Iraqi Journal of Desert Studies 2024, 14 (2): 66-74 **Original Article**

Effect of Irrigation and Spraying with Boron and Potassium Silicate in Improving the Quality and Productivity of Sugar beet under Water Stress Conditions

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Abstract:

Addressing Egypt's water scarcity challenge requires innovative approaches to reduce irrigation water use without significantly affecting crop yields. This field study evaluated the effectiveness of boron and potassium silicate foliar applications in mitigating the impact of reduced irrigation on sugar beet production. The experiment was conducted using a split-plot trail in randomized complete design (RCBD), as it was structured with irrigation treatments as the main plots: $\mathbf{T_1}$ (Traditional irrigation with 7 events, no skipped events), $\mathbf{T_2}$ (6 irrigation events, skipping the 2nd), $\mathbf{T_3}$ (6 irrigation events, skipping the 3rd), and $\mathbf{T_4}$ (6 irrigation events, skipping the 4th). Sub-main plots included foliar treatments: $\mathbf{F_1}$ (Control, no foliar application), $\mathbf{F_2}$ (Borax at 0.5 cm^3 L^{-1}), $\mathbf{F_3}$ (Potassium silicate at 2.5 cm^3 L^{-1}) and $\mathbf{F_4}$ (Combined treatment of Borax 0.25 cm^3 L^{-1} + Potassium silicate 1.25 cm^3 L^{-1}). Results showed that skipping irrigation events negatively impacted sugar content and juice quality, with the highest reductions observed in $\mathbf{T_3}$ and $\mathbf{T_4}$. However, the combined foliar treatment of boron and potassium silicate significantly improved sugar yield and juice quality, particularly in $\mathbf{T_2}$, compensating for the skipped irrigation event. The combination of $\mathbf{T_1}$ with $\mathbf{F_4}$ produced the highest Na% (1.50–1.56%) and α-amino N% (4.30–4.40%). Additionally, $\mathbf{T_1} \times \mathbf{F_4}$ recorded the highest sucrose content (19.14–19.93%) and purity (87.68–87.76%), whereas $\mathbf{T_2} \times \mathbf{F_1}$ exhibited the lowest sucrose content (15.81–16.44%). Furthermore, the same combined treatment ($\mathbf{T_1} \times \mathbf{F_4}$) achieved the highest recoverable sugar yield (4.65 – 4.91 Mg fed^{-1}), contrasting with $\mathbf{T_2} \times \mathbf{F_1}$, which had the lowest yield (3.25–3.44 Mg fed^{-1}). The combined treatment proved effective in maintaining crop performance under reduced irrigation, offering a promising strategy for water-saving agriculture. Subsequent investigations have to concentrate on the enduring consequences and flexibility of these therapies in various environmental settings.

Keywords: Water scarcity, Sugar yield and Juice quality

تأثير الري والرش بالبورون وسيليكات البوتاسيوم في تحسين نوعية وإنتاجية البنجر السكري تحت ظروف الإجهاد المائي

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المستخلص:

تتطلب معالجة تحدي ندرة المياه في مصر اتباع نهج مبتكر للحد من استخدام مياه الري دون التأثير بشكل كبير على إنتاج المحاصيل. قامت هذه الدراسة الميدانية بتقييم فعالية رش الأوراق بالبورون وسيليكات البوتاسيوم في التخفيف من تأثير تقليل الري على إنتاج البنجر السكري. أجريت التجربة باستخدام تجربة القطع المشقة في تصميم قطاعات كاملة العشوائية (**RCBD**)، حيث تم تنظيمها مع معالجات الري كقطع رئيسية: $\mathbf{T_1}$ (الري التقليدي مع 7 ريات، بدون تخطي)، $\mathbf{T_2}$ (6 ريات مع تخطي الرية الثانية)، $\mathbf{T_3}$ (6 ريات مع تخطي الرية الثالثة)، و$\mathbf{T_4}$ (6 ريات مع تخطي الرية الرابعة). وشملت القطع الفرعية المعاملات الورقية: $\mathbf{F_1}$ (مجموعة التحكم، بدون رش ورقي)، $\mathbf{F_2}$ (بوراكس بتركيز 0.5 سم^3 لتر$^{-1}$)، **F3** (سيليكات البوتاسيوم بتركيز 2.5 سم^3 لتر$^{-1}$) و$\mathbf{F_4}$ (المعاملة المشتركة للبوراكس بتركيز 0.25 سم^3 لتر$^{-1}$ + سيليكات البوتاسيوم بتركيز 1.25 سم^3 لتر$^{-1}$). أظهرت النتائج أن تخطي أحداث الري أثر سلبًا على محتوى السكر وجودة العصير، مع ملاحظة أعلى انخفاض في $\mathbf{T_3}$ و$\mathbf{T_4}$. ومع ذلك، فإن المعالجة الورقية المشتركة للبورون وسيليكات البوتاسيوم حسنت بشكل كبير من محصول السكر وجودة العصير، وخاصة في $\mathbf{T_2}$، مما عوض عن حدث تخطي الري. أنتج مزيج $\mathbf{T_1}$ مع $\mathbf{F_4}$ أعلى نسبة صوديوم (1.50-1.56٪) و**α-amino N**٪ (4.30-4.40٪). بالإضافة إلى ذلك، سجلت $\mathbf{T_1} \times \mathbf{F_4}$ أعلى محتوى من السكروز (19.14-19.93٪) ونقاء (87.68-87.76٪)، في حين أظهرت $\mathbf{T_2} \times \mathbf{F_1}$ أقل محتوى من السكروز (15.81-16.44٪). وعلاوة على ذلك، حققت نفس المعاملة المشتركة ($\mathbf{T_1} \times \mathbf{F_4}$) أعلى إنتاج للسكر قابل للاسترداد (4.65 - 4.91 ميجا جرام فدان$^{-1}$)، على النقيض من $\mathbf{T_2} \times \mathbf{F_1}$، التي كان لها أقل إنتاج (3.25-3.44 ميجا جرام فدان$^{-1}$). أثبتت المعاملة المشتركة فعاليتها في الحفاظ على أداء المحصول تحت الري المنخفض، مما يوفر استراتيجية واعدة للزراعة الموفرة للمياه. يجب أن تركز الأبحاث المستقبلية على التأثيرات طويلة المدى وقابلية التكيف لهذه المعالجات في ظل ظروف بيئية مختلفة.

الكلمات المفتاحية: ندرة المياه، إنتاج السكر وجودة العصير

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Introduction

One of Egypt's biggest problems with agricultural output is water shortage, especially since the nation depends so largely on irrigation to maintain crop harvests. Effective water management in agriculture has become a critical issue due to the growing demand for water across several sectors and the continuing effects of climate change. Strategic crops like sugar beetroot (*Beta vulgaris* L.) are vital to Egypt's agricultural economy as a major source of sugar production and a factor in food security. However, regular watering is necessary for sugar beetroot development, and any decrease in water supply might have a detrimental impact on output and quality. It is considered an essential crop in Egypt to increase food security and reduce reliance on sugar imports. The crop's high level of resistance to unfavorable environmental factors including drought and soil salt makes it ideal for growing on recently constructed and reclaimed land.

The sugar business, which is vital to nutrition and other food sectors, uses sugar beetroot as its main raw material. More than 650,000 feddans of sugar beetroot are grown in Egypt, which goes a long way towards satisfying domestic demand. This boosts the nation's economy and promotes the sustainability of agriculture (**Faiyad and Hozayn, 2020; Seadh *et al*. 2021**).

Reducing the impact of water scarcity on agricultural output requires improving water use efficiency. Utilizing growth stimulants and plant nutrients is one of the most promising methods for increasing a plant's resistance to water stress. Two elements that have demonstrated promise in enhancing plant resilience to abiotic stressors, such drought, are boron (B) and potassium silicate (K_2SiO_3). Both the integrity of cell walls and the metabolism of carbohydrates depend on boron.

Additionally, boron increases the structural integrity of cell walls, increasing their resistance to stress and decreasing transpiration water loss (**Nemeat Alla *et al*. 2019**). In contrast, potassium silicate strengthens plant tissue, encourages water retention, and increases a plant's resistance to environmental stress. Potassium promotes strong root development, allowing plants to reach deeper water sources in the soil, whereas silicon increases water loss through evaporation by creating a protective covering on the leaf surface (**Karvar *et al.* 2023**).

Because of these advantages, using potassium and boron silicate might be a useful strategy to lower irrigation water requirements without sacrificing sugar beetroot yields. This study examines the impact on sugar beetroot crop development, yield, and quality of foliar treatments of boron and potassium silicate combined with irrigation event skipping. The goal is to ascertain whether these treatments may lessen the adverse impacts of less irrigation in order to offer suggestions for possible water-saving techniques for Egypt's sustainable sugar beetroot cultivation.

Materials and Methods

Over two consecutive agricultural seasons (2022–23 and 2023–24), a field experiment was conducted at the Agriculture Faculty Farm of Mansoura University in Egypt, located at coordinates 31°03′00 N 31°22′59 E.

Soil samples were collected from a depth of 0 to 30 cm before to planting in both seasons (2022–23 and 2023–24), and they were analyzed following the methods outlined by **Sparks *et al.* (2020)** and **Dane and Topp (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)	**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

1. 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.

2. Experimental design and treatments

The experiment was conducted using a split-plot trail in randomized complete design (RCBD), 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 covered an area of 42.0 m^2 (3.5 m × 12.0 m), corresponding to each sub- 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 2nd irrigation event)

T_3: Plants were subjected to 6 irrigation events (skipping the 3rd irrigation event)

T_4: Plants were subjected to 6 irrigation events (skipping the 4th irrigation event)

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

F_1: Water spraying (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 (0.25$cm^3 L^{-1}$) + potassium silicate (1.25 cm^3 L^{-1})

3. Agro practices

Sugar beet seeds (C.V. Finoget) were obtained from the Sugar Research Institute, Agricultural Research Center (ARC), Egypt. Sowing was conducted on 20 September in both seasons, with seeds planted at a rate of 3-4 seeds per hill, placed on one side of the ridge with a 20 cm spacing between hills. Thinning was performed at 30- and 45-days post-sowing to maintain a single plant per hill. For fertilization, all plots received calcium superphosphate at a rate of 100 kg per feddan (15% P2O5) during soil preparation. Compost was incorporated at 20 m³ per feddan. Urea, containing 46.5% nitrogen, was applied at 80 kg nitrogen per feddan in two doses: the first before the initial irrigation and the second one month later. Potassium sulfate (48% K_2O) was applied at 50 kg per feddan alongside the first urea dose after thinning **(Seadh *et al.* 2021)**. Foliar applications of potassium silicate and borax began 50 days after sowing, with treatments repeated five times at two-week intervals. Conventional agricultural practices were followed throughout the experiment. Irrigation was initiated immediately after sowing. The specific irrigation treatments were applied starting 50 days after sowing, following the initial irrigation.

4. Measurements

<u>At a period of 180 days from sowing (maturity stage)</u>

The juice quality and its chemical attributes were assessed following the protocols established by the beet laboratory of a sugar factory in El-Dakahlya, which included several procedures:

1. Sodium (Na) content in roots was determined using a Gallen Kamp flame photometer, following the method outlined by **Walinga *et al.* (2013).**
2. Alfa amino nitrogen (α-amino-N %) was measured using the fluorometric OPA-method, as described by **Cooke and Scott (1993).**
3. Sucrose percentage was estimated in fresh root samples using a "Saccharometer," following the method described by **Le-Docte, (1927).**
4. Total Dissolved Solids percentage (TDS, %) was determined using the hand refractometer method according to **A.O.A.C, (1995)** standards.
5. Purity percentage was calculated using the formula proposed by **Carruthers and Oldfield, (1961),** where Purity % = {(Sucrose % - Sugar loss %) / Sucrose %} x 100.
6. Impurities (α-amino N, Na, and K contents in juice) were estimated using an Automated Analyzer following the procedures outlined by **Cooke and Scott, (1993).**
7. Sugar loss percentage was calculated using the formula by **Harvey and Dutton, (1993):** Sugar loss percentage = 0.29 + 0.343 (K+Na) + 0.094 α-amino-N.
8. Sugar Recovery (S.R. %) was determined according to **Cooke and Scott, (1993):** Sugar recovery (%) = sucrose % - Sugar loss %.
9. Recoverable sugar yield (Mg fed^{-1}) was calculated using the equation: Recoverable sugar yield (Mg fed^{-1}) = root yield (Mg fed^{-1}) x sugar recovery %, as outlined by **Cooke and Scott, (1993).**
10. Sugar loss yield (Mg fed^{-1}) was calculated as: Sugar loss yield (Mg fed^{-1}) = Root yield (Mg fed^{-1}) x Sugar loss %, following the method described by **Cooke and Scott, (1993).**

11. Quality index % was determined using the formula: Quality index % = (Sugar recovery % x 100) / Sucrose %, as proposed by **Cooke and Scott, (1993).**

7. 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 significant 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

(Tables 2) and (3) delineate the individual effects of skipping irrigation events at various times and applying boron and potassium silicate, as well as their interaction effects, on the chemical composition of roots, including Na and α-amino N (%) (Table 2), and juice quality parameters such as sucrose (%), TDS (%), purity (%), and impurity (%) (Table 3). (Table 4) also illustrates additional metrics related to sugar beet juice, such as sugar loss (%), sugar recovery (%), recoverable sugar yield (Mg fed^{-1}), sugar loss yield (Mg fed^{-1}), and the quality index (%). All parameters mentioned in (Tables 2,3) and (4) were assessed at the maturity stage of 180 days from planting across the growing seasons of 2022/23 and 2023/24.

Individual effect of irrigation regimes on the studied traits

Data depicted in Tables 2, 3 and 4 indicate that skipping irrigation events at various times exerted a significant impact on the values of all the aforementioned traits. Specifically, sugar beet plants irrigated traditionally (**T_1** treatment) exhibited the highest values for all the studied traits, except for purity and quality index (%), followed by **T_4** treatment, then **T_3**, and finally **T_2** treatment. Conversely, the highest values of purity and quality index (%) were observed when plants were subjected to the **T_2** treatment, which involved skipping the 2nd irrigation event and maintaining a total of 6 irrigation events throughout the growth period.

For example, traditional irrigation **(T_1)** exhibited the highest Na% (1.44–1.50%) in both seasons, while skipping the second irrigation event **(T_2)** resulted in the lowest values (0.91–0.95%). The highest α-amino nitrogen percentage (4.20–4.29%) was recorded under **T_1,** whereas **T_2** consistently showed the lowest values (2.72–2.78%). Sucrose content was greatest in **T_1** (18.83–19.58%), whereas **T_2** recorded the lowest (16.20–16.90%). Conversely, purity was highest under **T_2** (90.41–90.55%) and lowest under **T_1** (87.90–87.81%). The recoverable sugar yield reached its peak under **T_1** (4.65–4.91 Mg fed^{-1}), while **T_2** resulted in the lowest yield (3.25–3.44 Mg fed^{-1})

The observed variations in the traits of sugar beet plants in response to different irrigation treatments can be attributed to the plants' physiological responses to water availability and stress. Traditional irrigation (**T_1** treatment) ensures consistent water supply, allowing plants to maintain optimal growth and development, resulting in higher values for most traits. On the other hand, omitting irrigation events (T2, T3, and T4 treatments) causes sporadic water stress, which forces the plants to use their resources more wisely. Temporary water deficiencies may result in lower values for some features, especially in T2 treatment when the initial irrigation session is skipped. The T2 treatment, however, stands out in the purity and quality index (%) example because mild water stress in the early stages of growth might improve sugar concentration and accumulation in the beetroot, leading to a higher purity and quality index than other treatments. Overall, our findings show how water stress responses, irrigation management, and sugar beetroot physiology interact in complex ways, highlighting the need of optimizing irrigation methods to achieve the intended crop outcomes (**Li *et al*. 2019, Abdel Fatah and Khalil, 2020**).

Individual foliar spray effects on the studied traits:

Except for purity percentage, which did not change significantly as a result of foliar applications, and quality index percentage, it is evident that all of the supplements under investigation (F2, F3, and F4) had a positive impact on the values of the traits under study when compared to plants grown without foliar application (F1). But, differently, the combined treatment of boron and potassium silicate **(F_4)** recorded the highest values for most studied traits, followed by potassium silicate alone (**F_3**), then borax alone **(F_2),** and finally, the control group (**F_1**). As for the quality index percentage, its peak values were attained under the **F_1** and **F_2** treatments.

Table 2. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on Na and α-amino N of sugar beet roots at 180 days from sowing (maturity stage) during the seasons of 2022/23 and 2023/24

Treatments		Na %		αN %	
		1st season	2nd season	1st season	2nd season
Main factor: Irrigation treatments					
T_1		1.44a	1.50a	4.20a	4.29a
T_2		0.91d	0.95d	2.72d	2.78d
T_3		1.12c	1.16c	3.23c	3.30c
T_4		1.28b	1.34b	3.75b	3.83b
LSD at 5%		**0.03**	**0.02**	**0.06**	**0.02**
Sub main factor: foliar applications					
F_1		1.16b	1.21c	3.27d	3.34d
F_2		1.15b	1.19c	3.45c	3.52c
F_3		1.19ab	1.24b	3.55b	3.63b
F_4		1.24a	1.29a	3.64a	3.71a
LSD at 5%		**0.05**	**0.03**	**0.04**	**0.04**
Interaction					
T_1	F_1	1.39	1.45	4.08	4.17
	F_2	1.42	1.48	4.18	4.25
	F_3	1.45	1.51	4.25	4.33
	F_4	1.50	1.56	4.30	4.40
T_2	F_1	0.99	1.03	2.46	2.50
	F_2	0.81	0.85	2.68	2.73
	F_3	0.89	0.93	2.81	2.87
	F_4	0.94	0.98	2.95	3.01
T_3	F_1	1.05	1.09	3.06	3.13
	F_2	1.09	1.13	3.21	3.27
	F_3	1.14	1.18	3.32	3.40
	F_4	1.19	1.23	3.34	3.42
T_4	F_1	1.22	1.27	3.47	3.56
	F_2	1.26	1.31	3.73	3.81
	F_3	1.30	1.36	3.83	3.91
	F_4	1.35	1.41	3.96	4.03
LSD at 5%		**0.10**	**0.07**	**0.08**	**0.08**

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 2nd irrigation event); **T_3:** Plants were subjected to 6 irrigation events (skipping the 3rd irrigation event); **T_4:** Plants were subjected to 6 irrigation events (skipping the 4th irrigation event); **F_1**: Water spraying (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 juice quality of sugar beet at 180 days from sowing (maturity stage) during the seasons of 2022/23 and 2023/24

Treatments		Sucrose, %		TDS, %		Purity, %		Impurity, %	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Irrigation treatments									
T_1		18.83a	19.58a	21.43a	22.30a	87.90c	87.81d	8.89a	9.11a
T_2		16.20d	16.90d	17.93d	18.66d	90.41a	90.55a	6.27d	6.42d
T_3		17.22c	17.96c	19.26c	20.02c	89.43b	89.75b	7.23c	7.39c
T_4		18.09b	18.80b	20.34b	21.19b	88.98b	88.77c	8.10b	8.29b
LSD at 5%		**0.24**	**0.21**	**0.44**	**0.19**	**0.76**	**0.39**	**0.08**	**0.04**
Sub main factor: foliar applications									
F_1		17.27c	17.96d	19.32d	20.12d	89.47a	89.33a	7.31d	7.48d
F_2		17.45c	18.15c	19.59c	20.37c	89.18a	89.16a	7.53c	7.70c
F_3		17.70b	18.46b	19.85b	20.64b	89.27a	89.52a	7.74b	7.92b
F_4		17.92a	18.67a	20.20a	21.03a	88.80a	88.87a	7.92a	8.11a
LSD at 5%		**0.22**	**0.19**	**0.20**	**0.24**	**NS***	**NS***	**0.06**	**0.05**
Interaction									
T_1	F_1	18.54	19.25	21.01	21.92	88.21	87.82	8.65	8.88
	F_2	18.73	19.44	21.31	22.16	87.92	87.75	8.84	9.03
	F_3	18.92	19.69	21.55	22.40	87.78	87.91	8.97	9.18
	F_4	19.14	19.93	21.83	22.71	87.68	87.76	9.11	9.34
T_2	F_1	15.81	16.44	17.45	18.12	90.64	90.73	5.97	6.09
	F_2	16.01	16.69	17.71	18.45	90.42	90.46	6.09	6.23
	F_3	16.37	17.10	17.98	18.70	91.05	91.45	6.39	6.56
	F_4	16.62	17.35	18.56	19.37	89.51	89.57	6.63	6.78
T_3	F_1	16.88	17.58	18.86	19.63	89.51	89.58	6.92	7.07
	F_2	17.09	17.79	19.13	19.88	89.35	89.49	7.15	7.30
	F_3	17.33	18.14	19.38	20.13	89.44	90.12	7.36	7.53
	F_4	17.59	18.34	19.67	20.42	89.42	89.82	7.48	7.67
T_4	F_1	17.84	18.55	19.94	20.80	89.50	89.20	7.69	7.88
	F_2	17.98	18.68	20.20	21.00	89.03	88.95	8.03	8.23
	F_3	18.20	18.90	20.49	21.33	88.81	88.61	8.23	8.42
	F_4	18.35	19.08	20.72	21.61	88.58	88.31	8.47	8.64
LSD at 5%		**0.44**	**0.39**	**0.41**	**0.48**	**2.34**	**3.39**	**0.12**	**0.09**

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 2nd irrigation event); **T_3:** Plants were subjected to 6 irrigation events (skipping the 3rd irrigation event); **T_4:** Plants were subjected to 6 irrigation events (skipping the 4th irrigation event); **F_1**: Water spraying (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(0.25$cm^3$$L^{-1}$) + Potassium silicate (1.25 cm^3 L^{-1})

***NS= no significant**

Table 4. The effect of skipping irrigation events at various times and spraying boron and potassium silicate on sugar yield of sugar beet at 180 days from sowing (maturity stage) during the seasons of 2022/23 and 2023/24

Treatments		Sugar loss, %		Sugar recovery, %		Recoverable sugar yield, Mg fed^{-1}		Sugar loss yield, Mg fed^{-1}		Quality index, %	
		1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
Main factor: Irrigation treatments											
T_1		2.29a	2.35a	16.54a	17.23a	4.65a	4.91a	0.64a	0.67a	87.82d	88.02d
T_2		1.76d	1.80d	14.44d	15.10d	3.25d	3.44d	0.40d	0.41d	89.12a	89.35a
T_3		1.96c	2.00c	15.26c	15.96c	3.72c	3.95c	0.48c	0.49c	88.60b	88.86b
T_4		2.14b	2.18b	15.96b	16.62b	4.17b	4.40b	0.56b	0.58b	88.19c	88.39c
LSD at 5%		**0.01**	**0.01**	**0.23**	**0.21**	**0.06**	**0.06**	**0.005**	**0.004**	**0.10**	**0.19**
Sub main factor: foliar applications											
F_1		1.98d	2.02d	15.29c	15.93b	3.77d	3.98d	0.49d	0.51d	88.54a	88.75a
F_2		2.01c	2.05c	15.44bc	16.10b	3.87c	4.08c	0.51c	0.52c	88.49a	88.71ab
F_3		2.06b	2.10b	15.64ab	16.35a	4.01b	4.25b	0.53b	0.55b	88.40ab	88.63bc
F_4		2.10a	2.15a	15.82a	16.53a	4.13a	4.37a	0.55a	0.57a	88.30b	88.53c
LSD at 5%		**0.02**	**0.01**	**0.22**	**0.19**	**0.06**	**0.05**	**0.005**	**0.005**	**0.17**	**0.11**
Interaction											
T_1	**F_1**	2.24	2.30	16.29	16.95	4.46	4.71	0.61	0.64	87.90	88.06
	F_2	2.28	2.33	16.45	17.12	4.58	4.82	0.63	0.66	87.83	88.03
	F_3	2.31	2.36	16.61	17.33	4.72	4.98	0.66	0.68	87.80	88.02
	F_4	2.34	2.40	16.80	17.53	4.84	5.10	0.68	0.70	87.76	87.96
T_2	**F_1**	1.73	1.76	14.09	14.69	3.04	3.20	0.37	0.38	89.08	89.31
	F_2	1.71	1.75	14.30	14.95	3.14	3.31	0.38	0.39	89.30	89.53
	F_3	1.78	1.83	14.59	15.28	3.34	3.55	0.41	0.42	89.11	89.33
	F_4	1.83	1.87	14.79	15.48	3.46	3.69	0.43	0.44	88.98	89.24
T_3	**F_1**	1.90	1.93	14.98	15.65	3.57	3.77	0.45	0.47	88.74	89.00
	F_2	1.94	1.98	15.15	15.81	3.66	3.88	0.47	0.49	88.63	88.87
	F_3	1.99	2.03	15.34	16.11	3.76	4.01	0.49	0.50	88.54	88.83
	F_4	2.02	2.07	15.56	16.27	3.89	4.13	0.51	0.52	88.50	88.72
T_4	**F_1**	2.06	2.11	15.78	16.44	4.02	4.24	0.53	0.54	88.44	88.64
	F_2	2.12	2.16	15.86	16.51	4.11	4.32	0.55	0.57	88.22	88.41
	F_3	2.16	2.21	16.04	16.69	4.21	4.45	0.57	0.59	88.14	88.33
	F_4	2.21	2.25	16.14	16.83	4.33	4.56	0.59	0.61	87.96	88.20
LSD at 5%		**0.04**	**0.03**	**0.44**	**0.38**	**0.12**	**0.10**	**0.011**	**0.009**	**0.34**	**0.21**

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 2nd irrigation event); **T_3:** Plants were subjected to 6 irrigation events (skipping the 3rd irrigation event); **T_4:** Plants were subjected to 6 irrigation events (skipping the 4th irrigation event); **F_1**: Water spraying (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 combined application of borax and potassium silicate **(F_4)** consistently yielded the highest Na% (1.24–1.29%), compared to the lowest values observed with water spraying **(F_1)** (1.16–1.21%). Similarly, **F_4** achieved the highest α-amino N% (3.64–3.71%), while **F_1** recorded the lowest (3.27–3.34%). **F_4** also excelled in sucrose content (17.92–18.67%) and total dissolved solids (20.20–21.03%). Furthermore, F4 produced the maximum recoverable sugar yield (4.15–4.42 Mg fed^{-1}), while F1 produced the lowest yield (3.77–3.98 Mg fed^{-1}).

Because vital nutrients and chemicals are applied directly to the foliage, which speeds up the plants' absorption and utilization of them, foliar spray treatments are said to have good effects on the characteristics of sugar beetroot plants. Both separately and in combination, boron and potassium silicate are necessary for specific physiological processes necessary for the growth and development of plants (**Ali *et al*. 2019**). **Abo-Steet *et al*. (2015)** state that potassium silicate improves plant structural integrity, stress tolerance, and nutrient absorption efficiency, while boron plays a role in cell wall development, membrane integrity, and nutrient transport. These supplements are applied by foliar spraying, which enhances root growth, yield, and other features under investigation, while promoting optimal nutrient availability. However, the lack of significant effects on purity.

Interaction effects on the studied traits:

With the highest values for several parameters, including sucrose (%), TDS (%), Na and α-amino N (%), and impurity (%), including sugar loss (%), sugar recovery (%), recoverable sugar yield (Mg fed^{-1}), and sugar loss yield (Mg fed^{-1}), the combined treatment of T1 X F4 consistently outperformed the other combined treatments, according to the data in Tables 2, 3, and 4. The highest Na% (1.50–1.56%) and α-amino N% (4.30–4.40%) were produced by the combination of T1 and F4, highlighting the beneficial benefits of both full irrigation and combined foliar treatments.

T2 × F1 had the lowest sucrose content (15.81–16.44%), whereas T1 × F4 had the highest sucrose content (19.14–19.93%) and purity (87.68–87.76%). The highest recoverable sugar yield (4.65–4.91 Mg fed^{-1}) was also obtained by the same combination treatment (T1 × F4), whereas the lowest yield (3.25–3.44 Mg fed^{-1}) was obtained by T2 × F1. This implies that sugar beetroot performance is improved across a number of parameters when conventional irrigation (T1) and foliar treatment with boron and potassium silicate (F4) are applied together.

In addition, when there was a shortfall in irrigation water, treatments T2, T3, and T4 continuously showed the greatest values for the majority of the attributes assessed. This was especially noticeable when treatment T4 was combined with foliar sprays F3 and F4. Even while a lack of water may negatively affect the development and quality of sugar beets, this suggests that foliar treatments particularly those that contain potassium silicate may help lessen the negative effects of water stress and encourage improved crop performance.

Over the two seasons that were examined, a similar pattern was seen in both the individual and interaction effects. The sugar beetroot plants may have been more resilient to stress and lost less water through transpiration if boron had preserved the structural integrity of their cell walls. However, potassium may have encouraged strong root growth, allowing plants to reach deeper water sources in the soil, while silicon may have created a protective layer on the sugar beetroot leaf surface, minimizing water loss via evaporation. These results confirm the validity and consistency of our findings and are consistent with those reported in studies by **Abbas *et al*. (2018), AbdAllah *et al*. (2021), AlKahtani *et al*. (2021), and El Hamdi *et al*. (2017)**.

Conclusion

This study demonstrates how boron and potassium silicate may be used to lessen the negative effects of water stress on sugar beetroot growth when irrigation is limited. According to the findings, omitting irrigation events may save water without significantly lowering sugar beetroot yield, particularly when paired with foliar potassium silicate and boron treatments.

In comparison to the untreated control, the combined application of potassium silicate and boron produced the most promising results among the treatments, increasing the production and quality of sugar. This suggests that combining fertilizer management with carefully thought-out irrigation schedules may boost water consumption efficiency in sugar beetroot farming. Subsequent investigations must focus on extended field tests to corroborate these results in diverse environments and investigate the possible implementation of comparable therapies in other significant crops dealing with water stress issues.

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