EFFECTS OF NITROGEN AND IRRIGATION MANAGEMENT ON SUGAR BEET YIELD, SUGAR CONCENTRATION, AND NITROUS OXIDE EMISSIONS

S. De Silva and B. Maharjan
University of Nebraska-Lincoln, Lincoln, NE
bmaharjan@unl.edu (402)440-9013

ABSTRACT

Sugar beet (*Beta vulgaris* L.) is an important sugar-producing crop, accounting for about 55% of total sugar production in the United States. Optimizing nitrogen (N) and irrigation management is essential for achieving profitable and sustainable beet production. Excessive N application can lower sugar quality and increase nitrous oxide (N_2O) emissions, a potent greenhouse gas and ozone-depleting compound. This study evaluated the effects of irrigation and N fertilizer (urea) rates on sugar beet yield, sugar concentration, and N_2O emissions in Western Nebraska. The field experiment was conducted at the University of Nebraska Panhandle Research and Extension Center, Scottsbluff, NE, using a split-plot randomized complete block design with four replications. The main plot factor was irrigation level, full irrigation (100% of crop water requirement) and deficit irrigation (75%) and the split-plot factor was N rate (0, 50, 80, 100, 125, and 150% of the current university recommended rate). Nitrogen application significantly increased beet yield and N_2O emissions, whereas irrigation level had no significant effect on yield, sugar concentration, or cumulative N_2O emissions. Beet yield increased linearly with N rate, with 50% of the recommended N rate sufficient to achieve maximum yield under both irrigation regimes. Sugar concentration remained stable, showing a slight decrease as N rate increased. Although not statistically significant, full irrigation tended to produce higher yields and lower N_2O emissions compared to deficit irrigation. Overall, applying 50% of the recommended N rate under full irrigation can improve yield while minimizing N_2O emissions, providing a sustainable management strategy for sugar beet production in Western Nebraska.

INTRODUCTION

Sugar beet (Beta vulgaris L.) is an important sugar-producing crop, accounting for about 55% of total sugar production in the United States (USDA-ERS, 2023). Nebraska ranks sixth in U.S. sugar beet production, contributing significantly to the nation's sugar supply. Optimizing fertilizer nitrogen (N) and irrigation management is crucial for sustainable sugar beet production in the Nebraska Panhandle, where semi-arid conditions require substantial irrigation inputs.

Nitrogen is an essential nutrient for sugar beet growth and directly influences both root yield and sugar concentration. Adequate N promotes vegetative growth and yield, while excess N can reduce sugar concentration and increase impurities, leading to lower sugar recovery and reduced economic returns (Draycott, 2008). Overapplication of N also contributes to environmental issues, including increased emissions of nitrous oxide (N_2O), a potent greenhouse gas with a global warming potential nearly 300 times greater than carbon dioxide (Perera & Maharjan, 2021). N_2O emissions from sugar beet systems are largely driven by fertilizer N rates and soil moisture conditions (Maharjan et al., 2014).

Irrigation plays a vital role in achieving optimal beet yield and sugar concentration by maintaining favorable soil moisture for nutrient uptake and root development. However, irrigation management also influences N_2O emissions through its control over soil aeration and denitrification processes. Excessive irrigation can enhance N losses via leaching and gaseous emissions, whereas deficit irrigation may limit crop growth and sugar accumulation. Therefore, understanding the combined effects of fertilizer N and irrigation levels on beet performance and N_2O emissions is critical for improving productivity, quality, and environmental sustainability.

Previous studies have shown that sugar beet yield and sugar recovery are highly responsive to N management and environmental conditions, with optimum N rates varying across regions and seasons (Tarkalson et al., 2012; Maharjan & Hergert, 2019). However, limited information is available on how irrigation levels interact with N rates to affect beet yield, sugar concentration, and N_2O emissions in Western Nebraska.

The objective of this experiment was to assess the effects of urea-N rates and irrigation levels (full and deficit) on beet yield, sugar concentration, and N_2O emissions in the Nebraska Panhandle.

MATERIALS AND METHODS

This experiment was conducted in 2025 at the University of Nebraska–Lincoln (UNL) Panhandle Research, Extension, and Education Center (PREEC) in Scottsbluff, NE (41°03′39″ N, 103°40′54″ W; elevation 1198 m) to evaluate the effects of nitrogen (N) and irrigation management on sugar beet yield, sugar concentration, and N_2O emissions. The experiment followed a split-plot design with four replications. The main-plot factor was irrigation (Full and Deficit), and the split-plot factor was urea-N rates (0, 50, 80, 100, 125, and 150% of the recommended N rate based on the current UNL algorithm). The UNL algorithm accounted for the yield goal, pre-plant soil test N, and soil organic matter mineralization. The yield goal was 78.45 Mg ha-1 and pre plant soil test N indicated 66 kg N ha^{-1}. The corresponding N application rates were 0, 97, 155, 194, 243, and 291 kg N ha^{-1}. Urea was surface broadcast uniformly in all fertilized plots at crop emergence and incorporated into the soil with irrigation. Irrigation was supplied through a sprinkler system twice weekly. The full (100%) irrigation treatment received 18.98 inches of water, and the deficit (75%) treatment received 14.78 inches at the end of the season. The full (100%) irrigation level was determined based on weekly crop water-use data for sugar beet.

Soil N_2O fluxes were measured using a LI-7820 N_2O/H_2O trace gas analyzer equipped with a smart chamber top (LI-COR Biosciences, Lincoln, NE, USA). Polyvinyl chloride (PVC) rings (20 cm diameter, 12.5 cm height) were installed between the second and third crop rows in each plot, inserted 6 cm deep into the soil. Gas fluxes were measured before fertilization (baseline) and twice a week after fertilization until harvest. Cumulative N_2O emissions were calculated using trapezoidal integration of fluxes over time. The middle two rows of each plot were harvested to determine root yield. After weighing, 15–20 randomly selected beets from each plot were bagged and sent to the Western Sugar factory tare laboratory for beet sugar concentration. Treatment effects were analyzed using ANOVA in SAS at a significance level of 0.05.

RESULTS AND DISCUSSION

Table 1. Beet yield, sugar concentration, and cumulative N_2O emissions affected by N rates under deficit and full irrigation

Factors	Beet yield (Mg ha^{-1})	Sugar concentration (g kg^{-1})	Cumulative N_2O Emission (kg N ha^{-1})
Irrigation Level (I) (%, inches)			
Deficit (75, 14.78)	61.61	167.73	2.21
Full (18.98)	66.30	164.84	1.73
Significance level (p value)	0.119	0.316	0.241
Applied N (R) (%, kg ha^{-1})			
(0, 0)	51.43 **b***	169.55	0.26 **d**
(50, 97)	63.69 **a**	170.25	0.88 **cd**
(80, 155)	64.40 **a**	165.28	1.45 **bcd**
(100, 194)	67.91 **a**	166.74	1.92 **bc**
(125, 243)	67.38 **a**	161.81	2.85 **b**
(150, 291)	68.92 **a**	164.08	4.45 **a**
Significance level (p value)	**0.003**	0.201	**0.0001**
Interaction effect (I X R)			
Significance level (p value)	0.63	0.085	0.173

*Different letters behind mean values indicate significant treatment differences at $p \leq 0.05$.

There was no significant interaction between irrigation level and nitrogen rate for beet yield, sugar concentration, or cumulative N_2O emissions. Beet yield was not significantly affected by irrigation level (p = 0.119), with an average yield of 66.30 Mg ha^{-1} under full irrigation and 61.61 Mg ha^{-1} under deficit irrigation (Table 1). However, N application significantly influenced beet yield (p = 0.003) (Table 1). The lowest yield (51.43 Mg ha^{-1}) was observed in the control (0 % N) (Table 1). The treatments at ≥50% of the recommended N had higher root yield (63.69-68.92 Mg ha^{-1}), indicating that 50% of the recommended N rate was sufficient to achieve maximum beet yield under the tested conditions (Table 1).

However, the beet yield showed a significant positive linear relationship with the nitrogen rates (N) under both deficit (p=0.03, Figure 1.a) and full irrigation (p=0.03, Figure

1.b), suggesting that beet yield would increase with the increase in N rates. Ghimire & Maharjan (2024) also reported that fertilizer N application increased the root yield compared to the control treatment. In contrast, Ghimire et al. (2025) reported that treatments receiving ≥80% of the recommended N rate produced higher root yields than the control. In contrast, this study showed that ≥50% of the recommended N rate achieved higher root yields, likely because it also included deficit irrigation conditions. In deficit irrigation conditions, yield potential is reduced, thereby requiring less N than under full irrigation.

Sugar concentration was not significantly affected by either irrigation ($p = 0.316$) or N rate ($p = 0.201$). The mean sugar concentration was 167.73 g kg^{-1} under deficit irrigation and 164.84 g kg^{-1} under full irrigation. Across N rates, sugar concentration ranged from 161.81 to 170.25 g kg^{-1}, decreasing with increasing N application. This indicates that sugar concentration remained relatively stable despite variations in water and nitrogen supply under the tested conditions. Ghimire and Maharjan (2024) reported that fertilizer application reduced sugar concentration in most cases compared to the control treatment, consistent with the trend observed between N rate and sugar concentration in this study.

Cumulative N_2O emissions were not significantly affected by irrigation level ($p = 0.241$), with an average emission of 1.73 kg N ha^{-1} under full irrigation and 2.21 kg N ha^{-1} under deficit irrigation (Table 1). However, N application had a significant effect on cumulative N_2O emissions ($p < 0.001$) (Table 1). The lowest N_2O emissions (0.26 kg N ha^{-1}) were observed in the control (0% N), while N_2O emissions increased with increasing N rates. The cumulative N_2O emissions trend across N rate treatments was 0%≤50%≤80%=100%≤125%<150%, indicating that increasing fertilizer N beyond crop requirement substantially elevated N_2O losses (Table 1). The cumulative N_2O emission showed a significant positive linear relationship with the nitrogen
rates (N) under both deficit (p=0.02, Figure 2.A) and full irrigation (p=0.004, Figure 2.B), suggesting that emissions would increase with the increase in N rates. Ghimire et al. (2025) also reported that cumulative N_2O emissions increased linearly with increasing nitrogen rates over two years in irrigated sugar beet.

Overall, irrigation did not have a statistically significant effect ($p < 0.05$) on beet yield, sugar concentration, or cumulative N_2O emissions. However, certain trends were observed across treatments. Full irrigation resulted in a higher beet yield at a near-significant level (p=0.119) and lower cumulative N_2O emissions (p=0.241). Nitrous oxide is an intermediate product of the anaerobic denitrification process, which microbes can further reduce to harmless N_2 gas. Nömmik (1956) reported that maximum anaerobic denitrification occurs when the water-filled pore space is >70%. Full irrigation may have promoted complete anaerobic denitrification, as it likely increased the water-filled pore space >70%, allowing more complete reduction of N_2O to N_2. In contrast, deficit irrigation likely maintained the water-filled pore space below 70%, favoring both aerobic/anaerobic emissions and resulting in higher N_2O accumulation.

In contrast, sugar concentration was higher under deficit irrigation, showing a trend toward significance (p = 0.316), which was farther from the tested significance level. These results indicate that although irrigation effects were not statistically significant, full irrigation tended to enhance beet yield and reduce N_2O emissions, whereas deficit irrigation slightly increased sugar concentration.

Beet Yield & Sugar Concentration

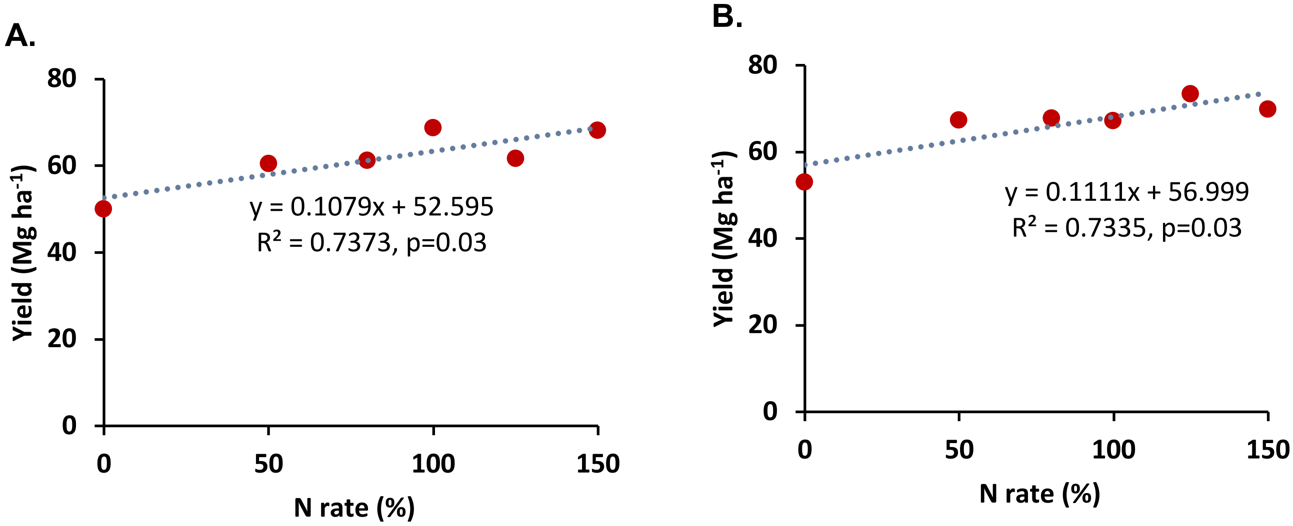

Figure 1. Relationships between sugar beet root yield and nitrogen rates under (A) deficit irrigation and (B) full irrigation.

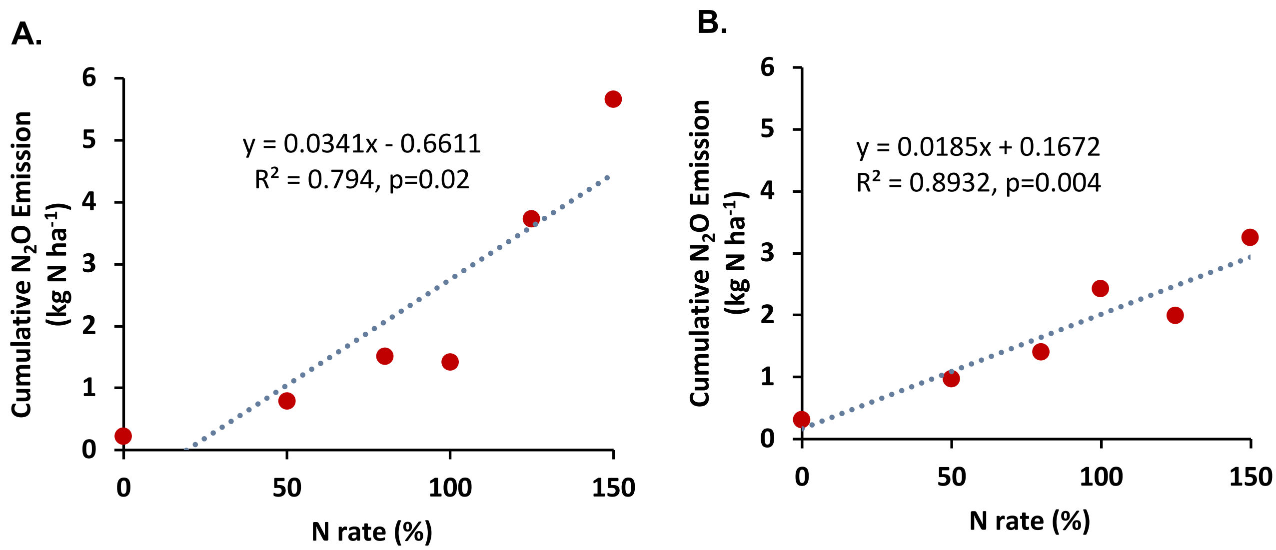

Figure 2. Relationships between Cumulative N_2O Emission and nitrogen rates under (A) deficit irrigation and (B) full irrigation.

CONCLUSIONS

This study examined the effects of irrigation and nitrogen rates on sugar beet yield, sugar concentration, and N_2O emissions in Western Nebraska. Nitrogen application significantly increased beet yield and N_2O emissions, while irrigation level had no significant effect. Full irrigation produced higher yield and lower N_2O emissions compared to deficit irrigation, likely due to greater soil moisture promoting more complete denitrification. In contrast, deficit irrigation slightly increased sugar concentration, possibly because mild water stress enhanced sugar accumulation. These results highlight trade-offs between irrigation and nitrogen management to optimize yield, sugar quality, and greenhouse gas emissions. Applying 50% of the recommended N rate under full irrigation appears to be a sustainable solution for maintaining productivity while minimizing environmental impacts in sugar beet systems of Western Nebraska.

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