

Effect of Nitrogen Rates and Mineral Nutrients on the Morphological, Physiological, and Yield Characteristics of Sugar beet (*Beta vulgaris* L.)

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ABSTRACT

Two field experiments were conducted during 2022/2023 and 2023/2024 growing seasons to evaluate the effect of nitrogen application rates (46,69 and 92 kg/fed.) and mineral nutrients (Control, boron, sulfur, and potassium) on the growth, yield and, quality of sugar beet. The results revealed that increasing chemical nitrogen rates up to 92 kg N/fed. significantly increased top weight, weight of roots, weight of plant, root length (cm), root diameter (cm), biological yield kg/plant, weight of root /plant (kg), top yield (ton/fed.), root yield (ton/fed.) and biological yield (ton/fed.) in both seasons, application of 92 kg N/fed. recorded the highest values for all studied traits compared with the application of 46 kg N/fed. Mineral nutrients recorded significant differences for all studied traits of sugar beet, the results revealed that potassium treatment recorded the highest significant values of top weight, weight of roots, weight of plant, root length, and top yield at the first season only, sulfur application gave the highest values of root yield and biological yield in both seasons followed by potassium treatment on root yield and biological yield in both seasons. On the other hand, the control treatment showed the lowest effect on the vegetative and yield characters. The results displayed that potassium treatment recorded the highest significant values of sugar% and potassium in both seasons, followed by sulfur or boron treatment. The highest root yield was recorded with the combination of sulfur plus 92 kg N/fed. in both seasons, compared with other treatments, followed by the combination of potassium plus 92 kg N/fed.

Keywords: nitrogen rates, nutrients, boron, potassium, sugar yield.

INTRODUCTION

Sugar beet is one of the important and economic crops in many countries and accounts for 20% of the world's total sugar production. It is the first source of sugar (about 70%) after sugar cane (about 30%), the cultivated area in the year 2021 was 610 thousand fed. with a root yield (13.3 million tons) in Egypt (CCSC, 2021). Several studies were conducted to improve the yield production of sugar beet under different conditions (Abdelaal et al., 2021; AlKahtani et al., 2021; Zalat et al., 2021; Mohamed et al., 2022a; Almuqrin et al., 2025). Chemical

fertilizer such as nitrogen, phosphorus, and potassium has a pivotal role in improving the growth and increasing the yield of several crops (Alharbi et al., 2022; Abd-El-Aty et al., 2024; Alaskar et al., 2024; Attaya et al., 2024a, b; El-Mahrouk et al., 2025). Nitrogen is an essential element for plant growth and optimal yield, it helps improve production and enhances sugar beet quality (Abdelaal and Tawfik, 2015; Abdelaal et al., 2019). However, the use of nitrogen at the end of the growing season can reduce sugar levels (Chandan et al., 2020). Afshar et al. (2019) reported that nitrogen application led to an increase in the production of sugar beet,

however, increased nitrogen also decreased the sucrose content and increased the amount of impurities in the roots. The increase in root yield and sugar content due to increased nitrogen might be because nitrogen improves plant nutrition, increases vegetative growth by increasing leaf area, and increases chlorophyll, which improves photosynthesis and increases root weight (Azaryar et al., 2024).

The application of mineral nutrients has emerged as a promising approach to crop enhancement. Boron plays a key role in sucrose transport from leaves to roots, in addition to other biological functions such as respiration, cell division and water relations. Boron primarily affects the growth and strength of cell walls, as well as the stimulation or inhibition of metabolic processes (Nemeat Alla et al. 2021). Boron is a very important element for cell tissue development and translocation of sugar, root weight, total soluble solids (TSS), sucrose percentage and juice purity, it has a role in maximizing the yield of sugar beet, sucrose content and juice purity. Mohamed et al. (2022b) reported that the application of boron recorded a significant increase in growth, yields and quality attributes. Boron had a positive effect on root diameter, root, top, and sugar yields/fed, and sucrose% (Enan, 2011; Nemeat Alla, 2017). Sulfur might help in decreasing soil alkalinity during sulphur biological oxidation and improves nitrogen utilization and increase foliage growth, root dimensions, crop yield, and sugar yield. Sulfur helps improve overall juice purity by decreasing root impurities; sulfur is favors sugar quality by reducing α -amino nitrogen content. Sulphur is a constituent element of some amino acids, namely Cystein and Methionine and it is involved in synthesis of chlorophyll, certain vitamins, carbohydrates and proteins (Thomas et al., 2000). In this regard, treating sugar beet with sulphur gave the highest values of dry weight, chemical composition, yield and best root quality (Tawfic et al., 2014; Mohamed et al., 2022c). Potassium is the most important nutrient in sugar beet cultivation in terms of quantity. It is known for its positive effects on yield formation and sugar content. It promotes

photosynthetic performance, which leads to increased formation of substances in carbohydrate metabolism (sucrose formation). Potassium strengthens the plant against diseases, therefore maintaining its efficiency. Nemeat Alla and El-Naqma (2023) showed that sugar beet fertilization with 48 kg K_2SO_4 /fed produced the greatest values of root diameter, fresh and foliage fresh weights/plant, root, top, and sugar yields/fed, potassium content, sucrose and extracted sugar percentages. also, Mohamed et al. (2022c) showed that application of potassium at rate 48 kg K_2O recorded the highest significant values of weight of plants, weight of roots, plant height, top yield length, root diameter and plant weight. While, the highest values of fresh top yield, total LA, LAI, K, Na and α -amino N content were obtained with potassium application at rate 24 kg K_2O . Therefore, this study aimed to evaluate the effect of chemical nitrogen (N) fertilizer, mineral nutrients, including Control, Boron, Sulfur and Potassium and their interaction on some morphological, physiological characters, and productivity of sugar beet.

MATERIAL AND METHODS

Two field experiments were conducted under the condition of Kafer EL-Sheikh Governorate, Egypt in both growing seasons 2022/2023 and 2023/2024 to study the effect of nitrogen rates and mineral nutrients and their interaction on growth, productivity and quality attributes of sugar beet (*Beta vulgaris* var. *Saccharifera*, L.). Split plot design in three replications was used in this study. The main plot included nitrogen rate treatments (46, 69, 92 kg/fed.) while, mineral nutrients (Control, Boron, Sulfur and Potassium) were occupied in a sub-plot. The sub-plot area was 14.40 m² including 6 ridges of 4 m in length and 60 cm in width. The agricultural practices were applied as recommended by the Ministry of Agriculture as follows calcium super phosphate (15% P_2O_5) was applied at the rate of 200 kg/fed at seed bed preparation. The sowing date of sugar beet variety "Gloria" was on the 14th and 15th of October in both seasons. The sugar beet

cultivation was on one side of the ridge with a single plant/hill, the plant density was 35000 plants/fed. The harvest date of sugar beet was 210 days after cultivation. Whereas, both the nitrogen rates and mineral nutrients

were added for sugar beet plants at the vegetative growth stage. Soil chemical analysis (the upper 30 cm) of the experimental site was determined according to the method of Jackson (1973) in Table 1.

Table 1. Physical and chemical soil characteristics at the experimental sites during 2022/23 and 2023/24 growing seasons

Season	EC _e dS/m	pH	K _s , cm/hr	ρ _a Mg/m ³	Available ppm			Particle size distribution %			Texture class
					N	P	K	sand	silt	clay	
2022/23	1.90	7.78	0.211	1.22	20.55	10.83	333	21.49	28.12	50.43	clayey
2023/24	1.94	7.83	0.215	1.18	19.65	10.91	347				

In both seasons, two samples, i.e. at 130 and 180 days after planting were collected from three replicates of each treatment for the morphological studies and chemical analysis. In each sampling date, the following growth characters were measured:

Vegetative and yield characters

Top weight, weight of roots, weight of plant, root length (cm), root diameter (cm), biological yield (kg/plant), weight of root/plant (kg), top yield (ton/fed.), root yield (ton/fed.) and biological yield (ton/fed.).

Sugar yield and juice quality characteristics

Sugar yield (ton/fed) and all sugar quality parameters as sucrose %, quality %, potassium, sodium %, and α-amino N were determined at harvest in the Delta Sugar Company, Kafr El-Sheikh, Egypt, according to Le Docte (1927), Where root samples were cleaned and then passed through a machine with knives to give macerated roots. Then, 40 g of macerated roots were mixed with 165 ml lead acetate (5%) solution by magnetic stirrer and then filtrate to determine sugar beet yield quality.

Sucrose percentage % was estimated in fresh samples of sugar beet roots by using a saccharometer according to the method described in AOAC (2005). Potassium and sodium concentration was determined using a flame photometer (mg/100 g sugar beet), Alpha amino nitrogen concentration (mg/100g sugar beet) was determined using Kjeldahl wet oxidation process as described by Blakemore et al. (1987). Purity percentage

% = {(Sucrose % - Impurities %) x 100 / sucrose %} as described by Carruthers et al. (1962). The purity of a sugar solution may be defined as the percentage of total solids (dry substance).

Statistical analysis

The analysis of variance according to Gomez and Gomez (1984) was used and the Treatment means were compared by Duncan's Multiple Range Test (Duncan, 1955). All statistical analyses were performed using the analysis of variance technique by means of the "Costate" computer software package.

RESULTS AND DISCUSSION

Vegetative and yield characters

Top weight, weight of roots, weight of plant, root length (cm), root diameter (cm), biological yield (kg/plant), weight of root/plant (kg), top yield (ton/fed.), root yield (ton/fed.) and biological yield (ton/fed.) as affected by nitrogen fertilization and mineral nutrients (Control, Boron, Sulfur and Potassium) and their interaction in 2022/23 and 2023/24 are presented in Tables 2-4.

Effect of nitrogen fertilization

Regarding the results in Tables (2-4) showing that the effect of nitrogen fertilization on all vegetative and yield characters as top weight, weight of roots, weight of plant, root length (cm), root diameter (cm), total fresh weight at harvest kg/plant, weight of root/plant (kg), top yield (ton/fed.), root yield (ton/fed.) and biological yield (ton/fed.) in both seasons. The results

revealed that the application of nitrogen fertilizer at the rate of 100 kg/fed. gave the highest significant values in all previous traits in both seasons. On the other hand, the application of nitrogen fertilizer at the rate of 50 kg/fed. recorded the lowest significant values of in all previous traits in both seasons. Similar results were reported by Abd El-Kader (2011), recommended that fertilized

sugar beet plants with 110 kg N/fed increased root and sugar yields/fed at El-Hammoul, Kafer El-Sheikh Governorate conditions, Leilah et al. (2005) and Abd El-Kader (2008) reported that increasing nitrogen fertilizer rate increased yields of top, root of sugar beet per fed, Abd El-Razek et al. (2011) found that Increasing N fertilizer up to 90 kg N/fed. significantly increased root of sugar beet.

Table 2. Effect of nitrogen fertilization and mineral nutrients on top weight, weight of roots, and weight of plant during two growing winter seasons (2022/23 and 2023/24)

Treatments	Top weight (kg/m ²)		Weight of roots (kg/m ²)		Weight of plant (kg/plant)	
	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24
Nitrogen (N)						
46	2.90 c	2.89 c	1.97 b	2.01 b	4.87 c	4.82 c
69	3.13 b	3.05 b	2.03 b	2.11 b	5.17 b	5.19 b
92	3.41 a	3.56 a	2.26 a	2.31 a	5.67 a	5.82 a
F-test	**	**	*	*	**	**
Mineral Nutrients (MN)						
Control	2.45 d	2.38 d	1.61 d	1.64 d	4.07 d	3.99 d
Boron	3.14 c	3.27 c	2.00 c	2.11 c	5.14 c	5.17 c
Sulfur	3.45 b	3.38 b	2.30 b	2.41 b	5.75 b	5.79 b
Potassium	3.55 a	3.62 a	2.43 a	2.76 a	5.98 a	6.08 a
F-test	**	**	**	**	**	**
(N x MN)	*	**	ns	ns	ns	ns

*, ** and NS indicate $p < 0.05$, < 0.01 and not significant, respectively. Means of each factor designated by the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Effect of mineral nutrients

Data in Tables 2-4 showed that, the application of mineral nutrients as control, Boron, Sulfur and Potassium as a foliar resulted in a significant increase in the following growth and yield characters as top weight, weight of roots, weight of plant, root length (cm), root diameter (cm), total fresh weight at harvest kg/plant, weight of root/plant (kg), top yield (ton/fed.), root yield (ton/fed.) and biological yield (ton/fed.) in both seasons. The results revealed that potassium recorded the highest significant values of vegetative characters in both seasons compared with other treatments. Such an effect of potassium promotes photosynthetic performance, which leads to increased formation of substances in carbohydrate metabolism in plants, which improves plant growth, the data in Table 4 show that both potassium and sulfur treatments register significantly higher values of top yield, root yield, and biological yield

at the two growing seasons compared with other treatments. On the other hand, the control treatment showed the lowest effect on the vegetative and yield characters.

Because potassium is involved in many essential plant processes, including membrane tissue growth, cell pressure variation and expansion, photosynthesis, enzyme activation, movement of photosynthesis-related creation of proteins, supplying the highest rate of K-fertilizer to the soil (75 kg potassium sulfate/fed or 36 kg K₂O/fed) may have beneficial impacts on yield components, overall quality, and yields (Marschner, 2012). Additionally, potassium increases dry matter accumulation, yield components, quality characteristics and harvest yields by strengthening plants' resistance to stressors like disease, pests, cold, and drought. This pattern of findings is consistent with those verified by Barlog and Grzebisz (2025) and Lamlo et al. (2025).

Effect of interactions

Data in Tables 2-4 showed a significant effect of interactions between nitrogen fertilization and mineral nutrients in 2022/23 and 2023/24 on all vegetative and yield

characters as top weight, root yield (ton/fed.) and biological yield (ton/fed.), root diameter and top yield biological yield (kg/plant) and weight of root (kg/plant) in both seasons.

Table 3. Effect of nitrogen fertilization and mineral nutrients on root length, root diameter, biological yield and weight of root/plant during two growing winter seasons (2022/23 and 2023/24)

Treatments	Root length (cm)		Root diameter (cm)		Biological yield (kg/plant)		Weight of root (kg/plant)	
	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24
Nitrogen (N)								
46	6.89 b	6.91 c	8.65 c	8.50 b	2.34 c	2.35 c	1.24 b	1.33 b
69	7.45 ab	7.49 b	9.22 b	9.31 ab	2.52 b	2.58 b	1.40 a	1.48 ab
92	7.81 a	7.90 a	9.63 a	9.74 a	2.69 a	2.71 a	1.45 a	1.62 a
F-test	*	**	**	*	**	**	*	*
Mineral Nutrients (MN)								
Control	6.95 d	6.88 d	8.62 d	8.58 d	1.93 d	1.92 d	1.11 d	1.18 d
Boron	7.22 c	7.26 c	8.92 c	8.88 c	2.36 c	2.41 c	1.24 c	1.26 c
Sulfur	7.39 b	7.41 b	9.10 b	9.14 b	2.64 b	2.70 b	1.39 b	1.45 b
Potassium	7.98 a	7.95 a	9.84 a	9.86 a	3.12 a	3.28 a	1.71 a	1.79 a
F-test	**	**	**	**	**	**	**	**
(N x MN)	ns	ns	*	ns	ns	*	ns	**

*, ** and NS indicate $p < 0.05$, < 0.01 and not significant, respectively. Means of each factor designated by the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Table 4. Effect of nitrogen fertilization and mineral nutrients on top yield, root yield (ton/fed.) and biological yield (ton/fed.) during two growing winter seasons (2022/23 and 2023/24)

Treatments	Top yield (ton/fed.)		Root yield (ton/fed.)		Biological yield (ton/fed.)	
	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24
Nitrogen (N)						
46	17.68 c	17.59 c	23.26 c	23.36 c	40.94 c	40.77 c
69	19.49 b	19.62 b	25.54 b	25.48 b	45.03 b	44.93 b
92	21.20 a	21.15 a	26.97 a	27.13 a	48.17 a	47.71 a
F-test	**	**	**	**	**	**
Mineral Nutrients (MN)						
Control	16.63 d	16.56 d	21.38 c	21.17 c	38.02 d	37.88 d
Boron	18.75 c	18.63 c	23.70 b	23.92 b	42.46 c	42.52 c
Sulfur	20.68 b	21.85 a	28.36 a	28.44 a	50.14 a	50.03 a
Potassium	21.77 a	20.73 b	27.57 a	27.61 a	48.26 b	48.37 b
F-test	**	**	**	**	**	**
(N x MN)	**	ns	**	**	**	**

*, ** and NS indicate $p < 0.05$, < 0.01 and not significant, respectively. Means of each factor designated by the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Data in Tables 4 and 5 showed a significant effect of interactions between nitrogen fertilization and foliar mineral nutrients on root yield in both seasons.

Results in Table 5 showed that root yield of sugar beet as affected by the interaction between nitrogen fertilization and mineral nutrients as a foliar in both growing seasons.

The highest root yield was obtained from plants which treated by the combination of sulfur plus 92 kg N/fed. in both seasons, compared with other treatments, followed by the combination of potassium plus 92 kg N/fed. without significant differences, the other combination between nitrogen rates and

sulfur and potassium as a foliar, these results are due to the effect of sulfur and potassium on biochemical process add that the effect of sulfur and potassium on soil environmental which improve the growth of sugar beet and increases sugar beet productivity.

Table 5. Effect of the interaction between nitrogen fertilization and mineral nutrients on root yield (ton/fed.) during two growing winter seasons (2022/23 and 2023/24)

Nitrogen (N)	Root yield (ton/fed.)							
	Control		Boron		Sulfur		Potassium	
	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24
46	19.66 d	19.37 d	22.05 bc	22.30 bc	24.18 b	24.13 b	27.23 ab	27.20 ab
69	21.39 bc	20.78 c	23.74 b	23.46 b	27.44 ab	27.41ab	29.64 ab	29.61 ab
92	23.12 b	23.26 b	25.38 b	25.34 b	31.19 a	31.19 a	28.25 ab	28.25 ab

Juice quality character

All sugar quality parameters as sugar percent, quality, potassium content, sodium content and α -amino N as affected by nitrogen fertilization and mineral nutrients and their interaction in 2022/23 and 2023/24 are presented in Table 5.

Effect of nitrogen fertilization

Data in Table 5 show the effect of nitrogen fertilization on all sugar quality parameters as sugar percent, quality, potassium content, sodium content, and α -amino N in both seasons. The results showed that the application of nitrogen fertilization at a rate of 100 kg N/fed. gave the highest significant values in the following traits sugar %, quality, potassium content and α -amino N in both seasons without significant differences with the rate of 75 kg N/fed on sugar % and quality characters in both seasons, and on sodium content in the first season only. While, the rate of 50 kg N/fed. showed the lowest significant values of all studied sugar quality parameters in both seasons. Similar results were reported by Leilah et al. (2005) and Abd El-Kader (2008), who reported that increasing nitrogen fertilizer rates increased sugar yields per fed. On the other hand, sucrose %, sodium %, and potassium % in sugar beet roots decreased

with increasing nitrogen fertilizer rates. Abd El-Razek et al. (2011) found that increasing N fertilizer up to 90 kg N/fed. significantly increased sugar yield, while decreasing the sucrose % of sugar beet

Effect of mineral nutrients

Data in Table 6 showed that the application of mineral nutrients as Control, Boron, Sulfur, and Potassium as foliar showed a significant effect on all sugar quality parameters as sugar percent, quality, potassium content, sodium content and α -amino N in both seasons. The results showed that Potassium treatment recorded the highest significant values of Sugar Percent and Potassium content in both seasons, followed by sulfur or boron treatment in the same characters. The treatments of boron recorded the highest values of Sodium content & α -amino N in both seasons. The control treatment gave the biggest percentage of quality characters in both seasons, followed by the treatment of potassium in the same effect on the same characters. Such effect of mineral nutrients could be attributed to a sustainable approach to crop enhancement, driven by increasing demand for environmentally friendly agricultural practices and reduced synthetic input dependency.

Table 6. Effect of nitrogen fertilization and mineral nutrients on sugar percent, quality, potassium content, sodium content and α -amino N during two growing winter seasons (2022/23 and 2023/24)

Treatments	Sugar %		Quality		Potassium content		Sodium content		α -amino N	
	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24	2022/23	2023/24
Nitrogen (N)										
46	17.75 b	17.78 c	75.70 a	75.71 ab	7.39 c	7.42 c	3.33 d	3.44 c	4.61 b	4.36 c
69	18.61 a	18.19 b	74.49 b	74.42 b	7.65 b	7.68 b	3.52 a	3.69 a	4.98 a	4.58 b
92	18.98 a	18.87 a	75.46 a	75.91 a	7.94 a	7.98 a	3.40 ab	3.56 b	4.39 c	4.99 a
F-test	**	**	*	*	**	*	*	*	*	**
Mineral Nutrients (MN)										
Control	18.02 c	18.13 c	78.65 a	78.59 a	7.09 d	7.18 d	3.04 c	3.19 c	3.48 d	3.44 d
Boron	18.44 ab	18.42 b	71.14 d	71.17 d	7.86 b	7.59 c	4.12 a	4.28 a	5.96 a	5.78 a
Sulfur	18.16 b	18.67 a	75.25 c	75.39 c	7.53 c	7.96 b	3.43 b	3.86 ab	4.12 c	4.32 c
Potassium	18.63 a	18.59 a	75.82 b	76.02 b	8.15 a	8.24 a	3.07 c	3.31 c	5.08 b	5.11 b
F-test	*	*	**	**	**	**	**	**	**	**
(N x MN)	**	**	**	**	**	*	**	**	**	**

*, ** and NS indicate $p < 0.05$, < 0.01 and not significant, respectively. Means of each factor designated by the same letter are not significantly different at 5% level, according to Duncan's multiple range test.

Effect of interactions

Data in Table 5 showed that a significant effect of interactions between nitrogen fertilization and foliar mineral nutrients on all sugar quality parameters as sucrose %, quality %, potassium, sodium %, and α amino N in both seasons.

CONCLUSIONS

The results demonstrated that increasing the nitrogen application rate to 92 kg N/fed. significantly increased root weight, plant weight, root length, root diameter, and root weight per plant in both growing seasons. The combination of 92 kg N/fed. with mineral nutrient applications also resulted in high top, root, and biological yields. Among the mineral nutrient treatments, sulfur application combined with 92 kg N/fed. produced the highest root yield in both seasons. These findings indicate that appropriate nitrogen fertilization combined with mineral nutrient application can enhance the growth and productivity of sugar beet under the conditions of the study.

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