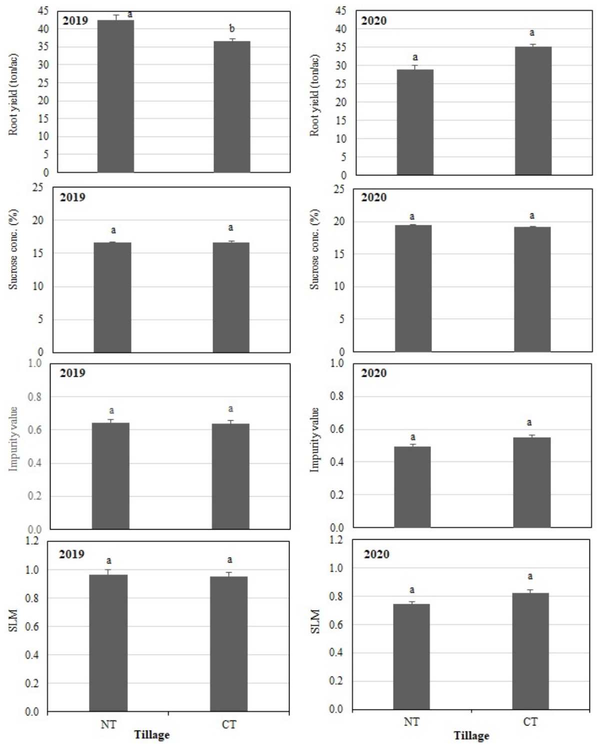

Figure 1. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by no-till (NT) and conventional tillage (CT) systems under different fertilizer-N application timing and rates. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P \leq 0.05$ according to the least significant difference (LSD) test.

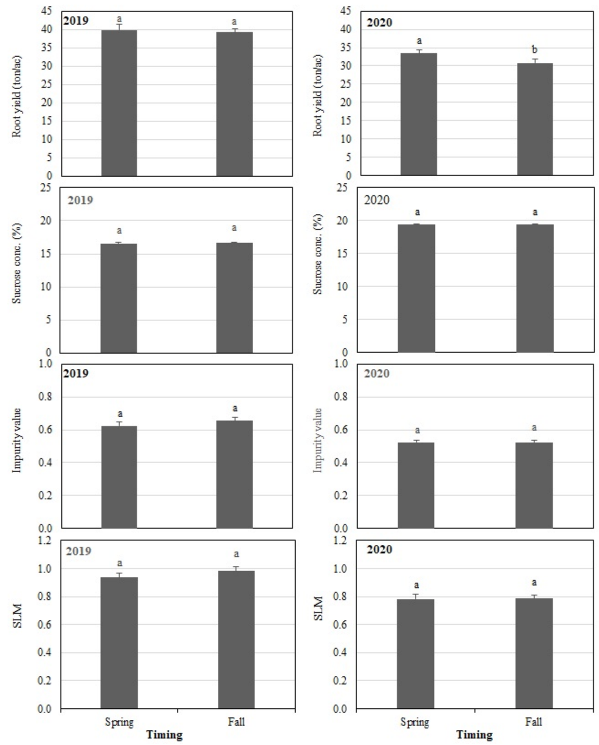

Figure 2. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by fertilizer-N application spring and fall timing under different no-till (NT) and conventional tillage (CT), systems and N rates. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P \leq 0.05$ according to the least significant difference (LSD) test.

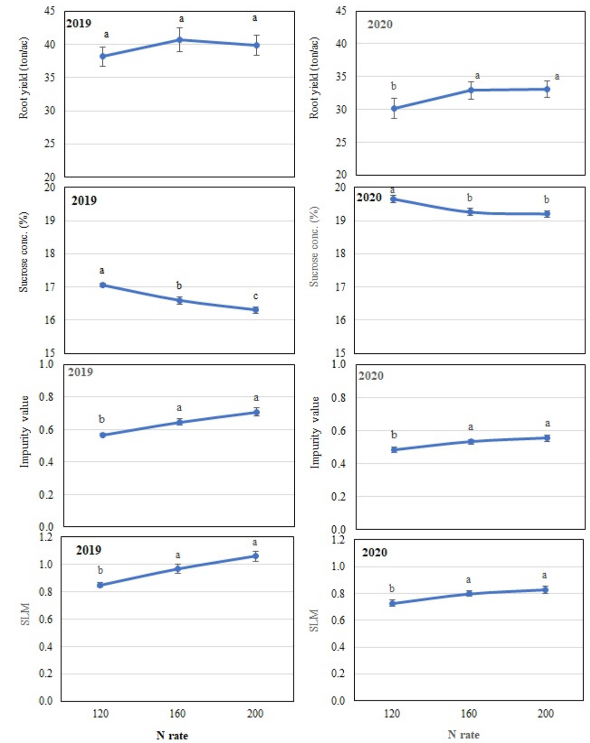

Figure 3. Sugar beet root yield, percent of sucrose extraction, impurity value (IV), and sucrose loss to molasses (SLM), influenced by fertilizer-N application rates (120, 160, and 200 lb N/ac) under different no-till (NT) and conventional tillage (CT), systems and spring and fall timing. Error bars are standard errors of the mean. Means with the same letters are not significantly different at $P \leq 0.05$ according to the least significant difference (LSD) test.

In contrast, N application decreased the sucrose%, coinciding with increasing N levels. However, the combined effect of Mg or Zn with N scored significantly lower sucrose % than N solely under all N levels. Impurity value (IV) and sucrose loss to molasses (SLM) behaved typically regarding the response to the combined effect of Mg or Zn with N. Fertilizer-N application increased the IV and SLM, and this increase was in parallel with increasing N levels. For example, applying N at 160 and 200 lb/ac increased by 12.0 and 19.8%, respectively. The combined effect of Mg or Zn with N aggravated the IV and SLM concentration compared to the N application alone (Table 4).

Table 3. Combined analysis of variance (mean square error) of sugar beet yield and its quality influenced by combined effects of N fertilizer rate with foliar nutrition (FN) with Mg or Zn under different tillage systems and fertilizer-N application timing across two years (Y) 2019 and 2020.

Source of variation	d.f.	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
Y	1	3865.16**	666.49**	1.08173**	2.43389**
Residual	6	65.37	0.8002	0.01664	0.03744
FN	8	68.81*	2.2295**	0.033477**	0.07532**
Y*FN	8	58.26	0.8088	0.006327	0.01424
Residual	48	31.07	0.5513	0.0083	0.01867

SLM, sucrose loss to molasses. *and** indicate significant and highly significant at $P \leq 0.05$ and $P \leq 0.01$; respectively.

Table 4. Sugar beet yield and its quality as influenced by combined effects of N fertilizer rate with foliar nutrition (FN) with Mg or Zn under different tillage systems and fertilizer-N application timing across two years (Y) 2019 and 2020.

Treatment	Root yield (t/ac)	Sucrose (%)	Impurity value	SLM
N120	34.2[†] c	18.4 a	0.526 d	0.788 d
N120+Mg	34.7 bc	17.9 bc	0.552 cd	0.828 cd
N120+Zn	34.3 c	18.0 ab	0.557 cd	0.835 cd
N160	36.8 abc	17.9 b	0.589 abc	0.883 abc
N160+Mg	38.0 a	17.5 cd	0.589 abc	0.884 abc
N160+Zn	35.9 abc	17.8 bcd	0.597 abc	0.896 abc
N200	36.5 abc	17.8 bcd	0.630 a	0.945 a
N200+Mg	37.8 a	17.5 d	0.614 ab	0.920 ab
N200+Zn	37.2 ab	17.7 bcd	0.576 bc	0.864 bc

[†]Mean values within the same column for each trait with the same lower-case letter are not significantly different according to the least significant difference (LSD) test at $P \leq 0.05$. SLM, sucrose loss to molasses.

The results revealed that sugar beet root yield and sucrose concentration showed no consistent differences between no-till and conventional farming practices or between spring and fall application of N. The lack of tillage management suggests farmers can achieve comparable yields and sucrose concentrations by adopting no-till practices, thereby reducing energy and labor inputs while safeguarding soil and water resources. Foliar application of Mg in combination with soil application of N tended to improve sugar beet root yield.

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