Egypt. J. Soil Sci. **Vol. 65**, No. 3, pp: 1729 - 1743 (2025)

Egyptian Journal of Soil Science
http://ejss.journals.ekb.eg/

Response of Sugar Beet Plant to Ascobien, Potassium Silicate Foliar Application under Different Irrigation Regimes

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Egypt imports about 1.0 million Mg for 2024 to bridge the gap between domestic production and rising consumption. Sugar beet production must be increased in the same planted area through better management of limited water resources. The main purpose of this study was to evaluate the effects of foliar application of nutrients and bioactive compounds on improving plant stress tolerance and enhancing physiological efficiency under water-deficit conditions, and investigating the role of strategic irrigation management in providing optimal soil moisture, minimizing water losses, and achieving the highest possible irrigation water use efficiency. An experiment was performed in the field at the Agricultural Research Farm of Delta Sugar Company at El-Hamol, Kafr El-Sheikh Governorate, Egypt, at the 2020/21 and 2021/22 growing seasons to study the effect of Ascobien acid, Potassium Silicate, and Lithovit foliar application on growth, yield, quality, and water use efficiency of sugar beet (*Beta vulgaris* L.) cv. Cleopatra grows under different irrigation regimes. The experimental design was a strip plot. Three irrigation regimens were allocated to the horizontal plots at I_1: 50%, I_2: 65%, and I_3: 80% depletion of the available moisture in the soil (DAM). Six foliar treatments were assigned to the vertical plots at F_1:(0 (control), F_2:Ascobien, F_3:Potassium silicate, F_4:Lithovit, F_5:Potassium silicate + Ascobien, F_6: Potassium silicate + Lithovit).The I_1 treatment demonstrated superior performance, producing the highest plant dry weight, root weight, root yield, and sugar yield in both seasons. Conversely, the I_3treatment showed the lowest yields but achieved the highest extractable white sugar percentage and juice purity while reducing impurities, including potassium, sodium, and α-amino nitrogen. The I_2treatment produced the optimal balance for water use efficiency, yielding the maximum root yield per unit of water consumed. The F_6 foliar application was above all other foliar treatments concerning growth parameters, plant dry weight, root and diameter, and root weight and top weight. It achieves the maximum root yield and top yield, with varying responses in the quality parameters. The F_6 treatment maintained an acceptable sugar content, optimizing water use efficiency. Most growth parameters achieved maximum values from F_6 treatments, such as plant dry weight, root length, root diameter, root weights, and sugar yield. Extractable white sugar percentage was increased by the I_3 treatment while decreasing impurities, potassium, sodium, and α-amino nitrogen. Extractable white sugar percentage and juice purity increased by 80% DAM while decreasing impurities, potassium, sodium, and α-amino nitrogen. The highest water use efficiency for root yield was obtained at I_2 when applied with F_6, giving 18.19 and 18.02 kg root/m³. Similarly, white sugar water use efficiency also found its place at the peak under I_2 (3.24 and 2.95 kg sugar/m³), where, in the case of F_6 treatment, this goes up to 3.34 and 2.87 kg sugar/m³. Future research should focus on foliar spray potassium silicate + Lithovit, with refined concentrations and application timings. Further study of irrigation regimes with different depletion levels or diverse irrigation systems will improve water management strategies.

Keywords: Lithovit, Potassium silicate, Ascobien, Irrigation regime.

1. Introduction

Sugar beet (*Beta vulgaris* var. saccharifera, L.) is an important sugar crop in Egypt and the world. It is the primary source of sugar supply. The sugar beet cultivated area in Egypt was approximately 251,156 ha in the 2022–2023 season, producing over 12.52 million tons of sugar beet root and 1.708 million tons of sugar (FAOSTAT, 2023). Egypt approved imports of 1.0 million Mg of sugar to meet shortfalls in domestic production and high demand in 2024 (USDA, 2024). Expanding beet cultivation and boosting its yield are pressing needs to narrow this gap. A significant challenge lies in improving agricultural productivity while utilizing available water resources efficiently. A water regime is a potential method of increasing the efficiency of water use (WUE). Sugar beet with a 70% water requirement optimized roots, sugar yields, and WUE of sugar beets. Studies have demonstrated that applying water at 25% to 50% of field capacity can substantially reduce water use while supporting reasonable yields (Yassin et al., 2021). Sugar beet plants irrigated at 55% depletion of available soil

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Received: 01/08/2025; Accepted: 24/09/2025
DOI: 10.21608/ejss.2025.409768.2291
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moisture (DAM) gave the maximum water efficiency for roots and white sugar production (Gharib and El-Henawy, 2011).

Research indicates that foliar application of potassium silicate can enhance the drought tolerance of sugar beet by improving water use efficiency and promoting root development(Ali et al., 2019). The influence of K on sugar beet is a function of its root in several individual biochemical and biophysical processes. It affects photosynthesis, both directly and indirectly, as well as the movement and utilization of assimilates, water transport, osmoregulation, and turgor (EL-Shal, 2016). Potassium silicate application increases sugar beet root yield and sugar content under water-stress conditions (Aksu and Altay, 2020). This may be explained by the more vital role of potassium in osmoregulation and maintaining cell turgor pressure during water deficit supply. (Salem et al., 2022).

The $CaCO_3$ carbonate in Lithovit® (Boron 05) fertilizer breaks down in the leaf stomata to release carbon dioxide (CO2) and calcium oxide (CaO) (Sorour et al., 2021). Lithovit® (Boron 05) carries iron, silica, magnesium, and boron (Faiyad et al., 2023). As a micronutrient that is fundamental to many physiological processes involved in plant growth and development, iron plays a critical function in plant nutrition (El Naqma et al., 2024). Silica regulates nutrient absorption and enhances plant resilience to abiotic stresses. Lithovit enhanced sugar beet development, root yield, and sugar yield compared to the control (Sorour et al., 2021).

Ascorbic acid applications have significantly improved sugar tolerance to water stress conditions, as stated by Abdel Fatah and Sadek (2020). As plants experience water stress, there is a marked production of ROS, including superoxide anions and hydrogen peroxide, primarily due to the malfunction of electron transport chains in photosynthesis and respiration (Tanveer et al., 2023). They mainly described the role of ascorbic acid in modulating photosynthesis and acting as a scavenger agent for reactive oxygen species (ROS) usually generated under any stress condition (Venkatesh and Park, 2014). Foliar application with ascorbic acid significantly increased growth and yield of sugar beet under water stress conditions (Ghazy et al., 2024; Yacoub et al., 2024).

This study aimed to investigate the interactive effects of various irrigation regimes and foliar applications on the performance and water relations of sugar beet.

2. Materials and Methods

Experiments were carried out at the Agricultural Research Farm of Delta Sugar Company in El-Hamol, Kafr El-Sheikh Governorate, Egypt, on September 28, 2020, and October 19, 202122 (31° 23' 51.47" N, 31°2' 33.45" E) (Fig.1). The preceding crop grown in the field was rice. Table 1 presents the experimental soil chemical composition analysis at deeps 0–30 cm, as determined following the methodology of Black et al. (1965). The texture of the soil was clay consisting of 56.2% clay, 26.5% silt, and 17.3% sand. The soil samples exhibit organic matter content with relatively low values of 1.32% and 1.41% across the two seasons. The field capacity % and wilting point % were assessed using a pressure plate extractor with controlled air pressure (Garcia, 1978). Soil bulk density was measured using the core sampling technique as described by Campbell (1994) (Table 2).

Fig. 1. The Agricultural Research Farm of Delta Sugar Company site.

Table 1. Experimental soil chemical composition analysis (0-30 cm) during the 2020/21 and 2021/22 seasons.

Seasons	pH* (1:2.5)	EC** (dS m^{-1})	Available (ppm)		
			N	P	K
2020/21	8.06	1.42	19.6	7.8	344.5
2021/22	7.90	1.35	18.5	8.3	327.2

*pH measured in soil suspension 1:2.5
** EC measured in soil paste extract

Table 2. Field capacity (%), wilting point(%), Available water (%), and bulk density (g/cm^3) for the experimental field during the 2020/21 and 2021/22 seasons.

Soil depth (cm)	Field capacity (%)		Wilting point (%)		Available water (%)		Bulk density (g/cm^3)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
0-20	34.30	35.62	18.15	18.92	16.15	16.69	1.506	1.418
20-40	32.15	32.28	17.08	17.15	15.07	15.13	1.523	1.492
40-60	30.65	30.80	16.32	16.36	14.33	14.43	1.528	1.578
Mean	32.37	32.90	17.18	17.48	15.18	15.42	1.519	1.496

Climate data were gathered from an agro-meteorological Sakha station, as indicated in Table 3.

Table 3. Monthly relative humidity (RH, %), wind speed (km day-1), mean minimum (Tmin), and maximum (Tmax) air, Wind Velocity (Km/24hr), Pan Evap. (mm) and Rain (mm/day) during the two winter growing seasons.

Month.	Air Temp.		RH%		Wind Velocity (Km/24hr)	Pan Evap. (mm)	Rain (mm/day)
	Max	Min	07:30	13:30			
			2020/21 season				
September	34.6	27.1	86.7	47.7	93.3	624.2	-
October	31.5	24.6	84.8	47.1	72.7	412.3	-
November	25	17.5	86.7	56.8	46.9	228.3	17.1
December	22.9	13.7	87.7	55.7	44.9	248.7	18.78
January	21	13.5	86.7	59.5	39.2	256.8	14.65
February	21.5	12.5	87.5	55.9	58.3	355.6	51.9
March	22.3	14.7	79.5	48.4	78.5	436	5.4
April	28.6	19.5	74.3	47.4	93.6	589.7	-
May	29.2	24.1	74.3	42.7	99.1	893.8	-
Mean	26.29	18.57	83.13	51.24	69.61	449.48	21.56
			2021/22 season				
September	32.5	25.1	83.9	49.4	96.7	757	-
October	28.5	21.4	75.8	61.9	80.2	506.3	-
November	26.7	18.8	88.1	57	63.5	389.3	3.7
December	20.2	11.3	88.1	59.9	62.7	398.3	20.7
January	16.2	9.8	88.1	62.6	51.9	371.3	47.6
February	19.3	10.1	85.7	53.6	81.3	352.2	25.3
March	19.2	11.2	85.6	52.5	98.2	357.6	5.3
April	27.6	19.8	76.5	45.4	114.4	545.2	-
May	29.1	21.8	78.5	44.4	100	683.2	-
Mean	24.36	16.58	83.36	54.07	83.21	484.48	20.52

Three replicas were employed in a strip plot arrangement (Fig.2). Three irrigation regimens were allocated to the horizontal plots. Six foliar treatments were assigned to the vertical plots. The three irrigation regimes were implemented at I_1: 50%, I_2: 65%, and I_3: 80% depletion of the available moisture in the soil (DAM). Six foliar application substances were F_1:(0 (control), F_2:Ascobien, F_3:Potassium silicate, F_4:Lithovit, F_5:Potassium silicate + Ascobien, F_6: Potassium silicate + Lithovit).

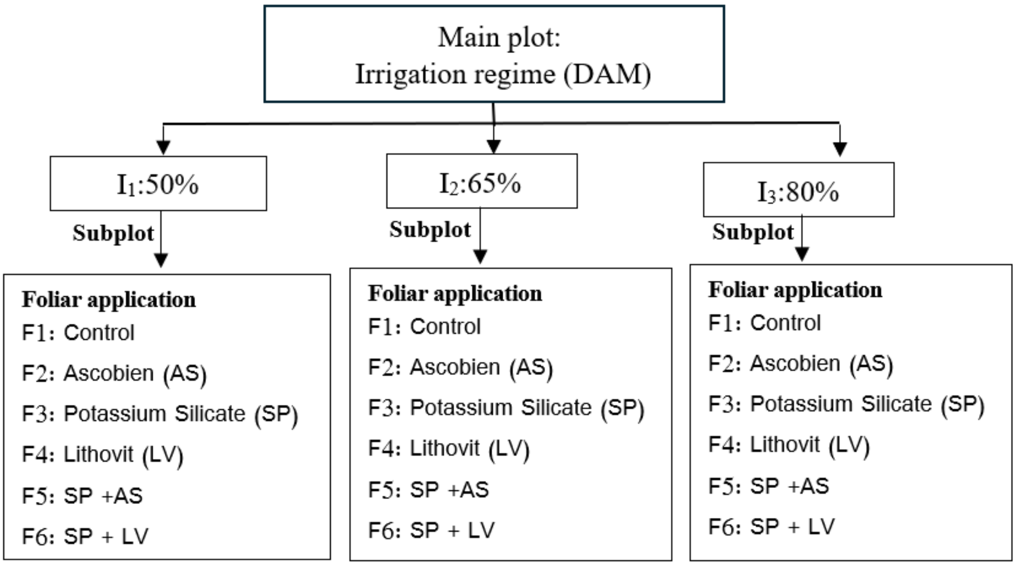

Fig. 2. One replicate, including all treatments used in this study.

As a foliar application, Ascobien at 2.5 g/L, Lithovit at 0.5 g/L, and Potassium silicate at 2 cm^3/L were applied twice at forty-five and sixty days from planting. Lithovit® (Boron 05) was obtained from Agrolink Agricultural Co., Egypt (Tribodyn, 2020). Potassium silicate obtained from Top silica tas commercial compound. Ascobien was obtained from the Agricultural Budget Fund at the Agricultural Research Center, Egypt. The Composition of foliar spray materials used in the study is presented in Table 4.

Table 4. Composition of foliar spray materials used in the study.

Material	Composition
Ascobien	(13% Citric acid, 25% Ascorbic acid, and 62% Organic materials)
Lithovit® (Boron 05)	(50% Calcium carbonate ($CaCO_3$), 28% Calcium oxide (CaO), 15.0% Boron (B), 9% Silicon dioxide (SiO_2), 1.8% Magnesium oxide (MgO), 1.0% Iron (Fe), and 0.02% Manganese (Mn))
Potassium Silicate	(Potassium 12% potassium and 25 % silica)

The dimensions of the plot were 3 meters by 6 meters, resulting in a total area of 18 m^2. Each plot was composed of six ridges, arranged 50 cm apart and extending a length of 6 m. On one side of the ridge, hills were spaced 20 cm apart, and the multigerm cultivar "Cleopatra" was planted at a density of 2-3 seeds per hill. Plant hand thinning was conducted thirty-five days after planting to establish one single seedling per hill. Two equal splits at thirty-five and seventy days after planting (DAS), nitrogen source at a rate of 90 N fed^{-1} was urea, 46% N. Before the second plowing, all plots received 50 kg/fed of triple super phosphate (20.07% P). Treatments on irrigation began following the third one. Other cultures carried on as usual.

Characteristics measured

The soil samples were dried for twenty-four hours at 110 ^oC and revealed the actual irrigation requirement; The moisture percentage was then calculated on a weight basis after being dried in the oven. To estimate sugar beet plant water consumptive use (WCU) from planting to harvest, the Israelsen and Hansen (1962) method of soil samples was collected both before and after every irrigation as follows:

$$WCU = \frac{\theta_2 - \theta_1}{100} \times B.d \times D \times 4200$$

Where:

WCU = amount of water consumptive use (m^3/feddan).

θ_2 = soil moisture water content measured post-irrigation, expressed as a percentage.

θ_1 = soil moisture water content measured before the next irrigation, expressed as a percentage.

B.d = Bulk density (g/cm^3).

D = Depth of soil layer (m).

Water use efficiency was calculated as the ratio of root or white sugar yields (kg/m^3) according to Doorenbos and Kassam (1979) as follows:

$$WUE = \frac{\text{Yield (kg/ feddan)}}{\text{water consumpitive use} (m^3 / \text{feddan})}$$

Within each experimental field plot, two rows were allocated for the growth sampling of sugar beet. In contrast, the remaining three rows were reserved for evaluating below-ground (root) and above-ground (shoot) yield components at crop maturity. Researchers randomly selected five guarded plants from each experimental plot to assess the dry matter accumulation in both the below-ground and above-ground portions of individual plants. The harvested plant organs were subjected to thermal dehydration in a forced-air drying oven maintained at 70°C. This process continued until the samples reached a state of equilibrium moisture content.

The middle section of three rows of 9.5 m^2 eliminates the border impact for top and root production (Ton/fed) at harvest (210 DAS). Ten randomly selected guarded plants were evaluated for root and top yields/plant, root diameter (cm), and root length (cm). Root quality parameters were assessed using standardized sugar industry analytical methods at the Delta Sugar Company laboratory. Total sucrose content (expressed as percentage) and impurity components, including Potassium (K+), sodium (Na+), and α-amino nitrogen, were quantified. Polarimetric sucrose determination (Pol%) in clarified beet extract was conducted using an automatic saccharimeter following lead acetate clarification, according to Le Docte (1927). α-amino nitrogen, Potassium (K+) and sodium (Na+) ions, were determined using venma, Automation BV Analyzer IIG-16-12-99, 9716JP/ Groningen/Holland. Temp 18-30ºC, surrounding humidity max. 70% according to Brown and Lillan (1964), results were expressed in milliequivalents per 100 grams of fresh beet tissue (meq/100 g). The alkalinity coefficient was calculated using the formula ((K + Na) / α-amino nitrogen), as outlined by Reinfeld et al. (1974). The following calculations were used for extractable white sugar, loss sugar, and juice purity percentages:

– Corrected sugar content (Extractable white sugar %) was determined using the equation:

ZB = Pol - [0.343 (K + Na) + 0.094 NBI + 0.29] (Harvey and Dutton, 1993),

Where ZB represents the corrected sugar content (white sugar %), Pol denotes gross sugar (total sugar content %), and NBI refers to α-amino-N, measured through the "blue number" method.

– Loss sugar % = (Gross sugar - Extractable white sugar).

– Juice purity % = (ZB / Pol) × 100.

Statistical analysis methods

The analysis of variance (ANOVA) was conducted following the method outlined by Gomez and Gomez (1984), and mean comparisons were performed using Duncan's Multiple Range Test (Duncan, 1955). Data analysis was carried out using CoStat 6.3, a free statistical analysis and data manipulation software developed by CoHort Software.

3. Results

3.1. Dry weight, length, and diameter of root

According to Table 5, dry weight, root length, and root diameter of sugar beet were significantly influenced by both irrigation regime (DAM) and foliar applications during the 2020/21 and 2021/22 growing seasons. At DAM 50%, dry weights were the highest for both seasons (214.92 and 226.03 g plant^{-1}), and at DAM 80%, the lowest values were recorded (175 and 174.46 g plant^{-1}). However, maximum values for root length were obtained from DAM 80% (29.33 and 29.73 cm), while minimum values were observed from DAM 50% (26.77 and 27.57 cm). The diameter of roots followed the trend of dry weights, having a maximum value at DAM 50% (11.86,13.25 cm) and a minimum at DAM 80% (10.52,11.33 cm).

Data in Table 5 show that the combination of SP + LV (Potassium silicate + Lithovit) demonstrated superior performance, producing the highest dry weight values (215.17 and 221.46 g plant-1) in both seasons. Individual applications of LV, or SP, and SP + AS combination registered dry weights that were statistically at par with each other, ranging between 197.42 and 205.33 g plant-1 in 2020/21 and 205.46 to 212.9 g plant-1 in 2021/22. Ascobien (AS) applied alone recorded intermediate values for dry weight at 183.5 and 191.53 g plant-1, while the control treatment recorded the lowest value consistently at 164.25 and 167.89 g plant-1. The difference between the best treatment (SP + LV) and the control represented an increase in dry weight of approximately 31% in both seasons.

Table 5. Dry weight, root length, and root diameter of sugar beet affected by irrigation regime and foliar application during the 2020/21 and 2021/22 seasons.

Treatments	Dry weight (g plant^{-1})		Root length (Cm)		Root diameter (Cm)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation regime (DAM)						
I_1: 50 %	214.92 a	226.03 a	26.77 c	27.57 c	11.86 a	13.25 a
I_2:65 %	194.46 b	204.02 b	27.82 b	29.87 b	11.45 b	12.94 b
I_3:80 %	175 c	174.46 c	29.33 a	29.73 a	10.52 c	11.33 c
F-test	*	**	**	*	**	**
Foliar application (FA)						
F_1: Control (C)	164.25 c	167.89 d	26.82 e	27.71 c	10.46 c	11.44 c
F_2: Ascobien (AS)	183.5 b	191.53 c	27.59 d	28.71 bc	10.98 bc	12.28 b
F_3: Potassium silicate (SP)	197.42 ab	205.46 b	27.72 cd	28.93 b	11.37 ab	12.7 ab
F_4: Lithovit (LV)	205.33 ab	212.9 b	28.38 b	29.45 ab	11.58 ab	12.83 a
F_5: SP + AS	203.08 ab	209.75 b	28.17 bc	29.44 ab	11.49 ab	12.85 a
F_6: SP + LV	215.17 a	221.46 a	29.17 a	30.09 a	11.78 a	12.97 a
F-test	**	**	**	**	**	**
Interaction (FA x DAM)						
F-test	NS	NS	NS	NS	NS	NS

*, **, and NS. denote significant at 0.05, 0.01, and insignificant. There is no difference between the treatment means, as indicated by the same alphabet at $p \leq 0.05$.

The SP + LV (Potassium silicate + Lithovit) combination treatment achieved the highest root length values (29.17 and 30.09 cm) in both seasons. Lithovit (LV) and SP + AS were statistically at par in both years, with root length ranging from 28.17 to 28.38 cm during 2020/21 and 29.44 to 29.45 cm during 2021/22. Single applications of Potassium silicate (SP) and Ascobien (AS) remained in between, while the control always resulted in the shortest roots, i.e., 26.82 and 27.71 cm. The difference between SP + LV and the control represented an increase in root length of approximately 8.8% and 8.6% in 2020/21 and 2021/22, respectively. The SP + LV (Potassium silicate + Lithovit) combination produced the largest root diameters (11.78 and 12.97 cm) in both seasons. Single applications of Lithovit (LV), Potassium silicate (SP), and the SP + AS combination showed statistically similar results in 2020/21, ranging from 11.37 to 11.58 cm. In 2021/22, Lithovit (LV) and SP + AS treatments performed equally well as SP + LV, with diameters ranging from 12.83 to 12.97 cm. Ascobien (AS) alone resulted in intermediate root diameters (10.98 and 12.28 cm), while the control treatment consistently produced the smallest root diameters (10.46 and 11.44 cm). The improvement in root diameter between SP + LV and the control was approximately 12.6% and 13.4% in 2020/21 and 2021/22, respectively.

The interaction between irrigation regimes and foliar applications was insignificant for any of the measured parameters in both growing seasons, as shown in Table 5.

3.2. Yields and Their Attributes

The irrigation regime (DAM) significantly affected (P< 0.01) root weight, top weight, and yields of sugar beet in both growing seasons (Table 6). The treatment of a 50% DAM irrigation regime produced the highest values across all parameters. Root weight reached 1370 and 1359.1 g plant^{-1}; top weight attained 479.5 and 475.7 g plant^{-1} in 2020/21 and 2021/22, respectively. Maximum root yields were recorded from this treatment (36.88 and 6.63 t/fed) and maximum top yields (13.02 and 12.91 t/fed) in 2020/21 and 2021/22. The subsequent best treatment in terms of root weights was recorded from the application of irrigation at the rate of 65% DAM, which gave root weights of 1225.8 and 1226.6 g plant$^{-1,}$ top weights of 429.0 and 429.3 g plant^{-1}, root yields of 34.41 and 6.28t /fed, while top yields at 12.07 and 12.04 t /fed. The 80% DAM treatment gave the lowest weights of roots, 1023.3 and 966.3 g plant^{-1}, weights of tops 358.1 and 338.2 g plant^{-1}, yields of roots 25.21 and 5.0 t/fed, yields of tops 9.36 and 8.82 t/fed, respectively.

Significant (P< 0.01) differences were observed in root weight, top weight, root yield, and top yield due to foliar applications during both growing seasons (Table 6). The treatment with potassium silicate + lithovit expressed its superiority by increasing the root weight by 17.5% and 19.9% (1291.6 and 1262.7 g plant^{-1} vs. 1099.1 and

1053.3 g plant-1), top weight by 17.5% and 19.9% (452.0 and 441.9 g plant-1 vs 384.7 and 368.6 g plant^{-1}), root yield by 19.0% and 18.1% (34.13 and 6.39 t/fed vs28 .68 and5 .41 t/fed), as well as top yields of 16 .5% and 19.0 % (12.23 and 11 .95 t/fed vs 10.50 and 10.04 t/fed) over control during the seasons of 2020 /21 and 2021/22, respectively. The single application of Lithovit (LV) and SP+AS combination gave statistically similar results, though better than the individual applications of Potassium silicate (SP) and Ascobien(AS). The control has given the minimum values against all these parameters.

Table 6. Root weight (g plant^{-1}), top weight (g plant^{-1}), root yield (t/fed), and top yield (t/fed) of sugar beet affected by irrigation regime and foliar application during the 2020/21 and 2021/22 seasons.

Treatments	Root weight (g plant^{-1})		Top weight (g plant^{-1})		Root yield (t/fed)		Top yield (t/fed)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation regime (DAM)								
I_1: 50 %	1370 a	1359.1 a	479.5 a	475.7 a	36.88 a	6.63 a	13.02 a	12.91 a
I_2:65 %	1225.8 b	1226.6 b	429.0 b	429.3 b	34.41 b	6.28 b	12.07 b	12.04 b
I_3:80 %	1023.3 c	966.3 c	358.1 c	338.2 c	25.21 c	5.0 c	9.36 c	8.82 c
F-test	*	**	**	*	**	**	**	*
Foliar application (FA)								
$F_{1:}$ Control (C)	1099.1c	1053.3 d	384.7 c	368.6 d	28.68 e	5.41 e	10.5 e	10.04 e
$F_{2:}$ Ascobien (AS)	1155 b	1137.4 c	404.2 b	398.0 c	31.28 d	5.77 d	11.12 d	10.95 d
$F_{3:}$ Potassium silicate (SP)	1196.6 b	1183.2 bc	418.8 b	414.1 bc	32.29 c	5.94 cd	11.43 c	11.3 c
$F_{4:}$ Lithovit (LV)	1248.3 a	1228.2 ab	436.9 a	429.8 ab	33.64ab	6.25 ab	11.98 b	11.77ab
$F_{5:}$ SP + AS	1247.5 a	1239.2 ab	436.6 a	433.7 ab	32.97bc	6.06 bc	11.64 c	11.54bc
$F_{6:}$ SP + LV	1291.6 a	1262.7 a	452.0 a	441.9 a	34.13a	6.39 a	12.23 a	11.95 a
F-test	**	**	**	**	**	**	**	**
Interaction (FA x DAM)								
F-test	**NS**	**NS**	**NS**	**NS**	**	*	**NS**	**NS**

*, **, and NS. denote significant at 0.05, 0.01, and insignificant. There is no difference between the treatment means, having the same alphabet at p≤ 0.05.

The interaction in Table 6 was only significant for root yield (P< 0.01 and P< 0.05) in 2020/21 and 2021/22, respectively, but not significant for any other parameter. All treatments attained high increases under irrigation at 50% DAM, where MO+LV attained the highest increases by recording 13.16% and 18.57% over the control during 2020/21 and 2021/22, respectively. Lithovit (LV) combination follows with high performance, attaining an increase of 11.06% and16.90% over control during both seasons, consequently (Fig.3). Treatments express positive effects at a slightly lower magnitude under irrigation with 65% DAM. MO+LV results are to be mostly effective, gaining 14.50 % and 14.92 % benefits during two seasons; lithovit also expresses strong performance, achieving increases of 11.52% and 14.58% over control(Fig. 3). The most striking increases come at 80 % DAM irrigation. The highest effectiveness was demonstrated by MO + LV with remarkable increases of 24.10% and 25.66% in respective seasons, followed by Lithovit with improvements of 22.22% and 21.87%. Even standalone treatments as effective as Potassium silicate (MO) and Ascobien (AS) recorded enhancements from a low of 10.81% to a high of 17.24% in both the seasons (Fig.1). Root yield (t/fed) surpassed control application under 50 % DAM when foliar application was used under 65 % DAM irrigation (MO + LV or MO + AS or Lithovit).

3.3. Sugar yield and root quality

Table 7 data showed that there was a statistically highly significant effect (P<0.01) of irrigation treatments on Potassium (K), sodium (Na), K+Na, and α-amino nitrogen in (meq/100 g), except for the alkalinity coefficient for both seasons. It was found that plants irrigated at 50% DAM recorded the highest values for potassium (4.28 and 5.13 meq/100g), sodium (1.15 and 2.43 meq/100g), α-amino nitrogen (1.9 and 1.78 meq/100g) hence K+Na (5.43 and 7.56 meg/100g) during the 2020/21 and 2021/22 seasons respectively Irrigation at 65% DAM was statistically similar to 50% DAM in some parameters, particularly for K and Na contents in both seasons. The irrigation level (80% DAM) consistently showed the lowest impurity values across all parameters.

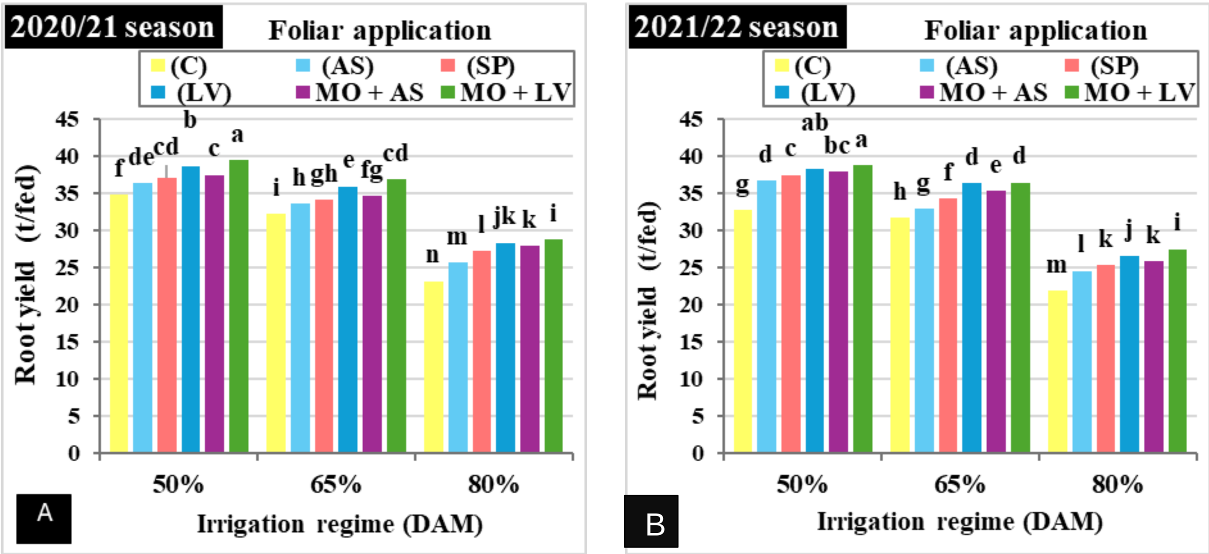

Fig. 3. The interaction effect between irrigation regime (DAM at Irrigation) and foliar application (mg L-1) (F) on Root yield (t/fed).Whereas, Ascobien (AS), Potassium silicate (SP), Lithovit (LV), and Control (C). There is no difference between the treatment means, as indicated by the same alphabet at p ≤ 0.05.

Table 7. Potassium (K) (meq/100g), sodium (Na) (meq/100g), K+ Na (meq/100g), α-amino nitrogen (meq/100g), Alkalinity coefficient of sugar beet affected by irrigation regime and foliar application during the 2020/21 and 2021/22 seasons.

Treatments	K (meq/100g)		Na (meq/100g)		α-amino nitrogen (meq/100g)		K+ Na (meg/100g)		Alkalinity coefficient	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation regime (DAM)										
I_1: 50 %	4.28 a	5.13 a	1.15 a	2.43 a	1.9 a	1.78 ab	5.43 a	7.56 a	2.96 a	4.34 a
I_2:65 %	4.2 ab	4.98 a	1.03 a	2.33 a	1.75 b	1.85 a	5.23 b	7.31 a	3.09 a	3.99 a
I_3:80 %	4.18 b	4.49 b	0.79 b	1.98 b	1.74 b	1.61 b	4.97 c	6.48 b	2.9 a	4.12 a
F-test	**	**	**	**	**	**	**	**	NS	NS
Foliar application (FA)										
$F_{1:}$ Control (C)	4.29 a	4.98 a	1.09 a	2.3 a	1.8 b	1.89 a	5.38 a	7.28 a	3.11 a	3.9 a
$F_{2:}$ Ascobien (AS)	4.27 b	4.94 b	0.92 b	2.3 a	1.82 ab	1.69 ab	5.18 bc	7.23 a	2.9 a	4.3 a
$F_{3:}$ Potassium silicate (SP)	4.2 c	4.82 c	1 ab	2.25 c	1.91 a	1.65 b	5.19 bc	7.06 b	2.83 a	4.35 a
$F_{4:}$ Lithovit (LV)	4.22 cd	4.82 cd	1.07 a	2.28 b	1.73 b	1.8 ab	5.29 ab	7.1 b	3.16 a	3.97 a
$F_{5:}$ SP + AS	4.17 cd	4.84 cd	0.98 ab	2.08 d	1.75 b	1.7 ab	5.15 cd	6.92 c	3 a	4.2 a
$F_{6:}$ SP + LV	4.15 d	4.79 d	0.9 b	2.28 b	1.78 b	1.74 ab	5.05 d	7.09 b	2.9 a	4.18 a
F-test	**	**	**	**	**	**	**	**	NS	NS
Interaction (FA x DAM)										
F-test	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*, **, and NS. denote significant at 0.05, 0.01, and insignificant. There is no difference between the treatment means, as indicated by the same alphabet at p ≤ 0.05.

Data in Table 7 revealed that foliar application treatments exerted a statistically highly significant influence (P<0.01) on Potassium (K), sodium (Na), K+Na, and α-amino nitrogen, except for the alkalinity coefficient, which showed no significant differences in both seasons. The control treatment recorded the highest values of potassium (4.29 and 4.98 meq/100g), sodium (1.09 and 2.3 meq/100g), and consequently K+Na (5.38 and 7.28 meq/100g) in both 2020/21 and 2021/22 seasons, respectively. For α-amino nitrogen, Potassium silicate (SP) showed the highest value (1.91 meq/100g) in 2020/21, while the control treatment recorded the highest value (1.89 meq/100g) in 2021/22. Ascobien (AS) treatment was statistically similar to the control in some parameters, particularly for Na content in the 2021/22 season (both 2.3 meq/100g), and showed the second-highest K values (4.27 and 4.94 meq/100g) in both seasons. The other combination treatments have always shown lower values in most parameters, especially in the case of K content (4.15-4.17meq/100g) in 2020 /21 and (4.79-4.84) meq /100g

in 2021/22 seasons, and K+Na values. Data in Table 8 shows the highly significant effects of irrigation regimes on loss of sugar (%), extractable white sugar (%), juice purity (%), and sugar yield (t/fed) for both seasons.
The percentage of sugar loss was highest at 50% irrigation (2.33% and 3.05%), respectively. The percentage of extractable white sugar performed better under a higher irrigation regime, with 80% (DAM) achieving 18.7% and 15.97%, respectively, for the two seasons. A clear positive relationship between juice purity and irrigation regime (DAM) has been noted, with maximum values realized at 80% irrigation (89.64% and 85.69%). Quality parameters were lower under water-stressed conditions since this is where actual sugar yields are maximized; the highest yield value was found at 50% irrigation (6.63 and 5.66 t/ha), followed by 65% irrigation (DAM) (6.28 and 5.42 t/ha). This can be compared to a low value at a high water application level of 80%, which yielded only 5.0 and 4.03 t/ha. The interaction between irrigation regimes and foliar applications was insignificant for any of the measured parameters in both growing seasons, as shown in Table 8.

Table 8. Loss of sugar (%), extractable white sugar (%), juice purity (%), and Sugar yield (t/fed) of sugar beet affected by irrigation regime and foliar application during the 2020/21 and 2021/22 seasons.

Treatments	Loss sugar (%)		Extractable white sugar (%)		Juice purity (%)		Sugar yield (t/fed)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation regime (DAM)								
I_1: 50 %	2.33 a	3.05 a	17.81 b	15.35 b	88.4 c	83.41 c	6.63 a	5.66 a
I_2:65 %	2.25 b	2.97 a	18.22 a	15.72 a	89.01 b	84.07 b	6.28 b	5.42 b
I_3:80 %	2.16 c	2.66 b	18.7 a	15.97 a	89.64 a	85.69 a	5 c	4.03 c
F-test	**	**	**	**	**	**	**	**
Foliar application (FA)								
$F_{1:}$ Control (C)	2.3 a	2.96 a	18.12 c	15.45 c	88.7 c	83.89 d	5.41 e	4.42 e
$F_{2:}$ Ascobien (AS)	2.24 ab	2.93 ab	18.21 b	15.54 c	89.02 b	84.08 c	5.77 d	4.86 d
$F_{3:}$ Potassium silicate (SP)	2.25 b	2.87 cd	18.24 ab	15.68 b	89 b	84.48 b	5.94 cd	5.04 cd
$F_{4:}$ Lithovit (LV)	2.27 bc	2.9 bc	18.29 ab	15.78 ab	88.95 b	84.47 b	6.25 ab	5.3 ab
$F_{5:}$ SP + AS	2.22 bc	2.82 d	18.27 ab	15.73 b	89.14 ab	84.77 a	6.06 bc	5.18 bc
$F_{6:}$ SP + LV	2.19 c	2.88 bc	18.33 a	15.91 a	89.3 a	84.64 ab	6.39 a	5.43 a
F-test	**	**	**	**	**	**	**	**
Interaction (FA x DAM)								
F-test	NS	NS	NS	NS	NS	NS	NS	NS

*, **, and NS. denote significant at 0.05, 0.01, and insignificant. There is no difference between the treatment means, as indicated by the same alphabet at $p \leq 0.05$.

3.4. Water relations

Based on Table 9, the water consumptive use and water use efficiency data reveal a significant difference for irrigation regime treatments in sugar beet cultivation. Water consumptive use showed a clear inverse relationship with depletion allowable management (DAM) levels, decreasing significantly from I1 (50% DAM) at 2171-2309 m^3/feddan to I3 (80% DAM) at 1531-1601 m^3/feddan across both seasons. However, under I_2, moderate water stress (65% DAM) could record the highest water use efficiency for both root yield (17.76-18.73 kg.root/m^3.water) and white sugar yield (3.24-2.96 kg. white sugar/m^3.water), higher than those recorded under the frequent irrigation regime I1 as well as the more stressed condition I_3. Table 9 presents the highly significant effects (P<0.01) of all water relations parameters in both seasons through foliar application. Consumptive water use has increased with foliar treatments, from control (1882-1886 m^3/feddan) to the highest consumption under combination treatment SP+LV (1905-1918 m^3/feddan). The combination treatments SP+LV (F6) emerged as the best treatment attaining maximum root as well as white sugar yield water use efficiencies (18.02-18.21 kg root/m^3 water and 2.88-3.33 kg white sugar/m^3water, respectively), which is around 15-22% better than that obtained under the control treatment.

Data from Table 9 on the interaction effects between different foliar applications and irrigation regimes (FA x DAM) on water consumptive use and water use efficiency indicated very highly significant trends (P<0.01) under all treatments in both seasons. Water consumptive use recorded its highest values with treatment I1 x F6 (2190-2323 m^3/feddan), then consumption gradually decreased by increasing the level of water regime, where it recorded the lowest consumption at I3 x F1 (1521-1591 m^3/feddan). In this regard, water use efficiency for root yield recorded its highest value with treatment I2 x F6 (18.87-19.67 kg root/m^3 water), which surpassed all the other treatments while recording its lowest value with I1 x F1(14.2-16.27 kg root/m^3water). For white sugar water use efficiency, the same treatment (I2 x F6) yielded results of 3.20-3.45 kg of sugar per m^3 of water.

Table 9. Water consumptive use (m^3/fed), Water use efficiency of root yield (kg root/m^3 water), and Water use efficiency of white sugar yield (kg white sugar/m3 water) influenced by irrigation regime and foliar application during the 2020/21 and 2021/22 seasons .

Treatments	Water consumptive use (m^3/fed)		Water use efficiency of root yield (kg root/m^3 water)		Water use efficiency of white sugar yield (kg white sugar/m^3 water)	
	2020/21	2021/22	2020/21	2021/22	2020/21	2021/22
Irrigation regime (DAM)						
I_1: 50 %	2171 a	2309 a	17.13 b	15.97 c	3.05 c	2.46 c
I_2:65 %	1942 b	1838 b	17.76 a	18.73 a	3.24 a	2.96 a
I_3:80 %	1601 c	1531 c	16.71 c	16.47 b	3.12 b	2.64 b
F-test	**	**	**	**	**	**
Foliar application (FA)						
F_1: Control (C)	1886 f	1882 f	15.82 f	15.29 f	2.86 f	2.35 f
F_2: Ascobien (AS)	1895 e	1885 e	16.74 e	16.62 e	3.05 e	2.59 e
F_3: Potassium silicate (SP)	1905 d	1890 d	17.12 d	17.13 d	3.13 d	2.7 d
F_4: Lithovit (LV)	1913 b	1900 b	17.89 b	17.79 b	3.27 b	2.83 b
F_5: SP + AS	1911 c	1893 c	17.4 c	17.49 c	3.17 c	2.76 c
F_6: SP + LV	1918 a	1905 a	18.21 a	18.02 a	3.33 a	2.88 a
F-test	**	**	**	**	**	**
Interaction (FA x DAM)						
I_1 x F_1	2136 e	2299 e	16.27 l	14.2 l	2.89 f	2.11 l
I_1 x F_2	2157 d	2302 d	16.8 jk	15.9 k	2.95 e	2.45 j
I_1 x F_3	2172 c	2303 d	17 hi	16.23 ij	3.01 d	2.46 j
I_1 x F_4	2185 b	2318 b	17.67 de	16.47 h	3.2 c	2.54 i
I_1 x F_5	2183 b	2310 c	17.1 h	16.37 hi	3.02 d	2.55 i
I_1 x F_6	2190 a	2323 a	17.97 c	16.67 g	3.2 c	2.64 h
I_2 x F_1	1931 h	1825 k	16.67 k	17.33 e	3 de	2.7 g
I_2 x F_2	1934 h	1831 j	17.33 g	17.9 d	3.2 c	2.8 e
I_2 x F_3	1943 g	1837 i	17.47 fg	18.63 c	3.19 c	2.89 d
I_2x F_4	1947 g	1844 g	18.43 b	19.63 a	3.29 b	3.15 b
I_2 x F_5	1946 g	1840 h	17.77 d	19.2 b	3.29 b	2.99 c
I_2 x F_6	1953 f	1849 f	18.87 a	19.67 a	3.45 a	3.2 a
I_3 x F_1	1591 m	1521 o	14.53 m	14.33 l	2.7 g	2.25 k
I_3 x F_2	1594 m	1523 o	16.1 l	16.07 jk	3 de	2.53 i
I_3 x F_3	1599 l	1529 n	16.9 ij	16.53 gh	3.19 c	2.74 f
I_3x F_4	1608 j	1539 m	17.57 ef	17.23 e	3.3 b	2.79 e
I_3 x F_5	1603 k	1529 n	17.33 g	16.9 f	3.2 c	2.75 f
I_3 x F_6	1612 i	1542 l	17.8 cd	17.77 d	3.35 b	2.79 e
F-test	**	**	**	**	**	**

*, **, and NS. denote significant at 0.05, 0.01, and insignificant. There is no difference between the treatment means in the column, having the same alphabet at p≤ 0.05.

4. Discussion

Water stress treatments have a significant influence on the dry weight and root diameter of sugar beet, which are affected differently by varying levels of duration of stress. Water stress decreased the dry weight of sugar beet plants, mostly attributed to the decreased photosynthesis and carbon assimilation during drought conditions. Leaves close stomata to reduce water loss, resulting in limited CO_2 levels in the leaf and diminished photosynthesis, which is the driving force needed for dry matter accumulation. A water deficit will also negatively affect cell division and expansion, consequently reducing growth and biomass yield. Water stress in plants also limits nutrient uptake and translocation, as water is central to transporting important minerals from roots to shoots. Water stress exacerbates limitations to metabolic pathways required to synthesize proteins and carbohydrates and dry matter development. Relative to well-watered conditions, plants undergoing water stress must redirect energy used for growth into survival precautions such as the synthesis of stress tolerance products. The water stress has caused a notable decrease in the diameter of sugar beet roots, largely through a suppression of secondary growth processes initiated in the cambium, where radial growth occurs. The decreased turgor pressure resulting from drought conditions reduces cell wall loosening and expansion, resulting in a restriction of radial growth in storage root tissues. Water deficit also harms the transport of photosynthates from leaves to developing roots, thereby limiting the availability of carbohydrate substrate, a necessary precursor for the building of cell walls and the inner formation of storage parenchyma. As a result of the stress conditions, cell division in the cambial tissues, which produces new vascular elements and storage cells, is compromised, and therefore, root girth is also compromised. Water stress conditions also affect the hormonal balance, specifically a reduction in auxin and cytokinin levels, which help regulate cell expansion and division. The decrease of root diameter is of particular significance to sugar beet production as it is quantitatively linked to the plant's ability to store sucrose, the main economic product, and this has become a stress-lasting consequence of the direct stress impact. One of the main reasons for greater root length under water stress is the limited availability of water, which encourages deeper root development so that moisture from below the strata can be tapped. Sugar beet roots proliferate in those soil layers where more water is available during periods of drought; hence, an increase in root length and surface area is obtained, which leads to better capability for absorption of both water and nutrients. These results are consistent with the study of (Hoffmann,2010; Gharib & El-Henawy, 2011; Stagnari et al., 2014; Fitters et al., 2018; Abu-Ellail & El-Mansoub, 2020; Tan et al.,2023; Abdelrazik & Mahmoud, 2024).

The application of potassium silicate remarkably enhanced the dry weight, root diameter, and root length in sugar beet plants through synergistic physiological processes. Potassium is thought to enhance the efficiency of photosynthesis and promote osmotic regulation, which is likely implicated in enhanced carbon assimilation and dry matter accumulation throughout the plant. The greater availability of carbohydrates facilitates the synthesis of structural elements required for root expansion, consequently increasing root diameter and length. Concerning root growth, potassium seems to promote the processes of cell division and expansion, resulting in greater root lengths from increased activity of the apical meristem and increased root diameters from enhanced cambial growth and secondary tissue development. The silica served as a reinforcement for cell walls and structural strength to promote a better root architecture and allow long-term growth to occur when roots were subject to variable environmental conditions. The deposition of silicon into root tissues serves to improve mechanical reinforcement of the root system as well as nutrient and water uptake efficiency, resulting in increased radial growth and root elongation. The potassium silicate optimized nutrient uptake and translocation, ensuring a suitable supply of essential elements for root development and the formation of storage tissue. These results are in agreement with Ali et al. (2019), Ibrahim et al. (2020), AbdAllah et al. (2021), Artyszak et al. (2021), Seadh et al. (2024).

Applying ascorbic acid increases root diameter, dry matter, and root length of sugar beet under water stress. Ascorbic acid is an antioxidant that facilitates mitigating oxidative stress brought by water scarcity. Conditions prevailing in drought reveal that all growth and development activities are interfered with due to cellular damage brought about by an increased build-up of reactive oxygen species (ROS), thus maintaining metabolic processes and facilitating more efficient accumulation of dry matter in roots. The results align with Venkatesh & Park, 2014; Farooq et al., 2020 Arjeh et al. (2021); Sorour et al. (2021); Yacoub et al. (2024).

Lithovit foliar spray increased root diameter, dry matter, and root length of sugar beet. In lithovit, $CaCO_3$, a carbonate that breaks down in the leaf stomata into carbon dioxide (CO_2) and calcium oxide (CaO), raises the concentration of CO_2 in the leaf intercellular spaces, encouraging photosynthesis, thus raising dry matter accumulation in sugar beet roots because of better carbohydrate synthesis and translocation. Boron is a major element in cell wall structural integrity as well as sugar transport mechanisms, which result in better root diameter through better cell expansion and strengthened cellular architecture. Root length development is very positively influenced by the synergy between the silicon dioxide component and the boron component since this combination enhances root cell wall strength and hydraulic conductivity, thus allowing the roots to go deep down through various layers of soil while keeping their original structure. Silicon dioxide and boron have beneficial effects on root length development, as both components enhance the physical properties of root cell walls and promote hydraulic conductivity, providing a greater potential for structural integrity at deeper soil depths. Calcium carbonate and calcium oxide facilitate a slow release of calcium that supports cell division and elongation, and the iron and manganese provide the micronutrients that are important for enzymatic activities essential for root metabolism and growth. These results agree with those reported by Bilal (2010), Marschner (2012 Issa et al. (2020), and Sorour et al. (2021).

Water stress treatments significantly impact root weight per plant, and top weight per plant decreases due to decreased cell expansion and limited carbohydrate allocation to storage roots. As a result, individual plant root and top weight reduction, the root yield (t/fed) and top yield (t/fed) decline as well, since water stress restricts both root and shoot growth. The result is in harmony with that of (Gharib & El-Henawy, 2011) and (Mahmoud et al., 2018).

Compared to well water, the improvement in root yield due to foliar application may be caused by a very vigorous early growth, expressed in the improved root yield and its components, like dry matter content, root length, diameter, and weight. This is in line with results found by AbdAllah et al. (2021); Seadh et al. (2024) for potassium silicate, (Arjeh et al., 2021; Yacoub et al., 2024), for ascorbic acid, and (Sorour et al., 2021) for lithovit in sugar beet.

Potassium silicate significantly positively influenced both root weight per plant and top weight per plant of sugar beet because it provided nutritional and structural benefits, increasing vegetative growth and storage root development. In this regard, potassium is considered a vital macronutrient that regulates osmotic balance, activates enzymes, and influences carbohydrate metabolism. The general effects observed increased root weight per plant as a result of high accumulation of sugars that improved cell turgor maintenance, simultaneously with photosynthetic efficiency, leading to general plant growth. The role of potassium in leaf structure, stomatal function, and chlorophyll stability expresses a great deal of high top weights per plant since silica strengthens cell walls, thereby reducing lodging and helping to maintain vigorous vegetative conditions during the growing season. The mechanical strength provided by silica nutrition to plant tissues minimizes transpiration loss, thereby enhancing resistance to stress conditions imposed by the environment. This results in better root yield per feddan from healthy plants under various field situations that favor root development. Top yield per feddan is improved incredibly following applications of potassium silicate because two favorable aspects for sustained above-ground biomass accumulation are met: higher photosynthetic capacity due to enhanced nutrition with potassium and better structural strength due to deposition of silica. These results are in agreement with Ali et al. (2019), Ibrahim et al. (2020), AbdAllah et al. (2021), Artyszak et al. (2021), Seadh et al. (2024).

Ascorbic acid applications manifest highly positive effects on biomass production and yield components of sugar beet through its multi-oriented functions as an antioxidant, growth regulator, and metabolic enhancer. It allows optimization of root and shoot development. In general, the application of ascorbic acid increases the weight of roots per plant, as it has a function in protecting root cells against oxidative stress and improving carbohydrate metabolism. This allows for the accumulation of more sugars in storage tissues, while also facilitating cell division and expansion. Application of ascorbic acid increased top weight per plant because this vitamin improved photosynthesis by protecting chloroplast membranes from damage due to photooxidation, thereby maintaining optimal chlorophyll content for leaf expansion, since it is involved in auxin metabolism and cell elongation. Root yield per feddan increases greatly from the protective effect against environmental stresses that would otherwise reduce plant survival and root development, plus nutrient uptake efficiency through optimal root-soil interaction, which ascorbic acid application sustains. Top yield per feddan increases greatly after applications of ascorbic acid due to its capability to maintain the longevity of leaves, reducing the rate of senescence while keeping high photosynthetic activity for a long period during the growing season, thus allowing for maximum biomass accumulation in vegetative tissues. The results align with Venkatesh & Park, 2014; Farooq et al., 2020 Arjeh et al. (2021); Sorour et al. (2021); Yacoub et al. (2024).

Lithovit (Boron 05) has positive effects on root weight (g plant^{-1}), top weight (g plant^{-1}), root yield (t/fed), and top yield (t/fed) of sugar beet sugar beets. Calcium carbonate and calcium oxide content in Lithovit improves cell wall structure and supports good root development, manifested in increased root weight per plant as well as improved root yield per feddan. High boron content helps proper translocation of carbohydrates from the photosynthesizing leaves to the sink, i.e., storage roots, hence better sugar accumulation and ultimately improved root biomass. Silicon dioxide assures better top weight through structural support to the plant and enhanced stress tolerance of the plant, expressed in vigorous vegetative growth. The micronutrients magnesium, iron, and manganese will assist in the proper formation of chlorophyll, which will lead to a better synthesis process and ultimately result in a higher top yield per feddan. This balanced mineral composition creates synergistic effects that promote both above-ground biomass production and the development of below-ground storage organs. These results agree with those reported by Bilal (2010), Marschner (2012), Issa et al. (2020), and Sorour et al. (2021).

The decrease of Potassium (K) (meq/100g) under water stress is due to disrupted ion transport mechanisms within the plant. Potassium plays a significant role in many physiological activities such as osmoregulation, enzyme activation, and photosynthesis. Under water stress, plants' potassium uptake from soil is reduced due to low root activity and impaired nutrient transport systems. This will lead to reduced concentrations of Potassium in the roots, negatively affecting plant growth and development. The other situation that should be highlighted about drought conditions is that root sodium-potassium balance has to be maintained because there exists competition between these two ions for uptake, which can decrease the level of sodium in the roots when there is inadequate Potassium. There is reduced assimilation of nitrogen due to poor function of the roots and uptake of nutrients, thereby decreasing α-amino nitrogen content in the sugar beet under water stress conditions. The alkalinity coefficient, calculated by (K+Na)/α-amino nitrogen, becomes lesser under conditions of water stress because there is impaired uptake and transport of potassium and sodium ions. These results are consistent with Aksu & Altay (2020b)

Several physiological interacting processes may account for the decreasing content of Sodium (Na) in the roots of sugar beet due to foliar-applied Potassium silicate and Lithovit. Potassium silicate enhances the plant's ability to concentrate K+ preferentially over Na+, thus reducing the buildup of sodium in the root tissues. The combination of potassium silicate and Lithovit improves water relations in the plants and their osmotic adjustment capacity, hence reducing the need for sodium accumulation as an osmolyte. Also, these sprays help the plant keep better ion homeostasis mainly by controlling Na^+/K^+ ratios, which shows lower sodium content in the roots. The decrease in α-amino nitrogen content in sugar beet roots by foliar application of potassium silicate and Lithovit is realized through several related physiological pathways. When applied as a foliar, such compounds improve the efficiency of nitrogen metabolism by enhancing the nutrition, absorption, and translocation of nitrogen to all parts of tissues within the plant system. This improved nutrient organization enhances the usage of nitrogen, thus reducing α-amino nitrogen accumulation in roots. Additionally, the combination of potassium silicate and Lithovit strengthens the plant's metabolic processes, leading to more efficient conversion of nitrogen into beneficial compounds rather than storage forms like α-amino nitrogen. These results are agreement with Sorour et al. (2021) ;Noreldin and Ahmed (2022)

The percentages of loss sugar, extractable white sugar, and juice purity diminished under water stress conditions. This decline was attributed to reduced impurities such as potassium, sodium, Potassium and sodium, and α-amino nitrogen. These factors contribute to complications during juice purification and crystallization processes, ultimately decreasing purity. These results are consistent with Soliman et al., 2013

The increasing extractable white sugar % and juice purity% for the foliar treatment through improving sugar beet quality by increasing gross sugar% and reducing K^+, Na, and N contents and loss sugar%. The augmented saccharose yield per hectare can be attributed to the synergistic effect of enhanced tuberous productivity and elevated sucrose extraction efficiency. This is in agreement with (AbdAllah et al., 2021; Seadh et al., 2024) potassium silicate in sugar beet (Arjeh et al., 2021; Yacoub et al., 2024), ascorbic acid in sugar beet (Sorour et al., 2021), and lithovit in sugar beet.

The highest consumptive water use occurs with high irrigation regimes because of increased soil moisture, resulting in high consumptive use of water (WU) due to good growth and perhaps luxury water consumption. The moderate irrigation gave the highest water use efficiency due to optimally controlled stress conditions that improved the sugar beet water conservation mechanisms. This irrigation level facilitated root yield maximization per unit of water used by encouraging efficient root growth and deeper extraction of soil water while allowing plant physiology to function normally. During the period of controlled water stress, the osmotic adjustment responses induced by controlled water stress helped cells maximize water retention without compromising growth by avoiding luxury water consumption with frequent irrigation and severe drought stress in extreme situations. All these characteristics developed the sweet spot between adequately providing moisture and inducing an appropriate amount of stress, which was evidenced by the highest water use efficiency for sugar beet root production. This is in agreement with (Gharib & El-Henawy, 2011).

All treatments recorded higher consumptive water use than the control for both seasons, particularly for foliar applications. This can lead to an assumption that foliar applications improve the plant's capacity to utilize available water by enhancing its physiological functions and root development. The highest water use efficiency was obtained with potassium silicate and Lithovit treatments. This made the plants more tolerant of stress and improved their physiological processes when water was scarce. This combination of treatments made the best use of water for both root yield and white sugar production by improving the ability of cells to hold onto water through better osmotic adjustment and by making plant structures stronger by adding silicon to cell walls. The potassium in Lithovit helped move water more easily and maintain turgor during periods of water stress. The micronutrients in Lithovit also helped photosynthesis work better and move carbohydrates to storage roots. The combined foliar treatment helped the roots grow deeper and made it easier for the plants to get water from the soil. This meant that the plants could keep growing while using less water. This nutritional strategy enhanced the plant's natural water-saving systems by strengthening cell membranes, improving stomatal regulation, and enhancing metabolic efficiency. Ultimately, this resulted in improved water use efficiency compared to either individual treatments or control applications. This is in agreement with (Gharib & El-Henawy, 2011).

5. Conclusion

It was observed that the foliar spray of potassium silicate combined with Lithovit and moderate irrigation at 65% soil moisture depletion could significantly invigorate the growth of sugar beet, its yield, and water use efficiency, particularly under conditions involving water stress. The combination treatment demonstrated maximum productivity with minimal water consumption, yielding higher root yields and better sugar quality than all other treatments. Farmers are advised to practice this protocol to maximize yield as well as save water. The author also envisions a future study in adjusting foliar application methods, utilizing smart irrigation systems, broadening trials across various regions, and leveraging current data analytics to promote sustainable yet efficient production of sugar beets.

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

Availability of data and material: Not applicable.

Competing interests: The authors declare that they have no conflict of interest in the publication.

Funding: The research was funded by Delta Sugar Company at El-Hamol, Kafr El-Sheikh Governorate.

Authors' contributions: All authors contributed to writing the original draft, finalizing the manuscript, and agreeing to submit it to the journal.

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