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Integrative Effect of Foliar and Soil Nutrition in Reducing Mineral Nitrogen Fertilizer and Enhancing Sugar Beet (*Beta vulgaris* L.) Yield and Quality by Applying Calcium Nanofertilizer

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TWO-FIELD experiment was conducted at the experimental farm of Delta Sugar Company at El-Hamoul area (latitude: 31.28 and longitude: 31.15) in North of Egypt, Kafr El-Sheikh Governorate, Egypt during 2020/21 and 2021/22 winter seasons to investigate the integrative effect of foliar and soil nutrition for partially reducing mineral nitrogen (N) fertilizer applied and enhancing sugar beet yield and quality. The experiments were carried out in strip plot design, where the vertical plots were devoted to soil application of fertilizers, while the horizontal plots were assigned to foliar fertilization treatments. Following are the three soil fertilization treatments: a) mineral N was top-dressed at a rate of 100 kg/fed, b) mineral N was top-dressed at a rate of 30 kg/fed + green foliar as a commercial fertilizer compound was drenched at a rate of 10 L/fed, and c) mineral N was top-dressed at a rate of 50 kg/fed + green foliar compound was drenched at a rate of 20 L/fed. Four foliar fertilization treatments where treatments were applied in this investigation as follows: a) control (plants sprayed with tap water), b) malty green at a rate of 5 L/fed, c) nano-calcium at a rate of 2.5 L/fed, and d) malty green at a rate of 2.5 L/fed + nano calcium at a rate of 1.25 L/fed. The obtained results indicated that spraying sugar beet plants with malty green (2.5 L/fed) + nano calcium (2.5 L/fed) treatment considerably improved of all the traits studied compared with sugar beet plants treated with tap water (control) in both seasons. The RY trait depicted a significant positive correlation with NAR, CGR and SY ($p \leq 0.05$) in 2020/21 season; however, in the 2021/22 season, RY showed a significant positive correlation with all the previously mentioned traits as RGR, NAR, RL, RFW, sucrose percentage, purity percentage, and SY under four foliar and three soil fertilization treatments in both seasons. In conclusion, fertilizing sugar beet plants with 50 kg N/fed + green foliar (20 L/fed) as a soil drenching integrated with foliar spraying of malty green (2.5 L/fed.) + nano calcium (2.5 L/fed.) was found by a promising agronomic practice for maximizing growth, root, sugar yields, and sugar quality of sugar beet cultivar under the study area.

Keywords: El-Hamoul area, foliar fertilization, Malty green, soil nutrition, nitrogen, sugar beet.

1. Introduction

Sugar beet cultivation in Egypt is vital for the sugar industry's main goal since its natural properties of salinity tolerance and ability to thrive in a desert climate make it the second choice for sugar production (EL-Shal, 2016, Sheha *et al*., 2023) After sugar cane, sugar beet (*Beta vulgaris* L.) is regarded as the second-most significant sugar crop in Egypt and many other nations throughout the world (Ali, *et al*., 2019, Dewdar *et al*., 2018). Bridging the gap between sugar production and demand are currently the first crucial phase in the Egyptian strategic plan (Zhou *et al*., 2021). By expanding the areas under cultivation for sugar crops and boosting unit area production, this gap can be closed (Singh *et al*., 2019). Because sugar beetroot is a short-lived crop and needs less water and fertilizer than sugar cane, it is one of the more crucial crops to plant in newly reclaimed soils

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(Richards *et al*., 2017).

Maximizing sugar beet productivity per unit land area and expanding cultivated areas by planting sugar beets in newly reclaimed lands are two strategies for improving sugar production (Weeks, 2017). However, the salinization and unbalanced fertilizer supply of the newly reclaimed soils are two serious challenges that cause low productivity. (Daba and Qureshi, 2021).

Nitrogen (N), as a key nutrient element, is required in high concentrations for sugar beet to produce a high yield since it positively affects growth and development. (Ghada *et al*., 2013, Varga *et al*., 2022). Because the effectiveness of other nutrients depends on N, it is known as the balancing wheel of sugar beetroot nutrition (Mordenti *et al*., 2021). The application of N fertilizer at the optimum rate is essential for the growth of crop plants and their yield quantity and quality (Anas *et al*., 2020).

Recently, agrochemical pollution has received a lot of attention, both locally and globally (Abou El-Enin *et al*., 2023, Feckler *et al*., 2023). The excessive use of various mineral fertilizers in agriculture is one of the major sources of pollution (Dai *et al*., 2022). The unwise use of chemical fertilizers is considered a key contributor to soil and aerial pollution and a threat to animal, beneficial biota, and human health. Consequently, minimizing the use of such agrochemical fertilizers can help to reduce environmental pollution and maintain the ecosystem balance. (Artiola *et al*., 2019).
Utilizing organic and nano fertilizers is one strategy to decrease the consumption of mineral N fertilizer (Qureshi et al., 2018). In the management aspects, efforts are made to increase the effectiveness of applied fertilizer with the aid of soil and foliar applications of fertilizer having numerous elements as well as the use of Nano fertilization technology, which introduces a new era of fertilizers and can maximize the plant optioning of the fertilizers and its quick effect, as well as decrease the environmental pollution as compared to regular manufactured (Mikula *et al*., 2020).

According to Shaban *et al*. (2014) and Nemeatalla *et al*. (2018), adding potassium humate to the soil boosted sugar beets root fresh weight, sucrose content, root, and sugar yields. Enan (2015) investigated the foliar spray of sugar beetroot with 288 ppm Ca/feddan (fed; 1 fed=4200 m^2), also, Artyszak *et al*. (2014) tested it with 262.g Ca/ha. They discovered higher sugar beetroot yield, fresh weight, sucrose content, and sugar production. In this concern, Enan *et al*. (2016), foliar application of potassium compound at a rate of 2 L ha^{-1} significantly improved sugar beetroot yield, root fresh weight, sucrose content, and root yield. Leilah *et al*. (2005), Hanafy *et al*. (2019), Leilah and Kan (2021) reported the sucrose content of sugar beetroot declined with incremental levels of N, root length, root fresh weight, plant canopy, and root yield increased. Mekdad and Rady (2016) found spraying of a micronutrient mixture containing iron-Fe, zinc-Zn, and manganese-Mn boosted sugar beet crop yield and its characteristics. According to Dewdar *et al*. (2018), sugar beet plants treated with 200 mg/L of nano-microelements and 1% of urea improved sugar beet root length and diameter, dry matter per plant, and root, top, and sugar yields. Also, in the study by Hassanein *et al*. (2019), the treatment with mineral N at a rate of 54 or 90 kg N/fed plus nano sissay (810 g/fed) + combined with nano micro elements (200 ppm) produced the highest root weight, sucrose content, and plant sugar production. Additionally, they discovered that this treatment saved roughly 46 kg of N without noticeably lowering root and sugar output.

Therefore, the objective of our study was to explore the potential integrative effect of foliar (e.g., malty green and nano calcium as commercial fertilizer compounds) and soil (e.g., green foliar as a commercial fertilizer compounds) nutrition for partially reducing the applied mineral N fertilizer and enhancing the growth and sugar yield and quality of *Beta vulgaris* L. cv. Karam.

2. Material and Methods

2.1. Geographic and climatic data of the studied site

A two-year field experiment (2020/21 and 2021/22 winter seasons) was conducted at the experimental farm of Delta Sugar Company (latitude: 31.28 and longitude: 31.15) at El-Hamoul area in North of Egypt, Kafr El-Sheikh Governorate, Egypt, to explore the integrative effect of foliar and soil nutrition for partially reducing mineral N fertilizer applied and enhancing *Beta vulgaris* L. cv. Karam sugar yield and quality. Geographic coordinates for the experimental field site are presented in Figure 1.

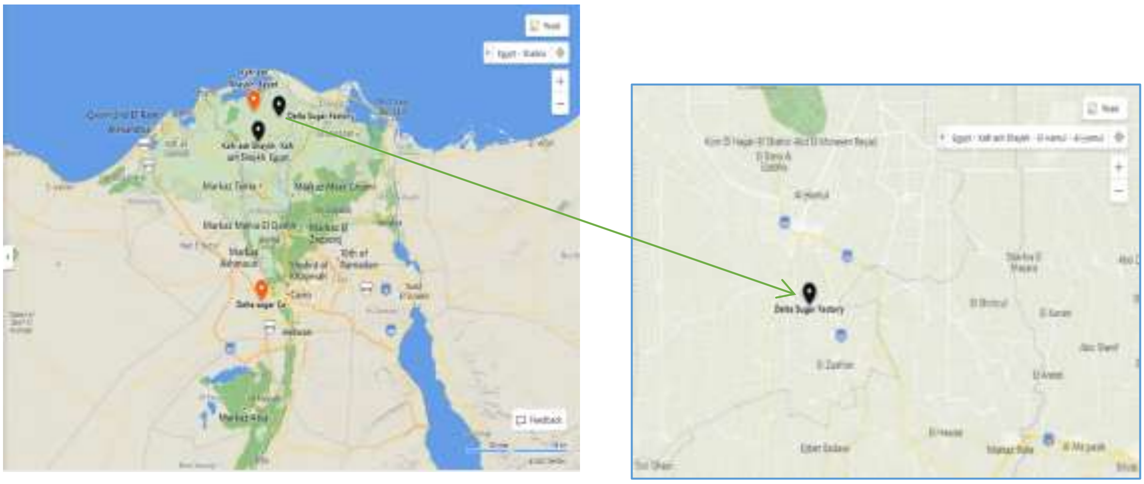

Fig. 1. Geographic coordinates for the cultivated location. ***https://maps.google.com.***

2.2. Soil characteristics of the experimental field site

Before the planting date in the 2020/21 and 2021/22 growing seasons, soil samples were randomly collected from the experimental locations at a 0–30 cm soil depth for main physico-chemical properties. Following Page's (1982) standard method, the physico-chemical properties of soil samples for each experimental season (Table 1) were analyzed at the soil analysis laboratory, Sakha Research Station, Agricultural Research Center, Sakha, Kafr Elsheikh Governorate, Egypt.

Table 1. Physico-chemical properties of soil at experimental sites during the 2020/21 and 2021/22 seasons.

Variable	Seasons 2020/21	Seasons 2021/22
Physical analysis		
Sand (%)	22.53	23.43
Silt (%)	26.65	24.61
Clay (%)	50.82	51.96
Texture class	Clay	Clay
Chemical analysis		
Soil reactions pH (1:7.5)	7.86	8.01
EC in soil paste (dS/m)	3.55	3.41
Organic matter (%)	2.02	1.96
Available N (ppm)	17.73	16.58
Available P (ppm)	6.82	6.37
Available K (ppm)	270.5	285.2
Soluble Cations (cmolc kg^{-1})		
Ca^{2+}	3.60	3.80
K^{+}	0.55	0.62
Na^{+}	11.41	12.73
Fe^{2+}	9.33	10.24
Cu^{2+}	5.60	4.72
Zn^{2+}	1.46	2.38
Soluble anions (cmolc kg^{-1})		
HCO_3-	5.67	6.14
Cl-	8.42	7.77
SO_4^{2-}	2.45	2.61
CO_3^{2-}	0.0	0.0

Source: *Soil analysis Lab, Faculty of Agric, Kafrelsheikh University, Egypt.* Electrical conductivity (EC), calcium (Ca), potassium (K), sodium (Na), iron (Fe), copper (Cu), zinc (Zn), Bicarbonate (HCO3), chloride ion (Cl), Sulfate Ion (SO_4^{2-}), Carbonate Ion (CO_3^{2-})

2.3. Experimental design and treatment details

This experiment was carried out in a strip plot design based on a completely randomized block arrangement with four replicates. The horizontal plots (14 m in width × 28 m in length) were assigned for foliar fertilization treatments, whereas the vertical plots (14 m in width × 21 m in length) were allocated for the soil application fertilizers. The net experimental plot area measured 21 m^2(3.5 m wide × 7 m long).

2.4. Soil application treatments

Following are the three soil fertilization treatments: a) mineral N was top-dressed at a rate of 100 kg/fed, b) mineral N was top-dressed at a rate of 50 kg/fed + green foliar as a commercial fertilizer compound was drenched at a rate of 10 L/fed, and c) mineral N was topdressed at a rate of 50 kg/fed + green foliar compound was drenched at a rate of 20 L/fed. These three soil fertilization treatments were abbreviated as MN_{100}, MN_{50}+GF_{10}, and MN_{50}+GF_{20}, respectively. Ammonium nitrate (33.3% N), a N fertilizer form that was utilized and each level of N fertilizer or green foliar compound was applied into two equal additions. The first was added at 40 days after sowing (DAS), and the second was added at 70 DAS.

2.5. Foliar application treatments

Four foliar fertilization treatments were applied in this investigation as follows: a) Control (plants sprayed with tap water), b) Malty green at a rate of 5 L/fed, c) nano calcium at a rate of 2.5 L/fed, and d) malty green at a rate of 2.5 L/fed + nano calcium at a rate of 1.25 L/fed. These four foliar fertilization treatments were abbreviated as control, MG_5, $CaNPs_{2.5}$, and $MG_{2.5}$+$CaNPs_{1.25}$, respectively.

The sugar beetroot plants received two applications of malty green compound and nano calcium at 50 and 70 DAS. The chemical constituents of green foliar, malty green, and nano calcium are shown in Table 2.

Table 2. Chemical constituents of green foliar, malty green and nano calcium.

Green foliar	(%)	Malty green	(%)	Nano calcium	%
Low purait urea	7.10	N	20.0	Calcium	16.03
Humic acid	10.0	Sea algae	5.00	Oxide	
Organic acid	1.00	K- humate	10.0	Organic	0.0
Amino acid	5.00	Lignosulfonate	1.00	substances	5.00
Fulvic acid	1.00	Plant extracts	5.00	Lignosulfon	
Plant extracts	20.0	K- oxide	10.0	ate Boron	2.00

Source: Green Power Co. (EGYMATEC GROUP), Al-Hamoul General Hospital Street, Dr. Ali Abu Talib Tower, Kafrelsheikh, greenpoweregypt.com.

2.6. Agronomical management practices

In the 2020/21 and 2021/22 growing seasons, respectively, seeding is done on October 15 and 20, following thorough soil preparation. The preceding summer crop was rice in both seasons. Multigerm sugar beetroot cultivar "Karam" seeds were manually seeded in hills with roughly three to four seed balls per hill at 0.2m apart (30 thousand /fad). The sugar beet seedlings were thinned to one plant per hill at 35 DAS. The recommended cultural practices for sugar beetroot crops were also followed.

***2.7. Growth* attributes**

At 90 and 120 DAS, 10 plants samples were taken from each plot to measure the following traits: Relative growth rate (RGR) mg/day was calculated according to the following formula (Watson 1958):

$$RGR = \frac{\log_e W_2 - \log_e W_1}{T_2 - T_1}$$

Net assimilation rate (NAR) mg/cm^2/day was calculated according to the following formula (Radford 1967):

$$NAR = \frac{(W_2 - W_1)(\log_e A_2 - \log_e A_1)}{(T_2 - T_1)(A_2 - A_1)}$$

Where: W_1 and W_2 refer to total dry weight per plant at first (T_1) and second (T_2) times in days, respectively. Log refers to logarithm Napierian (natural logarithm × 2.303). While, A_1 and A_2 refer to leaf area at first (T_1) and second (T_2) times, respectively.

Crop growth rate (CGR) in mg/cm^2/day was calculated according to the following formula (Watson 1958):

$$CGR = NAR\ x\ LAI$$

The leaf area (LA) was calculated using a correction factor of 0.75 (Milford *et al*., 1985) as follows: LA = leaf blade length (cm) × leaf blade width (cm) × 0.75. Furthermore, the leaf area index (LAI; m2 m−2).

2.8. Agronomic traits, yield and its components, and juice quality traits

The four central ridges of each plot were harvested at maturity (205 DAS) to estimate the following characters: Root fresh weight (g) and root length (cm) According to the method described by Le Docte (1927). The total soluble solids percentage (TSS%) in fresh root was measured using a hand refractometer (Phillip Lee Drive Atlanta, Georgia 30336 USA). The sucrose percentage (sucrose %) was measured using a saccharometer apparatus (Ludwig Schneider Sugar saccharometer, ProfiLab24 GmbH Landsberger Str. 24512623 Berlin, Germany), and the juice purity percentage (purity%) was obtained using the following formula:

$$\text{Purity (\%)} = \frac{\text{Sucrose\%}}{\text{TSS\%}} \times 100$$

2.9. Statistical analysis methods

The Kolmogorov-Smirnov test was used to confirm the normality of the data distribution. Using the Micro-computer Statistical (MSTAT-C) software package (Mstat 6.1.4, Michigan State University, USA), all data were statistically analyzed in accordance with the technique of analysis of variance (ANOVA) for the strip plot design. The least significant difference (LSD) method was used to test the differences between treatment means at the 5% level of probability (Gomez and Gomez 1984; Steel and Torrie, 1997). For a better understanding of the link between the researched qualities across experimental conditions, Pearson's correlation analysis was employed. The computer software program OriginPro 2022 was used to plot Pearson's Correlogram.

2. Results

The effects of soil and foliar fertilization on RGR, NAR, CGR (Table 3), root length, root fresh weight (Table 4), sucrose percentage, juice purity percentage (Table 5), root yield, and sugar yield (Table 6). in the 2020–2021 and 2021–2022 seasons are shown in Tables 3–6

The findings shown in Tables 3–6 demonstrated a substantial difference between soil fertilization treatments for all traits examined in both seasons. The obtained results clearly demonstrate that fertilized sugar beet root plants with 50 kg N+ green foliar (20 L/fed) as soil fertilization outperformed 100 kg N/fed as well as 50 kg N+ green foliar (10 L/fed) treatments in relative growth rate by 92.36 and 89.53% as well as 55.42 and 39.85%, net assimilation rate (mg/cm^2/day) by 24.22 and 19.93%

as well as 16.12 and 12.59%, as well as 1.30 and 1.21%, root yield /fed by 2.02 and 7.16 % as well as 9.55 and 9.11% and sugar yield /fed by 7.7 and 24.89 % as well as 16.31 and 16.18 % in 2020/2021 and 2021/2022 seasons respectively.

In this regard, 50 kg N+ green foliar (10 L/fed) treatment yielded the best purity percentages of 89.36 and 95.03%, whereas 100 kg N/fed resulted in the lowest purity percentages of 88.40 and 89.48% in the 2021 and 2021/2022 seasons, respectively (Tables 3–6).

Table 3. Physiological characteristics of sugar beet as affected by soil and foliar fertilization Treatments as well as their interaction in 2020/2021 and 2021/2022 seasons.

Treatments	Relative growth rate (RGR) mg/day		Net assimilation rate (mg/cm2/day)		Crop growth rate (mg/cm2/day)	
	2020/2021	2021/2022	2020/2021	2021/2022	2020/2021	2021/2022
Main factor: Foliar fertilization (F)						
Control	4.65d	5.47c	0.30c	0.31c	0.88d	0.90d
MG_5	8.49c	9.94b	0.35b	0.37b	1.37c	1.49c
$CaNPs_{2.5}$	9.99b	12.33a	0.38a	0.40a	1.69b	1.83b
$MG_{2.5}$+$CaNPs_{1.25}$	10.26a	12.56a	0.39a	0.42a	1.84a	2.04a
LSD at 0.05 for	**0.10**	**0.28**	**0.01**	**0.02**	**0.08**	**0.07**
Sub main factor: Soil fertilization (S)						
MN_{100}	11.57c	13.48c	0.40b	0.41c	1.99d	2.22c
MN_{50}+GF_{10}	7.45b	9.64c	0.35b	0.37b	1.26c	1.32b
MN_{50}+GF_{20}	6.02b	7.11b	0.32b	0.35b	1.07b	1.16b
LSD at 0.05 for	**0.34**	**0.58**	**0.01**	**0.02**	**0.07**	**0.10**
F x S interactions						
Control + MN_{100}	5.12d	4.92d	0.31c	0.29d	1.12e	1.02d
Control + MN_{50}+GF_{10}	4.88d	6.52e	0.31c	0.33c	0.79e	0.87c
Control + MN_{50}+GF_{20}	3.94c	4.99c	0.30c	0.32c	0.72d	0.82c
MG_5 + MN_{100}	13.03b	14.14b	0.42b	0.44b	2.14c	2.22c
MG_5+ MN_{50}+GF_{10}	5.93c	7.98d	0.32c	0.34bc	1.06d	1.00c
MG_5 + MN_{50}+GF_{20}	6.51b	7.72ab	0.31b	0.33c	0.90c	1.23ab
$CaNPs_{2.5}$ + MN_{100}	13.89b	17.34a	0.43a	0.46a	2.29b	2.71b
$CaNPs_{2.5}$+ MN_{50}+GF_{10}	9.37a	11.80b	0.38a	0.40a	1.55b	1.65a
$CaNPs_{2.5}$+ MN_{50}+GF_{20}	6.71a	7.84a	0.33b	0.35b	1.22a	1.13b
MG2.5+CaNPs1.25 + MN_{100}	14.25a	17.53a	0.45a	0.47a	2.40a	2.94a
$MG_{2.5}$+$CaNPs_{1.25}$ + MN_{50}+GF_{10}	9.61a	12.25a	0.38a	0.41a	1.65a	1.74a
$MG_{2.5}$+$CaNPs_{1.25}$+ MN_{50}+GF_{20}	6.91a	7.90a	0.36a	0.39a	1.45a	1.45a
LSD at 0.05 for	**0.82**	**0.74**	**0.02**	**0.03**	**0.14**	**0.23**

MG: Malty green (MG), Nano calcium (CaNPs), mineral nitrogen (MN), green foliar (GF), Least significant difference (LSD).

Table 4. Average root length and fresh weight of sugar beet as affected by soil and foliar fertilization treatments in 2020/2021 and 2021/2022 seasons.

Treatments	Root length/cm		Root fresh weight (g)	
	2020/2021	2021/2022	2020/2021	2021/2022
Main factor: Foliar fertilization (F)				
Control	17.89c	17.89d	724.80c	798.45c
MG_5	18.57b	19.45c	845.14b	945.65b
$CaNPs_{2.5}$	19.14a	19.77b	849.10b	959.69b
$MG_{2.5}$+$CaNPs_{1.25}$	19.30a	20.02a	861.05a	977.45a
LSD at 0.05 for	**0.74**	**1.13**	**61.33**	**80.19**
Sub main factor: Soil fertilization (S)				
MN_{100}	18.34bc	18.13c	838.54c	853.67c
MN_{50}+GF_{10}	18.74b	19.14b	764.08b	925.98b
MN_{50}+GF_{20}	19.11bc	20.57c	857.45a	981.28c
LSD at 0.05 for	**1.12**	**1.29**	**75.97**	**78.18**
F x S interactions				
Control + MN_{100}	17.23d	18.05d	673.92d	715.30d
Control + MN_{50}+GF_{10}	19.48c	18.93c	768.90c	893.73d
Control + MN_{50}+GF_{20}	19.69b	16.67d	731.57d	786.32d
MG_5 + MN_{100}	20.03a	20.92ab	906.07c	1018.67b
MG_5+ MN_{50}+GF_{10}	18.40c	19.14b	803.18a	908.70bc
MG_5 + MN_{50}+GF_{20}	18.10d	18.30b	826.18c	909.57a
$CaNPs_{2.5}$ + MN_{100}	19.32a	21.50b	917.56b	1092.34a
$CaNPs_{2.5}$+ MN_{50}+GF_{10}	19.13a	19.23a	747.00cd	914.97c
$CaNPs_{2.5}$+ MN_{50}+GF_{20}	18.03d	18.57b	882.76b	871.76b
MG2.5+CaNPs1.25 + MN_{100}	18.14c	21.80a	932.27a	1098.81a
$MG_{2.5}$+$CaNPs_{1.25}$ + MN_{50}+GF_{10}	18.42b	19.26a	737.22d	986.50a
$MG_{2.5}$+$CaNPs_{1.25}$+ MN_{50}+GF_{20}	18.76a	18.99a	913.65a	847.04c
LSD at 0.05 for	**1.47**	**0.89**	**119.39**	**122.84**

MG: Malty green (MG), Nano calcium (CaNPs), mineral nitrogen (MN), green foliar (GF), Least significant difference (LSD).

The findings shown in Tables 3–6 demonstrate a substantial difference between foliar fertilization treatments for all traits examined in both seasons. The results of our study showed that spraying sugar beet plants with Malty green (2.5L/fed.) + Nano calcium (2.5L/fed.) produced the highest values for relative growth rate (RGR), net assimilation rate (NAR), crop growth rate (CGR), 4.65 and 5.47 mg/cm2/day, root length (19.30 and 20.02 cm), root fresh weight (861.05 and 977.45 g), sucrose% (21), Contrarily, sugar beetroot plants sprayed with tap water (control) produced the lowest root length, fresh weight, sucrose%, purity%, root yield/fed., and sugar yield/fed. values in the 2020/21 and 202/22 seasons, respectively.

According to Tables 3-6, all assessed variables in both seasons showed substantial interaction effects between soil and foliar fertilization application. Results in the current study clearly demonstrate that Malty Green (2.5L/fed.) + Nano Calcium (2.5L/fed.) sprayed sugar beet plants outperformed all treatments in all examined traits over both seasons at all soil fertilization treatments.

Fertilized sugar beet plants with 50kgN/fed +green Foliar (20L/fed) as a soil address and sprayed by Malty green (2.5L/fed.) +Nano calcium (2.5L/fed.) treatment gave the highest values of relative growth rate (RGR) 14.25 and 17.53 mg / day, net assimilation rate (NAR) 0.45 and 0.47 mg/ cm^2 /day, crop growth rate (CGR) 2.40 and 2.94. mg/cm^2/day, root length 20.03 and 21.80 cm, root fresh weight 932.27 and 1098.81 g, sucrose % 22.53 and 24.84 %, purity % 91.46 and 98.88 %, root yield / fed. 37.44 and 41.30 ton and sugar yield / fed. 8.43 and 10.26 ton as compared with all interaction treatments in 2020/2021 and 2021/2022 seasons, respectively, (Tables 3-6).

Table 5. Sugar beet's juice sugar quality as affected by soil and foliar fertilization treatments in 2020/2021 and 2021/2022 seasons.

Treatments	Sucrose percentage (%)		Juice purity percentage (%)	
	2020/2021	2021/2022	2020/2021	2021/2022
Main factor: Foliar fertilization (F)				
Control	19.02c	18.56c	86.08c	88.47c
MG_5	20.40c	21.55b	87.41bc	94.08b
$CaNPs_{2.5}$	21.65b	22.26a	89.97b	94.64b
$MG_{2.5}$+$CaNPs_{1.25}$	21.94a	22.81a	92.37a	95.50a
LSD at 0.05 for	**0.35**	**0.45**	**0.90**	**0.80**
Sub main factor: Soil fertilization (S)				
MN_{100}	19.63b	20.44b	89.48b	88.40b
MN_{50}+GF_{10}	21.52cd	20.26b	95.03b	89.36bc
MN_{50}+GF_{20}	22.73d	21.56c	94.99c	89.11b
LSD at 0.05 for	**0.28**	**0.61**	0.73	0.68
F x S interactions				
Control + MN_{100}	19.23d	18.17e	86.13d	85.22d
Control + MN_{50}+GF_{10}	19.02c	19.55d	85.46d	93.27c
Control + MN_{50}+GF_{20}	18.81d	17.97c	86.67d	86.91c
MG_5 + MN_{100}	22.25b	23.81c	87.90c	97.84b
MG_5+ MN_{50}+GF_{10}	19.26c	21.55c	87.41c	94.53bc
MG_5 + MN_{50}+GF_{20}	19.69c	19.30bc	86.93c	89.86b
$CaNPs_{2.5}$ + MN_{100}	22.24b	24.10b	90.95a	98.03a
$CaNPs_{2.5}$+ MN_{50}+GF_{10}	21.23a	22.16b	89.75b	95.72b
$CaNPs_{2.5}$+ MN_{50}+GF_{20}	21.48a	20.51a	89.21b	90.16a
MG2.5+CaNPs1.25 + MN_{100}	22.53a	24.84a	91.46a	98.88a
$MG_{2.5}$+$CaNPs_{1.25}$ + MN_{50}+GF_{10}	21.55a	22.82a	94.84a	96.62a
$MG_{2.5}$+$CaNPs_{1.25}$+ MN_{50}+GF_{20}	21.76a	20.76a	90.80a	91.00a
LSD at 0.05 for	**0.54**	**0.75**	**1.96**	**1.35**

MG: Malty green (MG), Nano calcium (CaNPs), mineral nitrogen (MN), green foliar (GF), Least significant difference (LSD).

From these results it could be seen that fertilized sugar beetroot plants with 50kgN/fed +green Foliar (20L/fed) as a soil address and sprayed by Malty green (2.5L/fed.)+Nano calcium (2.5L/fed.) increased root yield /fed by 29.19 and 30.99% as well as sugar yield /fed by 54.68 and 80.95% as compared with plants received 100 kg N/fed and sprayed with tap water (control) in 2020/21 and 2021/22 seasons, respectively Feddan is determined to apply green foliar at a rate of 20 litres per feddan as a soil application or spraying plants with malty green at a rate of 2.5 litres per feddan plus nano calcium at a rate of 2.5 litres per feddan can save 50 kilograms of nitrogen per feddan and reduce environmental pollution (Tables 3–6).

Generally, it could be recommended that fertilizing sugar beet plants with 50kgN/fed +Green Foliar (20L/fed) as a soil address and spraying by malty green (2.5L/fed.) + Nano calcium (2.5L/fed.) treatment to maximizing root and sugar yields of sugar beet plants cv. Karam at El-Hamoul area condition, Kafr El-Sheikh Governorate, Egypt.

Table 6. Sugar beet yields as affected by soil and foliar fertilization treatments in 2020/2021 and 2021/2022 seasons.

Treatments	Root yield (t/fed)		Sugar yield (t/fed)	
	2020/2021	2021/2022	2020/2021	2021/2022
Main factor: Foliar fertilization (F)				
Control	29.58d	32.41c	5.63d	6.01c
MG_5	33.01c	36.09b	6.76c	7.80b
$CaNPs_{2.5}$	35.48b	38.81a	7.69b	8.66ab
$MG_{2.5}$+$CaNPs_{1.25}$	36.56a	38.79a	8.03a	8.87a
LSD at 0.05 for	**1.48**	**1.69**	**0.37**	**0.25**
Sub main factor: Soil fertilization (S)				
MN_{100}	35.88c	34.14bc	7.07b	7.02bc
MN_{50}+GF_{10}	35.24c	31.94c	7.60b	6.50c
MN_{50}+GF_{20}	38.45c	34.89b	8.83c	7.56c
LSD at 0.05 for	**0.69**	**1.55**	**0.30**	**0.33**
F x S interactions				
Control + MN_{100}	30.29c	32.62d	5.82d	5.91d
Control + MN_{50}+GF_{10}	29.52d	33.08bc	5.62d	6.46c
Control + MN_{50}+GF_{20}	28.93d	31.53d	5.45d	5.67d
MG_5 + MN_{100}	34.47b	38.77b	7.68b	9.24b
MG_5+ MN_{50}+GF_{10}	30.05c	33.41bc	5.80cd	7.20bc
MG_5 + MN_{50}+GF_{20}	34.50c	36.11b	6.80c	6.96c
$CaNPs_{2.5}$ + MN_{100}	37.36a	41.13a	8.31a	9.91b
$CaNPs_{2.5}$+ MN_{50}+GF_{10}	33.08b	37.49a	7.02b	8.31ab
$CaNPs_{2.5}$+ MN_{50}+GF_{20}	36.02b	37.80a	7.74b	7.75ab
MG2.5+CaNPs1.25 + MN_{100}	37.44a	41.30a	8.43a	10.26a
$MG_{2.5}$+$CaNPs_{1.25}$ + MN_{50}+GF_{10}	35.12a	36.99b	7.57a	8.44a
$MG_{2.5}$+$CaNPs_{1.25}$+ MN_{50}+GF_{20}	37.14a	38.08a	8.08a	7.91a
LSD at 0.05 for	**2.57**	**1.66**	**0.59**	**0.36**

MG: Malty green (MG), Nano calcium (CaNPs), mineral nitrogen (MN), green foliar (GF), Least significant difference (LSD).

Pearson's correlation coefficient

Based on the primary effects of foliar and soil fertilization treatments on sugar beetroot in 2020/21 and 2021/22, a Pearson's correlations analysis was carried out to investigate the relationship between RY and other examined variables, (Figure 2a, b).

A positive association ($p \leq 0.01$) was found among all traits, i.e., RGR, NAR, CGR, RL, RFW, sucrose percentage, juice purity percentage, RY, and SY as they were impacted by the four foliar fertilizers and the three soil fertilizers in both seasons. In the first season of 2020/21, RY attributes also showed a significant positive correlation with NAR, CGR, and SY ($p<0.05$).

3. Discussion

In Egypt, sugar beetroot has taken over as the primary source of the sweetener (Kandil et al., 2020). Almost every area of agricultural production is currently impacted by nanotechnology, including pesticides, insecticides, and fertilizers (Biswas and Wu 2005; Abdelsalam *et al*. 2019). As a result of their high absorbance and high reactivity, nanoparticles can be applied to plants to promote growth (Liu and Lal 2015). Furthermore, the overall yield and various yield components in numerous crop species, including maize, wheat, beans, and sugar beetroot, were enhanced by the foliar application of nano fertilizers in conjunction with mineral fertilizers (Moghaddasi et al. 2013; Sabir *et al*. 2014; Jakienė *et al*. 2015; Abdelsalam *et al*. 2019). To determine the impact of nano and conventional fertilizers on the quantity and quality of sugar beetroot, variety Karam (*Beta vulgaris*, L), in the El-Hamoul region of Kafr El-Sheikh Governorate, Egypt, this inquiry was carried out.

Using 50 kg N + green Foliar (20 L/fed) as a soil fertilizer, we found that fertilized sugar beet plants outperformed 100KgN/fed and 50kg N + green Foliar (10 L/fed) treatments in terms of relative growth rate, net assimilation rate, crop growth rate, root length, root fresh weight, sucrose percentage, root yield, and sugar yield in both seasons. In this regard, 50kgN+green Foliar (10L/fed) treatment yielded the highest purity percentage.

(A)

(A)

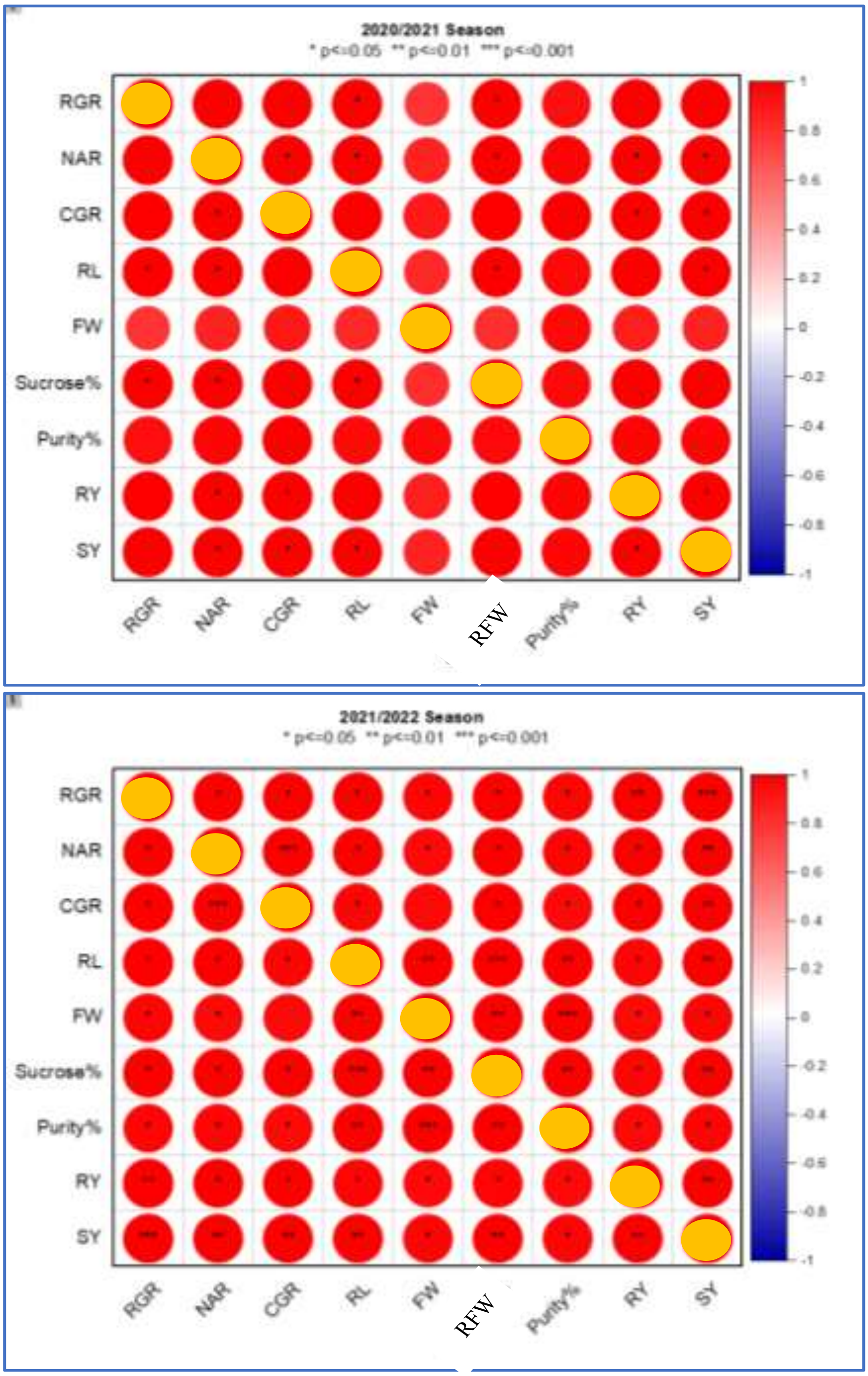

Fig. 2. Heatmap plot correlation describing the effects of foliar and soil fertilization treatments on the researched sugar beetroot attributes in 2020/21 and 2021/22. RL= root length, RFW= root fresh weight, RY= root yield, SY= sugar yield, NAR= net assimilation rate, CGR= crop growth rate, and RGR= relative growth rate. The big and medium red (positive) circles denote a significant (*$p \leq 0.05$) or highly significant ($p \leq 0.01$) association.**

The green foliar's humic acid, organic acids, amino acids, fulvic acid, and plant extracts, which increased relative growth rate, net assimilation rate, and crop growth rate and consequently increased root length and weight as well as sucrose%, may be responsible for the rise in root yield and sugar yield following 50kgN+green Foliar (20L/fed) treatment.

Additionally, this technique reduces environmental pollution and saves 50 kg N/fed without affecting the sugar beet plants' ability to produce sugar or roots. These findings concur with those of Shaban *et al.* (2014), Nemeatalla *et al.* (2018), and Mekdad *et al.* (2022).

In contrast, spraying sugar beetroot plants with tap water (control) resulted in the lowest values of root length, root fresh weight, sucrose %, purity%, root yield, and sugar yield as compared to all other studied treatments in both seasons. The superiority of Malty green (2.5L/fed.) +Nano calcium (2.5L/fed.) for had the highest values of all studied characters may be explained by its inclusion of nitrogen, sea algae, potassium humate, plant lignosulfonate, plant extracts, and potassium oxide in addition to nano calcium. These components of malty green are thought to stimulate plant growth and increase cell division and elongation, which raise root length and weight and increase dry matter accumulated in roots. Additionally, calcium is necessary for healthy root growth and glucose translocation, hence it exhibited increases in all examined features. In this regard, sugar yield increased with increasing sucrose% and root yield which was caused by foliar application of Malty green and Nano calcium. The increase in root yield per feddan may be due to the highest values of length and weight of root owing to foliar application of Malty green and Nano calcium. These findings support those of Artyszak *et al*. (2014), Enan (2015), Abdel-Kader (2018), Dewdar *et al*. (2018), and Hassanein *et al*. (2019).

In the current study, sugar beet plants sprayed with Malty green (2.5L/fed.) + Nano calcium (2.5L/fed.) outperformed all other treatments in all investigated attributes over both seasons. The maximum values of RGR, NAR, CGR, root length, root fresh weight, sucrose%, purity%, root yield, and sugar yield were produced by sugar beet plants that had been fertilized with 50 kg N/fed + green foliar (20 L/fed) as a soil address and sprayed with malty green (2.5 L/fed) + nano calcium (2.5 L/fed). Applying green foliar at a rate of 20 litres per feddan to the soil or spraying plants with malty green + nano calcium at a rate of 2.5 litres per feddan can both save 50 kg of nitrogen per feddan and reduce environmental pollution.

To maximize the root and sugar yields of sugar beet plants at El-Hamoul area conditions, Kafr El-Sheikh Governorate, Egypt, it is generally advised that fertilizing sugar beet plants with 50kgN/fed + Green Foliar (20L/fed) as a soil address and spraying by malty green (2.5L/fed.) + Nano calcium (2.5L/fed.) treatment.

In our study, RY in 2020–2021 season showed a substantial positive association with NAR, CGR, and SY. However, in 2021/2022 season, under four foliar fertilizers and three soil fertilizers in both seasons, RY exhibited a positive connection with all the examined parameters e.g., RGR, NAR, RL, FW, sucrose %, purity %, and SY. These findings are consistent with several research, including Singh *et al*. (2018), who found that root yield was positively linked with all study features, except for Brix (%), highlighting the significance of these qualities in yield selection. Ojo *et al*. (2006) and Malik *et al*. (2005) discovered similar outcomes. Except for Brix (-0.025%), the genotypic correlation between root yield and other characteristics was positive. These findings are consistent with those made by Yousuf and Saleem (2001). In contrast to the circumstance when many strong negative correlations are seen between the traits along with strong positive associations, the presence of positive associations or non-significant relationships among most biochemical traits represents a favorable environment for selection.

4. Conclusion

We concluded that, fertilizing sugar beet plants with soil applied of 50kgN/fed +Green Foliar (20L/fed) and spraying by Malty green (2.5L/fed.) + Nano calcium (2.5L/fed.) treatment to maximizing root and sugar yields of sugar beet plants cv. Karam at El-Hamoul area condition, Kafr El-Sheikh Governorate, Egypt. Also, RY showed a significant positive correlation with most of the studied traits under four foliar fertilizers and three soil fertilizers in both seasons.

5. Conflicts of interest: There are no conflicts to declare.

6. Author contribution: Conceptualization: AWAE Mohamed, AAA Abdel Hafez; investigation, methodology, and data curation: HMH Shaib, DAA Al-Hajj; preparing original draft: AAA Abdel Hafez, HMH Shaib, DAA Al-Hajj; review and final editing: AWAE Mohamed, AAA Abdel Hafez, HMH Shaib, DAA Al-Hajj. All authors read and approved the final manuscript.

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