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Enhancing Sugar Beet Performance under Water Scarcity Via Spraying Boron and Potassium Silicate: A Field Trial under Egyptian Conditions

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ABSTRACT

The water scarcity challenges confronting Egypt necessitate persons working in plant nutrition and strategic crop production to seek solutions aimed at minimizing irrigation water quantities while sustaining productivity levels without experiencing a significant decline. So, a field experiment with a split-plot design was implemented to delve into the efficacy of boron and potassium silicate application as a means to alleviate irrigation water demand during sugar beet cultivation. The main plots were irrigation treatments [T_1: Traditional irrigation without skipping any irrigation event, T_2: Skipping the first irrigation event, T_3: Skipping the second irrigation event, T_4: Skipping the third irrigation event]. While the sub main plots were boron and potassium silicate treatments [F_1: Without foliar application (control); F_2: Borax at rate of 0.5 cm^3 L^{-1}; F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}; F_4: Combined treatment of borax (0.25cm^{3}L^{-1}) + potassium silicate (1.25 cm^3 L^{-1})]. T_1 treatment exhibited superior performance in obtaining the highest values of leaf chemical constituents (NPK, %), chlorophyll (SPAD), plant height (cm) and top fresh weight (g plant^{-1} & Mg fed^{-1}), followed by T_4 then T_3 treatment and finally T_2 treatment. The combined treatment of boron and potassium silicate (F_4) was achieved the most elevated levels of all aforementioned traits. The combined treatment of T_1 F_4 emerged as the most superior, consistently recording the highest values among all combined treatments. Under irrigation water deficit treatments (T_2, T_3, T4), the highest values were observed in treatment T_4, particularly when combined with foliar applications (F_3 and F_4).

Keywords: Boron, Fertilization, Irrigation, Performance**,** Potassium silicate, Sugar Beet, Water demand

INTRODUCTION

Egypt stands at the crossroads of a pressing agricultural dilemma, grappling with the dual challenges of water scarcity and burgeoning population growth (Gad, 2017). The country's situation is underscored by its classification as falling below the water poverty line, where the per capita allocation of water is less than 1000 m^3 per year (Abd Ellah *et al.* 2020).

Among the crops vital to the nation's agricultural landscape, sugar beet (*Beta vulgaris* L.) holds a pivotal position due to its economic significance and nutritional value for both human and animal consumption (Abd El-All and Makhlouf, 2017). However, the cultivation of sugar beet in Egypt is intertwined with a substantial demand for irrigation water, a resource in increasingly short supply. As the scarcity of water resources intensifies, the sustainability and resilience of sugar beet production come under scrutiny (Mahmoud *et al.* 2018; Ali *et al.* 2019). Moreover, the current strategic initiatives of the Egyptian Government are oriented towards bridging the gap between sugar consumption and domestic production. In line with this objective, there is a concerted effort to incentivize and support sugar beet growers in expanding the cultivated area. This governmental encouragement underscores the critical role of sugar beet cultivation in bolstering domestic sugar production, thereby reducing reliance on imports and ensuring greater food security for the nation (Faiyad and Hozayn, 2020). Consequently, the imperative to enhance the efficiency and sustainability of sugar beet farming practices becomes even more pronounced, as increased cultivation amplifies the demand for water resources. In this context, the exploration of innovative approaches to optimize water usage in sugar beet cultivation assumes paramount importance, aligning with broader national goals of agricultural self-sufficiency and resource conservation (Seadh *et al.* 2024).

In response to this pressing issue, researchers in the field of plant nutrition have embarked on a quest to devise innovative strategies that mitigate irrigation water requirements, while preserving or even enhancing crop productivity. Among the array of potential solutions, attention has turned to the application of specific substances known to bolster plant performance under stress conditions. Notably, boron and potassium silicate have emerged as promising candidates for improving the resilience of sugar beet crops to water scarcity-induced stress (Abbas *et al.* 2018; Bukhari *et al.* 2021).

Boron, classified as an essential micronutrient, holds significant importance despite its minimal requirement in plant nutrition. It plays a vital role in various physiological processes crucial for plant growth and development. In sugar beets specifically, boron functions as a facilitator of sugar transport, primarily aiding in the translocation of sugars from the shoots to the roots. This process is pivotal for the accumulation of sucrose in the root, which is the primary

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source of sugar harvested from sugar beet crops (Nemeat Alla *et al.* 2019; Ibrahim *et al.* 2020; Rashed 2020).

Additionally, potassium silicate has been identified for its capacity to enhance the tolerance of sugar beet plants to drought stress, thus potentially reducing their reliance on frequent irrigation. Potassium silicate is a compound that holds importance in various agricultural applications, particularly in enhancing plant resilience to stress factors like drought (Bukhari *et al.* 2021). It consists of potassium and silicate ions and is commonly used as a foliar spray or soil amendment in crop cultivation. In sugar beet farming, potassium silicate plays a vital role in improving the plant's tolerance to water scarcity. It functions by strengthening cell walls, promoting root growth, and enhancing the plant's ability to withstand drought stress. By bolstering the structural integrity of the plant and facilitating nutrient uptake, potassium silicate contributes to overall crop health and productivity, making it a valuable tool for sustainable agriculture in water-limited environments like Egypt (Gomaa *et al.* 2021; Salem *et al.* 2022; Karvar *et al.* 2023) .

Therefore, the current study aims to delve into the efficacy of boron and potassium silicate application as a means to alleviate irrigation water demand during sugar beet cultivation in Egypt. By investigating the impact of these substances on sugar beet performance under water-limited conditions, we seek to contribute valuable insights to the quest for sustainable agricultural practices in a water-constrained environment. Through meticulous experimentation and analysis, our objective is to offer actionable recommendations that hold the potential to enhance the resilience and productivity of sugar beet cultivation while conserving precious water resources.

MATERIALS AND METHODS

Experimental location

A field trial was implemented during two succssive agricultural seasons (2022/23 and 2023/24) at the Agriculture Faculty Farm of Mansoura University in Egypt, situated at coordinates 31°03′00″N 31°22′59″E.

Soil analysis and its characteristics properties

Soil samples were collected from a depth of 0-30 cm before sowing in both seasons (2022/23 & 2023/24) and analyzed according methods outlined by Dane and Topp (2020) and Sparks *et al.* (2020). In addition, the soil characteristics and its properties were also evaluated. The results of soil analysis and its characteristics properties are presented in Table (1)

Table 1. Characteristics of initial soil before sowing at both seasons

Initial soil characteristics		Values: First season (2022/23)	Values: Second season (2023/24)
Particle size distribution (%)	C. sand,%	2.40	2.50
	F. sand,$	19.5	19.8
	Silt,%	28.0	28.2
	Clay,%	50.1	49.5
Textural class is Clay			
EC dSm^{-1}		1.4	1.6
pH		8.1	8.13
$CaCO_3$ %		2.1	2.13
Organic matter, %		1.0	1.2
Available macro-nutrients	Nitrogen, mgKg^{-1}	62.09	65.03
	Phosphorus , mgKg^{-1}	10.00	11.00
	Potassium, mgKg^{-1}	236.9	245.0
Available boron, , mgKg^{-1}		0.600	0.7400

Substances studied

Potassium silicate, containing 12.0% K_2O and 25% SiO_2, and borax, alternatively known as sodium borate and comprising 5.0% boron, were acquired from Atanor for Fertilizer Manufacture, then the studied solutions at investigated rates were prepared.

Experimental design and treatments

The experiment was conducted using a split-plot design, comprising 16 treatments with three replicates each, resulting in 48 experimental units. This design incorporated four irrigation treatments and four foliar application treatments. Each experimental unit was covered an area of 42.0 m^2 (3.5 m × 12.0 m), corresponding to each sub-main plot. Within each sub-main plot, there were four ridges, each measuring 0.85 m wide and 12.0 m long. These ridges were further subdivided into three replicates, with each replicate occupying a length of 4.0 m within the ridge.

- Main plots were irrigation treatments as follows:

T_1: Traditional irrigation process (without skipping any irrigation event), subjected to 7 irrigation events

T_2: Plants were subjected to 6 irrigation events (skipping the first irrigation event)

T_3: Plants were subjected to 6 irrigation events (skipping the second irrigation event)

T_4: Plants were subjected to 6 irrigation events (skipping the third irrigation event)

- Sub main plots were boron and potassium silicate treatments as follows:

F_1: Without foliar application (control)

F_2: Borax at rate of 0.5 cm^3 L^{-1}

F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}

F_4: Combined treatment [borax (0.25cm^{3}L^{-1}) + potassium silicate (1.25 cm^3 L^{-1})

Cultivation

Sugar beet seeds (C.v. Finoget) were sourced from the Sugar Research Institute, Agricultural Research Center (ARC), Egypt. Sowing took place on 20 September in both seasons, with a seeding rate of 3-4 seeds per hill, positioned on one side of the ridge with a spacing of 20 cm between plants. Thinning occurred at 30 and 45 days post-sowing, with the objective of maintaining one plant per hill.

Fertilization

Before sowing, all plots were received calcium superphosphate during soil preparation at a rate of 100 kg per feddan (15% P2O5 content). Additionally, compost was incorporated into the soil at a rate of 20 m3 per feddan during soil preparation. Urea, with a nitrogen content of 46.5%, was applied at a rate of 120 kg of nitrogen per feddan in two equal doses. The first dose was administered after thinning, while the second dose was applied one month later. Potassium fertilization was carried out using potassium sulfate (48% K2O content) at a rate of 50.0 kg per feddan, coinciding with the first urea application after thinning.

The initial foliar application of potassium silicate and borax treatments occurred 50 days after cultivation, with subsequent applications repeated five times at two-week intervals. In addition, all conventional agricultural practices were adhered to throughout the experiment at the optimum time.

Irrigation

Irrigation process was done immediately after sowing. The irrigation treatments were implemented starting

50 days after sowing, following the initial irrigation event. (After life irrigation event).

Measurements

- At a period of 125 days from sowing

Following 125 days from sowing, the chemical constituents, namely nitrogen, phosphorus, and potassium, present in sugar beet foliage were analyzed. This analysis involved complete wet digestion, as outlined by Walinga *et al.* (2013). Nitrogen content was determined using the micro-Kjeldahl method, while phosphorus content was measured colorimetrically at a wavelength of 680 nm using a spectrophotometer (Spekol). Potassium content was determined using a Gallen Kamp flame photometer. Additionally, the total chlorophyll content was assessed using a portable chlorophyll meter (SPAD-502) according to the method described by Castelli *et al.* (1996).

- At a period of 180 days from sowing (maturity stage)

Plant samples were collected and gently removed from the soil to determine the fresh weights of both the top (expressed in g $plant^{-1}$ and Mg fed^{-1}) and root parts (g $plant^{-1}$).

Statistical analysis

The collected data underwent analysis of variance as outlined by Gomez and Gomez (1984). Treatment means were compared using the least significant difference (LSD) at a significance level of 0.05. All statistical analyses were conducted utilizing the analysis of variance technique through the CoStat computer software package (Version 6.303, CoHort, USA, 1998–2004).

RESULTS AND DISCUSSIONS

Plant performance (leaves chemical constituents and photosynthetic pigments) at a period of 125 days from sowing

Data in Tables 2 and 3 show the effect of skipping irrigation event at various times and spraying boron as well as potassium silicate on leaves chemical constituents (N, P, K, %) and chlorophyll content (SPAD readings) of sugar beet.

The data pertains to observations made at the 125-day mark from sowing, spanning 2022/23 and 2023/24 seasons.

Individual effect of irrigation regimes

Tables 2 and 3 illustrate that T_1 treatment, representing the traditional irrigation process with no skipped irrigation events and subjected to 7 irrigation events, exhibited superior performance in obtaining the highest values of leaf chemical constituents (N, P, K,%) and chlorophyll content (measured by SPAD readings). Following T_1, T_4 treatment, where plants were subjected to 6 irrigation events with the third irrigation event skipped, demonstrated the next highest performance, succeeded by T_3 treatment (6 irrigation events with the second irrigation event skipped), and finally T_2 treatment (6 irrigation events with the first irrigation event skipped).

In essence, among the irrigation deficit treatments, T_4 treatment, involving skipping the third irrigation event, showed superiority compared to both T_2 and T_3 treatments. In this respect, Moosavi *el al*, (2017) confirm our results, who are mentioned that the irrigation process without skipping any irrigation gives the highest yield in compered few to many times of irrigation.

T_1 treatment, being the traditional irrigation process with no skipped events, ensures consistent and adequate water availability throughout the growing period. This stable water supply promotes optimal nutrient uptake and utilization by sugar beet plants, leading to higher concentrations of leaf chemical constituents such as nitrogen (N), phosphorus (P), and potassium (K), essential for plant growth and chlorophyll synthesis (Mahmoud *et al.* 2018). By avoiding skipped irrigation events, T_1 treatment allows for uninterrupted growth and development of sugar beet plants, minimizing stress-induced disruptions in physiological processes. This continuity in growth supports efficient nutrient assimilation and chlorophyll production, resulting in enhanced photosynthetic activity and ultimately higher chlorophyll content.

Water availability directly may have affected the nutrient absorption and photosynthetic efficiency, which is crucial for sugar beet growth and yield. Chlorophyll content serves as a proxy for photosynthetic activity. Adequate water supply supports optimal photosynthetic rates, leading to higher chlorophyll content and overall plant vigor (Moosavi *et al.* 2017). Omitting irrigation events during critical growth stages may disrupt photosynthetic processes, resulting in reduced chlorophyll content and compromised plant growth, as observed in each of T_2 and T_3 treatments.

Table 2. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on leaves chemical constituents of sugar beet at 125 days after sowing during the season of 2022/23

Treatments		N, %	P, %	K, %	Chlorophyll, SPAD reading
Main factor: Irrigation treatments					
T_1		2.89a	0.302a	2.25a	42.35a
T_2		2.38d	0.220d	1.64d	37.41d
T_3		2.56c	0.246c	1.87c	39.27c
T_4		2.72b	0.274b	2.07b	40.87b
LSD at 5%		0.07	0.004	0.04	0.55
Sub main factor: foliar applications					
F_1		2.56c	0.250d	1.88d	39.28c
F_2		2.62bc	0.257c	1.93c	39.79b
F_3		2.66ab	0.264b	1.99b	40.21ab
F_4		2.71a	0.272a	2.04a	40.63a
LSD at 5%		0.07	0.003	0.03	0.60
Interaction					
T_1	F_1	2.82	0.290	2.19	41.77
	F_2	2.87	0.298	2.24	42.15
	F_3	2.90	0.305	2.27	42.51
	F_4	2.96	0.315	2.31	42.96
T_2	F_1	2.28	0.211	1.53	36.34
	F_2	2.34	0.216	1.60	37.31
	F_3	2.42	0.223	1.70	37.76
	F_4	2.47	0.230	1.74	38.24
T_3	F_1	2.50	0.235	1.80	38.64
	F_2	2.55	0.241	1.85	39.04
	F_3	2.58	0.250	1.89	39.48
	F_4	2.63	0.258	1.95	39.93
T_4	F_1	2.65	0.265	1.99	40.35
	F_2	2.71	0.272	2.05	40.65
	F_3	2.74	0.277	2.10	41.10
	F_4	2.78	0.284	2.16	41.39
LSD at 5%		0.14	0.005	0.06	0.99

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Since, T_1: Traditional irrigation process (without Skipping any irrigation event), subjected to 7 irrigation events; T_2: Plants were subjected to 6 irrigation events (skipping the first irrigation event); T_3: Plants were subjected to 6 irrigation events (skipping the second irrigation event); T_4: Plants were subjected to 6 irrigation events (skipping the third irrigation event); F_1: Without foliar application (control); F_2:Borax at rate of 0.5 cm^3 L^{-1}; F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}; F_4: Combined treatment [borax(0.25cm^3L^{-1}) + Potassium silicate (1.25 cm^3 L^{-1})

Table 3. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on leaves chemical constituents of sugar beet at 125 days after sowing during the season of 2023/24

Treatments		N, %	P, %	K, %	Chlorophyll, SPAD reading
Main factor: Irrigation treatments					
T_1		2.97a	0.315a	2.32a	43.19a
T_2		2.43d	0.229d	1.69d	38.18d
T_3		2.63c	0.256c	1.93c	40.08c
T_4		2.80b	0.286b	2.13b	41.69b
LSD at 5%		0.03	0.004	0.04	0.46
Sub main factor: foliar applications					
F_1		2.63c	0.260d	1.93d	40.04c
F_2		2.69b	0.267c	1.99c	40.58b
F_3		2.72b	0.275b	2.05b	41.05a
F_4		2.78a	0.283a	2.10a	41.47a
LSD at 5%		0.05	0.003	0.03	0.43
Interaction					
T_1	F_1	2.91	0.302	2.26	42.63
	F_2	2.96	0.311	2.30	42.87
	F_3	2.97	0.318	2.34	43.43
	F_4	3.03	0.328	2.38	43.84
T_2	F_1	2.33	0.219	1.57	36.97
	F_2	2.4	0.226	1.65	38.12
	F_3	2.47	0.232	1.76	38.59
	F_4	2.52	0.239	1.79	39.04
T_3	F_1	2.56	0.244	1.85	39.33
	F_2	2.61	0.250	1.90	39.82
	F_3	2.64	0.260	1.95	40.29
	F_4	2.7	0.269	2.02	40.88
T_4	F_1	2.73	0.276	2.06	41.24
	F_2	2.78	0.283	2.11	41.50
	F_3	2.82	0.289	2.16	41.90
	F_4	2.87	0.296	2.21	42.11
LSD at 5%		0.09	0.006	0.07	.086

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Since, T_1: Traditional irrigation process (without Skipping any irrigation event), subjected to 7 irrigation events; T_2: Plants were subjected to 6 irrigation events (skipping the first irrigation event); T_3: Plants were subjected to 6 irrigation events (skipping the second irrigation event); T_4: Plants were subjected to 6 irrigation events (skipping the third irrigation event); F_1: Without foliar application (control); F_2:Borax at rate of 0.5 cm^3 L^{-1}; F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}; F_4: Combined treatment [borax(0.25cm^3L^{-1}) + Potassium silicate (1.25 cm^3 L^{-1})

Skipping irrigation events, as in T_2, T_3 and T_4 treatments, can lead to intermittent water stress, which may affect root development and nutrient absorption processes. T4, where the third irrigation event is skipped, may mitigate the negative impacts of water stress compared to T_2 and T_3 treatments, allowing for more extensive root exploration and improved nutrient uptake despite reduced water availability (Abd El-All and Makhlouf, 2017).

Plants subjected to moderate water stress, as in T_2, T_3 and T_4 treatments, may undergo physiological adaptations to cope with water scarcity. T_4 treatment, experiencing water stress later in the growth cycle, may exhibit enhanced stress tolerance mechanisms compared to T_2 and T_3 treatments, resulting in better nutrient retention and utilization, including chlorophyll synthesis. The differences in irrigation timing among treatments (T_2, T_3 and T_4 treatments) may influence resource allocation within sugar beet plants. T_4 treatment, where water stress occurs at a later stage, may prioritize resource allocation towards essential physiological processes such as chlorophyll synthesis, leading to higher chlorophyll content compared to T_2 and T_3 treatments (Li *et al.* 2019).

Overall, the superiority of T_1 treatment in leaf chemical constituents and chlorophyll content can be attributed to its consistent water availability and uninterrupted growth, while the relatively higher performance of T_4 treatment compared to T_2 and T_3 treatments may be linked to optimized stress adaptation and resource allocation strategies. These findings are in harmony with results reported before by Seadh *el al.* (2021)

Individual effect of foliar applications

Tables 2 and 3 reveal that the combined treatment of boron and potassium silicate (F4) achieved the most elevated levels of leaf chemical constituents (N, P, K, %) and chlorophyll content (measured by SPAD readings). Subsequently, potassium silicate alone (F3), which came in the second order, demonstrated superior results compared to borax alone (F2), while the control group (F1) was showed the lowest values across all measured parameters. The observed superiority of the combined treatment (F4) in achieving the highest values of N, P, K and chlorophyll content, followed by potassium silicate alone (F3) and borax alone (F2), can be elucidated by several the following reasons.

Boron and potassium silicate interact synergistically to enhance nutrient uptake and assimilation in sugar beet plants (Abd El-All and Makhlouf, 2017). Boron facilitates the uptake of essential nutrients such as nitrogen (N), phosphorus (P), and potassium (K), while potassium silicate improves nutrient transport and utilization within the plant (Bukhari *et al*,. 2021). The combined treatment (F_4) capitalizes on these synergistic effects, leading to increased levels of leaf chemical constituents.

Potassium silicate promotes efficient nutrient utilization by enhancing root development and increasing nutrient absorption capacity. Additionally, it enhances plant resilience to environmental stresses, allowing for improved nutrient uptake under suboptimal conditions. As a result, sugar beet plants were treated with potassium silicate alone (F_3) exhibit higher levels of leaf chemical constituents compared to borax alone (F_2) and the control group (F_1). These results are agreement with the finding reported by Salem *el al*., (2022)

Both boron and potassium silicate contribute to chlorophyll synthesis and maintenance, thereby promoting photosynthetic efficiency. Boron is involved in chlorophyll formation, while potassium silicate strengthens cell walls and improves water and nutrient uptake, supporting optimal photosynthesis. The combined treatment (F4) harnesses these benefits, resulting in higher chlorophyll content and enhanced photosynthetic activity compared to individual treatments.

Potassium silicate enhances sugar beet plant resilience to various biotic and abiotic stresses, including drought and disease. By alleviating stress, potassium silicate improves overall plant health and vigor, leading to increased nutrient assimilation and chlorophyll production. This contributes to the superior performance of treatments containing potassium silicate (F_3 and F_4) in leaf chemical constituents and chlorophyll content (Ali *et al.* 2019).

The combined treatment of boron and potassium silicate (F4) likely promoted the overall growth and development of sugar beet plants through synergistic effects on nutrient uptake, photosynthetic activity, and stress resilience. This comprehensive approach may have resulted in the highest levels of leaf chemical constituents and chlorophyll content compared to individual treatments and the control group (Abo-Steet *et al.* 2015 and AbdAllah *et al.* 2021).

In summary, the superior performance of the combined treatment (F_4) in leaf chemical constituents and chlorophyll content may have been attributed to synergistic interactions between boron and potassium silicate, enhanced nutrient utilization efficiency, improved photosynthetic activity, stress alleviation, and overall promotion of growth and development in sugar beet plants.

Interaction effect

Tables 2 1 and 2 3 illustrate that all foliar supplements resulted in increased values of leaf chemical constituents (N, P, K, %) and chlorophyll content (measured by SPAD readings) across all studied irrigation regimes, including both traditional regime (T_1) and water deficit conditions (T_2, T_3, T_4). The combined treatment of T_1 X F_4 was emerged as the most superior, consistently yielding the highest values among all combined treatments.

Under irrigation water deficit treatments (T_2, T_3, T4), the highest values of leaf chemical constituents (N, P, K, %) were observed in treatment T_4, particularly when combined with foliar applications (F_3 and F_4).

Chlorophyll content, as measured by SPAD readings, serves as an indicator of photosynthetic activity and overall plant health. The results show an increasing trend in chlorophyll content with the application of foliar treatments under all irrigation regime treatments. Under deficit irrigation treatments, T_4 treatment, in combination with foliar treatments F_3 and F_4, consistently exhibits the highest chlorophyll content, indicating enhanced photosynthetic activity and physiological efficiency in sugar beet plants. In this regards, Li, *el al*. (2019) mentioned that increasing the content of chlorophyll in the leaves increases the enzymatic and physiological activity within, which leads to an increase in the amount of the crop.

Under water deficit conditions (T_2, T_3, T_4), the highest values observed in treatment T_4, particularly when combined with foliar applications F_3 and F_4, can be explained by the plants' ability to prioritize nutrient uptake and utilization in response to stress. This likely involves mechanisms such as enhanced root exploration, improved water use efficiency, and activation of stress-responsive pathways, ultimately leading to superior performance in terms of leaf chemical constituents and chlorophyll content.

A consistent trend was observed for both individual and interaction effects across both studied seasons. The obtained results align with those reported in the study by Ghaffari *et al.* (2021); Karvar *et al.* (2023); Seadh *et al.* (2024), corroborating the consistency and reliability of our findings.

Plant height and top fresh weight at a period of 180 days from sowing (maturity stage)

Data presented in Tables 4 and 5 illustrate the impact of skipping irrigation events at different times of plant life and applying boron and potassium silicate spray on the performance of sugar beet. This performance was quantified in terms of plant height (cm), top fresh weight (expressed in g plant^{-1} and Mg fed^{-1}) and root fresh weight (g plant^{-1}). The data pertains to observations made at harvest stage, spanning 2022/23 and 2023/24 seasons.

Individual effect of irrigation regimes

Tables 4 and 5 present the results of the individual effects of skipping irrigation events and applying boron and potassium silicate on sugar beet performance at 180 days after sowing, across two seasons. Treatments T_1 to T_4 represent different irrigation regimes, with T_1 being the traditional approach with no skipped events and T_2 to T_4 involving the omission of specific irrigation events.

Results show variations in plant height (cm) and top fresh weight (expressed in g plant^{-1} and Mg fed^{-1}). Significant differences between treatments are indicated by letter suffixes, with LSD values provided for reference. The results illustrate that the best irrigation treatment for obtaining the maximum values of plant height (cm), top fresh weight (expressed in g plant^{-1} and Mg fed^{-1}) and root fresh weight (g plant^{-1}) was T_1 [traditional irrigation process, subjected to 7 irrigation events] followed by T_4 [plants were subjected to 6 irrigation events (skipping the third irrigation event)] then T_3[plants were subjected to 6 irrigation events] and lately T_2 [plants were subjected to 6 irrigation events].

Table 4. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on plant height and top fresh weight of sugar beet at 180 days from sowing (maturity stage) during the season of 2022/23

Treatments		Plant height, cm	Top fresh weight, g plant^{-1}	Top fresh weight, Mg fed^{-1}	Root fresh weight, g plant^{-1}
Main factor: Irrigation treatments					
T_1		47.22a	402.84a	8.86a	1277.42a
T_2		42.06d	317.09d	6.98d	1021.00d
T_3		44.22c	353.75c	7.78c	1108.50c
T_4		45.93b	381.91b	8.40b	1187.33b
LSD at 5%		0.58	7.13	0.16	3.08
Sub main factor: foliar applications					
F_1		44.19b	355.05d	7.81d	1116.58d
F_2		44.61b	360.01c	7.92c	1134.58c
F_3		45.12a	367.74b	8.09b	1160.25b
F_4		45.51a	372.80a	8.20a	1182.83a
LSD at 5%		0.48	3.38	0.07	4.06
Interaction					
T_1	F_1	46.77	399.95	8.80	1244.33
	F_2	47.11	402.45	8.85	1265.00
	F_3	47.32	403.76	8.88	1290.33
	F_4	47.69	405.18	8.91	1310.00
T_2	F_1	40.89	305.80	6.73	980.33
	F_2	41.53	311.06	6.84	997.67
	F_3	42.73	322.85	7.10	1041.67
	F_4	43.09	328.66	7.23	1064.33
T_3	F_1	43.63	345.28	7.60	1083.33
	F_2	43.95	350.31	7.71	1098.67
	F_3	44.42	356.48	7.84	1115.00
	F_4	44.87	362.95	7.98	1137.00
T_4	F_1	45.48	369.17	8.12	1158.33
	F_2	45.83	376.21	8.28	1177.00
	F_3	46.00	387.86	8.53	1194.00
	F_4	46.40	394.39	8.68	1220.00
LSD at 5%		0.96	6.75	0.15	8.12

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Since, T_1: Traditional irrigation process (without Skipping any irrigation event), subjected to 7 irrigation events; T_2: Plants were subjected to 6 irrigation events (skipping the first irrigation event); T_3: Plants were subjected to 6 irrigation events (skipping the second irrigation event); T_4: Plants were subjected to 6 irrigation events (skipping the third irrigation event); F_1: Without foliar application (control); F_2:Borax at rate of 0.5 cm^3 L^{-1}; F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}; F_4: Combined treatment [borax(0.25cm^{3}L^{-1}) + Potassium silicate (1.25 cm^3 L^{-1})

Table 5. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on plant height and top fresh weight of sugar beet at 180 days from sowing (maturity stage) during the season of 2023/24

Treatments		Plant height, cm	Top fresh weight, g plant^{-1}	Top fresh weight, Mg fed^{-1}	Root fresh weight, g plant^{-1}
Main factor: Irrigation treatments					
T_1		48.63a	409.46a	9.01a	1293.75a
T_2		43.29d	322.42d	7.09d	1034.67d
T_3		45.61c	359.12c	7.90c	1123.33c
T_4		47.35b	387.33b	8.52b	1202.08b
LSD at 5%		1.01	4.30	0.09	2.23
Sub main factor: foliar applications					
F_1		45.47c	360.61d	7.93d	1130.75d
F_2		45.99b	365.66c	8.04c	1148.50c
F_3		46.53a	372.98b	8.21b	1176.75b
F_4		46.89a	379.08a	8.34a	1197.83a
LSD at 5%		0.47	3.97	0.08	4.45
Interaction					
T_1	F_1	48.21	406.51	8.94	1263.33
	F_2	48.56	408.93	9.00	1281.00
	F_3	48.72	409.44	9.01	1307.33
	F_4	49.02	412.96	9.09	1323.33
T_2	F_1	42.04	311.47	6.85	991.67
	F_2	42.79	317.17	6.98	1008.00
	F_3	44.05	327.57	7.21	1056.33
	F_4	44.26	333.46	7.34	1082.67
T_3	F_1	44.86	350.17	7.70	1095.00
	F_2	45.31	355.54	7.82	1115.00
	F_3	45.79	361.57	7.95	1130.33
	F_4	46.46	369.20	8.12	1153.00
T_4	F_1	46.76	374.30	8.23	1173.00
	F_2	47.29	380.98	8.38	1190.00
	F_3	47.57	393.33	8.65	1213.00
	F_4	47.80	400.70	8.82	1232.33
LSD at 5%		0.96	7.94	0.18	8.90

Means within a row followed by a different letter (s) are statistically different at a 0.05 level

Since, T_1: Traditional irrigation process (without Skipping any irrigation event), subjected to 7 irrigation events; T_2: Plants were subjected to 6 irrigation events (skipping the first irrigation event); T_3: Plants were subjected to 6 irrigation events (skipping the second irrigation event); T_4: Plants were subjected to 6 irrigation events (skipping the third irrigation event); F_1: Without foliar application (control); F_2:Borax at rate of 0.5 cm^3 L^{-1}; F_3: Potassium silicate at rate of 2.5 cm^3 L^{-1}; F_4: Combined treatment [borax(0.25cm^{3}L^{-1}) + Potassium silicate (1.25 cm^3 L^{-1})

The obtained results showing the effectiveness of different irrigation regimes treatments on sugar beet performance can be attributed to several scientific reasons, including the vital role of selecting the timing for skipping irrigation events and its relation to physiological processes in sugar beet plant. In these connections, Abdel Fatah and Khalil, (2020) fount that the sugar beet plants have a critical phase during their growth where root development and water uptake are crucial. Skipping irrigation events during specific times can affect root development differently. For instance, omitting irrigation early in the growth stage, as in T_2 (skipping the first irrigation event), might hinder initial root establishment and subsequent water uptake, thereby affecting overall plant growth and performance.

Controlled stress can induce physiological responses in plants, leading to adaptations that enhance resilience and productivity. Skipping irrigation events strategically can induce mild stress in sugar beet plants, prompting them to allocate resources more efficiently, such as increasing root penetration depth or enhancing water retention mechanisms. This adaptive response may result in improved performance under subsequent irrigation events, as observed in T_4 (skipping the third irrigation event), where plants might have adapted to manage water scarcity more effectively. These findings are in the same line with results reported by Moustafa (2020).

The timing of irrigation events can influence nutrient availability and absorption by sugar beet plants. Water stress during critical growth stages can affect nutrient uptake and translocation within the plant. For example, skipping irrigation during periods of high nutrient demand, such as during rapid vegetative growth or early root development, may lead to suboptimal nutrient assimilation. Conversely, strategic irrigation scheduling, such as in T_1 (traditional irrigation process), ensures consistent water availability, facilitating optimal nutrient uptake and translocation, thereby promoting better plant growth and performance.

Finally, it can be noticed that the selection of timing for skipping irrigation events plays a pivotal role in shaping sugar beet physiology and ultimately influencing plant performance. Strategic irrigation management can modulate stress responses, nutrient dynamics, and photosynthetic efficiency, contributing to improved yield and quality in sugar beet cultivation.

Individual effect of foliar applications

Tables 4 and 5 displays the impact of spraying boron and potassium silicate on the performance of sugar beet at 180 days after sowing (maturity stage) across the seasons of 2022/23 and 2023/24. Results indicate significant variations in plant height (cm), top fresh weight (expressed in g plant^{-1} and Mg fed^{-1}) and root fresh weight (g plant^{-1}). The highest values across all parameters were observed with the combined treatment (F_4), followed by potassium silicate alone (F_3) and borax alone (F_2), while the control group (F_1) exhibits the lowest performance.

The obtained results demonstrating the effectiveness of spraying boron and potassium silicate on sugar beet performance can be explained by several scientific reasons. Boron plays a vital role in various physiological processes in plants, including cell wall formation, carbohydrate metabolism, and pollen tube elongation (Rashed 2020). Boron aids in the formation and cross-linking of pectin molecules in cell walls, contributing to their strength and integrity. This can result in improved structural support for sugar beet plants, leading to enhanced growth and development (Othman and El-Moursy, 2020). Boron also facilitates the uptake of other nutrients, such as calcium and magnesium, by improving membrane permeability and nutrient transport within the plant. This can lead to better overall nutrient utilization and plant vigor (Seadh *et al.* 2021).

In the same direction, Gomaa *et al.* (2021) mentioned that potassium (in potassium silicate) is essential for maintaining cellular osmotic potential, which regulates water uptake and distribution within the plant. This helps sugar beet plants cope with water stress and maintain turgor pressure, even under challenging environmental conditions. In addition, silicon (sourced from potassium silicate) deposition in plant tissues enhances their structural integrity and resistance to various biotic and abiotic stresses, including pathogens, pests, and environmental stressors as said by Salem *et al.* (2022), which can lead to improved resilience and productivity in sugar beet plants. In general, potassium silicate application may have stimulated the production of phytochemicals and activate defense mechanisms within sugar beet plants, resulting in enhanced resistance to diseases and pests, as well as improved overall health and vigor (Karvar *et al.* 2023).

The combined application of boron and potassium silicate (F_4) likely elicits synergistic effects, where the individual benefits of each element were enhanced when applied together. Boron facilitates the uptake and utilization of potassium and silicon, amplifying their effects on sugar beet growth and development. The combined treatment may have provided comprehensive nutrient support, addressing multiple physiological needs of sugar beet plants simultaneously. This includes were improved cell wall integrity (from boron), enhanced osmotic regulation (from potassium), and increased stress tolerance (from silicon), resulting in superior overall performance. The combined treatment may have also optimized metabolic processes within sugar beet plants, leading to more efficient nutrient utilization, enhanced photosynthetic activity, and improved resource allocation. This can contribute to increased biomass accumulation, higher chlorophyll content, and ultimately, improved yield and quality.

In summary, the observed superiority of the combined treatment (F_4) compared to boron alone (F_2) and potassium silicate alone (F_3) can be attributed to the synergistic effects of boron, potassium, and silicon, which collectively promote various aspects of sugar beet growth, development, and stress tolerance. These results are in harmony with the results obtained by each of Rashed (2020) and Salem *et al.* (2022).

Interaction effect

Tables 4 and 5 also indicate the interaction between different irrigation regime treatments (T_1, T_2, T_3, T_4) and foliar applications (F_1, F_2, F_3, F_4) providing insights into the impact of various treatments on sugar beet performance.

Across all irrigation treatments, there is a clear trend of increasing plant height (cm), top fresh weight (expressed in g plant^{-1} and Mg fed^{-1}) and root fresh weight (g plant^{-1}) with the application of foliar treatments. In addition, under all irrigation treatments except the traditional treatment (T_1), the highest values of plant height were observed in the treatment T_4, particularly, when combined with foliar applications (F_3 and F_4). This suggests that foliar applications contribute to enhanced vegetative growth and elongation of sugar beet plants. These findings are agreements with the results detected by Abd El-All, and Makhlouf, (2017).

Similar to plant height, the application of foliar treatments led to increased top fresh weight (g plant^{-1} and Mg fed^{-1}). This indicates that the foliar applications contribute to increased biomass accumulation and overall plant productivity, especially under drought conditions. Once again, The treatment T_4 stands out as the most effective, particularly when combined with foliar treatments F_3 and F_4, resulting in the highest top fresh weight values across both seasons under deficit irrigation treatments.

Generally, the obtained results demonstrate the positive impact of foliar applications on sugar beet performance, including increased plant height, top fresh weight, and chlorophyll content under all irrigation regimes. Under deficit irrigation treatments (T_2, T_3, T_4), the combined treatment (T_4) with foliar applications (F_3 and F_4) emerges as the most effective in promoting vigorous growth and biomass accumulation in sugar beet plants.

The same trend was found for individual and interaction effects during both studied seasons. The obtained results are in harmony with those of Nemeat Alla *et al.* (2019); Ibrahim *et al.* (2020); Moustafa, (2020); AlKahtani *et al.* (2021); Salem *et al.* (2022).

CONCLUSION

The investigation into the effects of skipping irrigation events and foliar applications on sugar beet growth performance revealed significant findings. Notably, traditional irrigation practices (T_1) consistently recorded superior results across various parameters, underscoring the importance of maintaining a consistent irrigation schedule for optimal crop performance. Regarding the T_4 treatment, which involved skipping the third irrigation event, it emerged as particularly noteworthy in the investigation. Despite the intentional deficit in irrigation, sugar beet plants subjected to the T_4 treatment consistently exhibited favorable performance across various parameters. The findings underscore the resilience of sugar beet plants in response to controlled water stress and highlight the potential benefits of strategic irrigation management.

Additionally, foliar applications, particularly those containing boron and potassium silicate (F_4), demonstrated notable positive effects on sugar beet performance. Furthermore, the interaction between irrigation treatments and foliar applications unveiled synergistic effects, emphasizing the importance of integrating both strategies to improve sugar beet performance. Overall, the study provides valuable insights into optimizing irrigation and foliar application practices to improve sugar beet performance.

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تحسين أداء بنجر السكر في ظل ندرة المياه عن طريق الرش بالبورون وسيليكات البوتاسيوم: تجربة حقلية تحت الظروف المصرية

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الملخص

إن تحديات ندرة المياه التي تواجهها مصر تحتم على العاملين في مجال تغذية النباتات وإنتاج المحاصيل الاستراتيجية البحث عن حلول عملية تهدف إلى تقليل كميات مياه الري مع الحفاظ على مستويات الإنتاجية دون التعرض لانخفاض كبير في المحصول. لذلك تم تنفيذ تجربة حقلية للتعمق في فهم مدى فعالية الرش الورقي بكل من سيليكات البوتاسيوم والبورون كوسيلة لتخفيف الطلب على مياه الري مع بنجر السكر. تم استخدام تصميم القطع المنشقة وكانت القطع الرئيسية هي انظمه الري [T_1:عملية ري تقليدية دون تخطي أي رية؛ T_2: تخطي الرية الأولي؛ T_3:تخطي الرية الثانية؛ T_4:تخطي الرية الثالثة].بينما كانت القطع المنشقة كانت معاملات الرش الورقي لسيليكات البوتاسيوم والبورون [F_1:بدون رش (كنترول)؛F_2: البوراكس بمعدل 0.5 سم^3 لتر$^{-1}$؛ F_3: سيليكات البوتاسيوم بمعدل 2.5 سم^3 لتر$^{-1}$؛F_4 : معامله مشتركة للبوراكس (0.25 سم^3 لتر$^{-1}$) + سيليكات البوتاسيوم (1.25 سم^3 لتر$^{-1}$)]. أظهرت المعاملة T_1 أداءاً فائقاً في الحصول على أعلى قيم لمحتوي النيتروجين والفسفور والبوتاسيوم،(%) و الكلوروفيل (SPAD) وارتفاع النبات (سم) والوزن الطازج للمجموع الخضري (بالجرام للنبات والميجا جرام للفدان). جاءت بعدها في المركز الثاني المعاملة T_4، ثم المعاملة T_3، وأخيرًا المعاملة T_2. وبمزيد من التعمق وجد أن، من بين معاملات نقص الري، أظهرت المعاملة T_4، التفوق مقارنة بمعاملتي T_2 وT_3. أيضا حققت المعاملة المشتركة لسليكات البوتاسيوم والبورون (F_4) أعلى مستويات لكل الصفات المدروسة. كذلك أظهرت المعاملة المشتركة لـ F_4 T_1 باعتبارها الأكثر تفوقاً ملحوظاً، حيث حققت أعلى القيم من بين جميع المعاملات المجمعة. ومن ناحية أخرى، فقد لوحظ أنه في معاملات نقص مياه الري (T_2،T_3،T_4)، أن المعاملة T_4 أعطت أعلى القيم ، خاصة عندما اقترنت بمعاملتي الرش الورقي (F_3 وF_4).

الكلمات الدالة :بنجر السكر، المحصول، التسميد، البورون، سيليكات البوتاسيوم، الري، الاحتياجات المائية