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RESEARCH ARTICLE

Determination of the effects of silicon applications on cauliflower under deficit irrigation conditions

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ABSTRACT

Agricultural production system is more effective with the appropriate use of existing resources. Climate change will have adverse effects on crop production depending on water sources scarcity in the future besides, Si may reduce this effect. The aim of this study is to analyze vegetative growth and yield of cauliflower (*Brassica oleracea* L. var. *botrytis* L.) with different levels of irrigation and Si doses applications. For this purpose, field experiments were conducted during 2022 and 2023 growing seasons in the Mediterranean environmental conditions. Treatments consisted of four Si doses (150, 100, 50 kg ha^{-1} and 0 kg ha^{-1} as control) and four irrigation treatments designed as pan coefficients ($I_{1.00}$: Ep × 1.00; $I_{0.75}$: Ep × 0.75; $I_{0.50}$: Ep × 0.50; $I_{0.25}$: Ep × 0.25). Experimental design was completely randomized with split-plot system with four replicates. For both growing seasons Si_{150}-$I_{1.00}$ interactions produced the highest marketable yields as 4.61 and 4.48 t ha^{-1}, respectively, while the lowest values were found from Si_0-$I_{0.25}$ as 1.12 and 1.41 t ha^{-1} respectively. The highest crown diameter and body length values of 16.19-17.13 and 15.70-15.88 cm were recorded with $I_{1.00}$ treatment across the two growing seasons. As a result of Si application, the efficiency of the cauliflower crop increased as the effects of water deficit decreased. According to research results in both years, water deficit up to 25% stress and 50 and 100 kg ha^{-1} Si doses in cauliflower cultivation improves crop yield-related characteristics.

Key words: *Brassica oleracea* var. *botrytis*, deficit irrigation, plant growth, silicon.

INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis* L.) belongs to the Brassicaceae family and is one of the most important winter vegetables consumed with flower crowns (Sable et al., 2016). Cauliflower is a fiber- and carbohydrate-rich vegetable that significantly contributes to human nutrition. Approximately 25.5 million tons of cauliflower and broccoli were produced worldwide in 2021 (FAO, 2022; Seymen et al., 2024). In Türkiye, one of the world's leading vegetable producers, the decrease in water resources has a great impact on sustainable agriculture due to the increasing global warming and climate change in recent years. Despite the rapid increase in the world population, limited water resources create problems in agricultural production. Due to limited water resources, economic water use technologies and researches need to be developed in agricultural areas. Water availability is one of the factors that directly interferes with the growth and nutrient uptakes by plants and makes an important role in agricultural production (Taiz et al., 2017). Due to the fact that Türkiye is located in the arid and semi-arid climate zone, it cannot meet the plant water needs with natural precipitation.

The main mechanisms that enable Si to alleviate the effects of drought stress include increasing water uptake and transport, regulating stomatal behavior and water loss, as well as accumulation of solutes and osmoregulatory substances. The mechanisms also support root osmotic propulsion, improve root/stem ratios, regulate aquaporins, increase root hydraulic conductivity, increase mineral nutrient uptake, maintain nutrient balance, and trigger plant defenses associated with signaling events. These are collectively known to help plants maintain water balance (Rehman et al., 2021; Thakral et al., 2021; Thorne et al., 2021; Wang et al., 2021). The use of Si in vegetables grown under water deficiency is promising, considering the increase in physical resistance of plant tissue and metabolic production and beneficial effects on plants in unfavorable physical-chemical soil conditions (Souza et al., 2015; Weerahewa and Somapala, 2016; Jadhao and Rout, 2020). The Si source allows alleviating stress condition and improving crop performance, increase yield and post-harvest quality in conditions of water deficiency and N toxicity (Barreto et al., 2017; Lozano et al., 2018; Nunes et al., 2019). Inadequate irrigation in cauliflower cultivation reduces plant growth and yield. Therefore, this study was carried out to examine the effects of the Si applications on growth and yield in cauliflower plant under different irrigation regimes conditions.

MATERIALS AND METHODS

Experimental site

The experiments were carried out in open field conditions in the research areas of Mersin University Silifke Vocational School (36°22' N, 33°55' W; 30 m a.s.l.) Typical Mediterranean climatic conditions are available in the study area. Mean annual rainfall is 560.7 mm, average annual temperature is 19.8 °C. Meteorologic data of study area along growing seasons (2022-2023) is given in Table 1.

Table 1. 2022-2023 monthly mean meteorological data of study area. Tmax: Maximum air temperature; Tmin: minimum air temperature; RH: relative humidity; Tmean: mean air temperature.

Years	Climatic parameters	August	September	October	November	December
2022	Tmax, °C	34.26	32.73	28.87	23.97	19.38
	Tmin, °C	25.26	22.90	20.22	15.13	11.78
	RH, %	61.00	51.00	49.00	53.00	57.00
	Evaporation, mm	172.80	165.90	127.80	59.90	44.90
	Wind speed, m s^{-1}	1.10	1.30	1.50	0.90	1.00
	Rainfall, mm	1.00	1.20	32.00	59.80	29.80
2023	Tmax, °C	35.25	33.54	30.30	23.97	20.24
	Tmin, °C	26.12	24.14	20.24	15.38	11.99
	RH, %	61.00	51.00	50.00	59.00	59.00
	Evaporation, mm	177.40	201.80	122.20	65.60	41.50
	Wind speed, m s^{-1}	1.10	1.50	1.00	0.80	0.70
	Rainfall, mm	6.40	0.02	34.00	124.00	143.00
Long-term (1975-2022)	Tmean, °C	28.90	26.43	22.38	16.61	12.04
	Rainfall, mm	0.98	6.19	37.13	82.48	126.50

Some of soil characteristic properties are given in Table 2. Soil of experimental site has pH range of 7.72-8.14, electrical conductivity 0.75-0.95 dS m^{-1} and volumetric field capacity and wilting point varied between 30.84%-28.61% and 20.16%-13.73%, respectively, also average bulk density values were 1.38-1.59 g cm^{-3} with clay-silty structure.

Table 2. Soil properties of the experimental area. FC: Field capacity; WP: permanent wilting point; BD: bulk density; EC: electrical conductivity; SOC: soil organic C; $CaCO_3$: calcium carbonate.

Soil depth	FC	WP	BD	pH	EC	SOC	$CaCO_3$
cm	%	%	g cm^{-3}		dS m^{-1}	%	%
0-30	30.84	20.16	1.38	7.72	0.75	2.36	39.84
30-60	28.94	19.68	1.56	7.88	0.80	1.03	41.36
60-90	28.61	13.73	1.59	8.14	0.95	0.82	44.21

Experimental design and treatments

Experimental design was completely randomized with split-plot system with four replicates in the study. There were 16 plots in each block with four rows and six plants and the block area was 19.68 m^2 with 5.25 length m and 3.75 m width. Measurements and observations were made on medium-sized plants without edge effects. Planting density of 75 cm between rows and 75 cm plant spacing was applied. The experimental treatments consist of three Si doses 50, 100, 150 kg ha^{-1} also 0 kg ha^{-1} as control and four irrigation coefficients designated as plant pan coefficients $I_{1.00}$: Class A pan evaporation (Ep) × 1.00; $I_{0.75}$: Ep × 0.75; $I_{0.50}$: Ep × 0.50 and $I_{0.25}$: Ep × 0.25. Irrigations were made when the amount of cumulative water evaporated from the Class A evaporation pan was equal to 25 ± 3 mm also water height in the evaporation pan was measured daily. The evaporation vessel used in the experiment was made of steel material with a round diameter of 120 cm and 25 cm depth. The vessel was placed on a wooden platform 20 cm above the soil level. The height of the water in the Class A evaporation vessel was measured with a tape measure at the same time every day. Irrigations were applied at 2-3 d frequency throughout the growing season based on accumulative evaporation from Class A pan located in the experimental area.

Irrigation system

Drip irrigation systems were used in the study. Polyethylene (PE) laterals with diameter of 20 mm with in-line emitters spaced 0.50 m apart and flow rate of 2.3 L h^{-1} at 200 kPa operating pressure in the drip irrigation plots. Irrigation water used in the research was taken from Silifke DSI irrigation canal to a 1 t water tank by pump. The quality of the irrigation water used is in the C_2S_1 class (USSL, 1954).

Agronomic practices

'Mervan f1' cauliflower (*Brassica oleracea* L. var. *botrytis* L.) was used as plant material in the study. The saplings grown in accordance with the seed planting method were planted in vials in a material medium consisting of a mixture of peat and perlite prepared in a ratio of 2:1. Seedlings were transplanted into the plots on 15 July 2022 and 15 July 2023. According to the soil analysis results, recommended fertilizer amounts were 200 kg ha^{-1} N, 150 kg ha^{-1} P and 240 kg ha^{-1} K and the applied NPK sources were ammonium sulfate, triple super phosphate and potassium nitrate forms.

Measurements and observations

The amount of irrigation water applied to the experimental plots at each irrigation was determined with the following equation (Doorenbos and Pruitt, 1977):

$$I = A \times Epan \times Kpc \times Pwet \quad (1)$$

where I is the volume of irrigation water (L), A is plot area (m^2); Epan is the cumulative evaporation amount from the Class A pan (mm), Kpc is plant pan coefficients (k coefficients given as sub-treatments in the experiment); Pwet is wetted area fraction (1.0).

The measurements made after each rainfall were recorded in the relevant tables and taken into account in the calculation of the irrigation water amount. The measured 4 d total evaporation amount was applied as irrigation water. The total amount of precipitations in the mentioned period of experiment years (2022-2023) were measured as 123.8 and 307.42 mm respectively. During the growing season of cauliflower 2022-2023, a total of 634 mm evaporation was measured from the Class A evaporation vessel. The amount of precipitation was measured using a pluviometer.

Statistical analysis

Data collected were subjected to ANOVA using the JMP Statistical software developed by SAS (SAS Institute, Cary, North Carolina, USA). Student's t test was carried out to compare control treatment with best performing drip treatments. Least square deviation (LSD) test was used to compare the treatment means.

RESULTS AND DISCUSSION

In the first year of the study (2022), the interactions of Si doses, irrigation coefficients and Si doses × irrigation coefficients on cauliflower crown lengths were found significant ($P < 0.01$). The highest plant crown lengths were obtained from the interaction of Si_{150}-$I_{1.00}$ treatments as 16.66-16.99 cm respectively in both years and the lowest plant crown lengths were Si_{0}-$I_{0.25}$ (11.29 cm) and Si_{0}-$I_{0.50}$ (11.84 cm) in 2022-2023 experimental years respectively. On the basis of the experimental years (2022-2023), Si_{150}-$I_{1.00}$ interactions increased by 50.4% compared to only Si applications (Tables 3 and 4). Silicon doses and irrigation coefficients on cauliflower crown diameters were significant ($P < 0.01$). It produced the highest plant crown diameters of 16.17 and 15.94 mm respectively from Si_{150} and $I_{1.00}$ doses in the 2022 experimental year.

Table 3. Statistical analysis result on effects of Si application on plant growth and yield at different irrigation levels in 2022. Values followed by different small letters indicate significant differences at $^{**}P < 0.01$; $^{*}P < 0.05$; ^{ns}nonsignificant.

Treatments	Treatments and statistical analyses	Crown length	Crown diameter	Body diameter	Body length	Crown weight	Marketable yield	Leaf length	Leaf diameter
		cm	mm	mm	cm	kg	t ha^{-1}	cm	cm
Si doses (SD)	Si_{150}	15.546	16.165a	35.851	15.579^{a}	2.539^{a}	3.669^{a}	52.73^{a}	22.378
	Si_{100}	15.416	15.941^{a}	35.928	15.283^{a}	1.983^{b}	3.607^{a}	50.93^{a}	22.133
	Si_{50}	14.435	15.112^{b}	35.833	14.413^{b}	1.708^{c}	2.724^{b}	50.74^{a}	21.858
	Si_{0}	14.210	14.780^{b}	35.561	13.815^{c}	1.165^{d}	2.116^{c}	49.31^{b}	21.269
	LSD (0.05)	-	0.690	-	0.470	0.107	0.107	0.894	-
	P (probability)	^{ns}	0.0040^{**}	^{ns}	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0224^{*}	^{ns}
Irrigation coefficients (IC)	$I_{1.00}$	16.189^{a}	16.8294^{a}	36.775^{a}	15.7006^{a}	2.417^{a}	3.698^{a}	51.99^{a}	23.13^{a}
	$I_{0.75}$	15.696^{a}	16.1744^{b}	36.175^{b}	15.198^{ab}	2.187^{b}	3.519^{b}	51.39^{a}	22.54^{b}
	$I_{0.50}$	15.030^{b}	15.1931^{c}	35.601^{c}	14.829^{b}	1.775^{c}	2.881^{c}	50.33^{b}	21.65^{c}
	$I_{0.25}$	12.792^{c}	13.8025^{d}	34.621^{d}	13.365^{c}	1.015^{d}	2.017^{d}	49.09^{c}	20.92^{d}
	LSD (0.05)	0.587	0.553	0.353	0.513	0.071	0.071	0.683	0.514
	P (probability)	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}
SD×IC	Si_{150}-$I_{1.00}$	16.662^{a}	17.270	37.295	16.460	2.717^{a}	4.611^{a}	52.692	23.535
	Si_{150}-$I_{0.75}$	16.637^{a}	17.082	36.880	16.220	2.618^{ab}	4.499^{a}	52.180	23.132
	Si_{150}-$I_{0.50}$	16.447^{ab}	17.030	36.610	16.090	2.576^{ab}	4.308^{b}	52.012	22.965
	Si_{150}-$I_{0.25}$	16.175^{ab}	16.590	36.442	15.827	2.551^{b}	4.153^{c}	52.012	22.875
	Si_{100}-$I_{1.00}$	16.097^{abc}	16.537	36.317	15.787	2.183^{c}	3.524^{d}	51.462	22.775
	Si_{100}-$I_{0.75}$	15.387^{bcd}	16.427	36.267	15.770	2.166^{c}	3.242^{e}	51.280	22.765
	Si_{100}-$I_{0.50}$	15.382^{bcd}	15.920	36.230	15.465	2.149^{c}	3.130^{ef}	51.175	22.557
	Si_{100}-$I_{0.25}$	15.360^{bcd}	15.902	35.825	14.740	1.960^{d}	3.023^{f}	51.050	22.075
	Si_{50}-$I_{1.00}$	15.282^{bcde}	15.452	35.762	14.465	1.727^{e}	2.743^{g}	50.760	21.952
	Si_{50}-$I_{0.75}$	14.990^{cdef}	15.157	35.632	14.410	1.671^{ef}	2.565^{h}	50.307	21.857
	Si_{50}-$I_{0.50}$	14.882^{def}	14.877	35.482	14.172	1.663^{ef}	2.444^{hi}	50.277	21.495
	Si_{50}-$I_{0.25}$	14.362^{def}	14.645	35.465	14.002	1.536^{f}	2.404^{i}	49.927	21.277
	Si_{0}-$I_{1.00}$	14.115^{ef}	14.540	34.740	13.670	1.097^{g}	2.323^{ij}	49.675	21.262
	Si_{0}-$I_{0.75}$	13.915^{f}	14.452	34.685	13.447	1.034^{gh}	2.195^{jk}	49.487	21.032
	Si_{0}-$I_{0.50}$	11.845^{g}	13.115	34.535	13.122	1.017^{gh}	2.178^{k}	49.407	20.987
	Si_{0}-$I_{0.25}$	11.295^{g}	12.997	34.527	12.717	0.911^{h}	1.124^{l}	47.535	20.415
	LSD (0.05)	1.174	-	-	-	0.153	0.142	-	-
	P (probability)	0.0332^{*}	^{ns}	^{ns}	^{ns}	0.0001^{**}	0.0001^{**}	^{ns}	^{ns}

Table 4. Statistical analysis result on effects of Si application on plant growth and yield at different irrigation levels in 2023. Values followed by different small letters indicate significant differences at $^{**}P < 0.01$; ^{ns}nonsignificant.

Treatments	Treatments and statistical analyses	Crown length	Crown diameter	Body diameter	Body length	Crown weight	Marketable yield	Leaf length	Leaf diameter
		cm	mm	mm	cm	kg	t ha^{-1}	cm	cm
Silicon doses (SD)	Si$_{150}$	15.702^{a}	16.008a	35.642	15.131a	2.718	3.610a	51.245	21.954
	Si$_{100}$	15.316^{b}	15.899^{a}	35.467	15.067^{a}	2.295	2.764^{b}	51.506	21.863
	Si$_{50}$	14.385^{c}	15.423^{b}	35.570	14.318^{b}	2.260	3.657^{a}	51.193	21.695
	Si$_{0}$	14.381^{c}	15.051^{b}	35.497	13.466^{c}	1.870	2.228^{c}	50.182	21.636
	LSD (0.05)	0.368	0.394	-	0.292	-	0.197	-	-
	P (probability)	0.0001^{**}	0.0013^{**}	^{ns}	0.0001^{**}	^{ns}	0.0001^{**}	^{ns}	^{ns}
Irrigation coefficients (IC)	I$_{1.00}$	16.551^{a}	17.132^{a}	36.538^{a}	15.883^{a}	2.570	3.646^{a}	52.176^{a}	23.248^{a}
	I$_{0.75}$	15.596^{b}	16.320^{b}	35.993^{b}	15.119^{b}	2.461	3.534^{a}	51.350^{ab}	22.525^{b}
	I$_{0.50}$	14.843^{c}	15.074^{c}	35.083^{c}	14.294^{c}	3.092	2.946^{b}	50.404^{bc}	21.521^{c}
	I$_{0.25}$	12.794d	13.855d	34.563d	12.686d	1.020	2.133c	50.196c	20.383d
	LSD (0.05)	0.373	0.491	0.404	0.395	-	0.131	1.123	0.507
	P (probability)	0.0001^{**}	0.0001^{**}	0.0001^{**}	0.0001^{**}	^{ns}	0.0001^{**}	0.0034^{**}	0.0001^{**}
SD×IC	Si$_{150}$-I$_{1.00}$	16.990^{a}	17.717	36.692	16.665	5.795	4.483^{a}	52.412	23.470
	Si$_{150}$-I$_{0.75}$	16.937^{a}	17.082	36.582	16.457	2.855	4.319^{ab}	52.320	23.235
	Si$_{150}$-I$_{0.50}$	16.440^{ab}	16.937	36.537	16.177	2.815	4.293^{ab}	52.300	23.165
	Si$_{150}$-I$_{0.25}$	16.320^{abc}	16.792	36.340	15.952	2.747	4.207^{b}	52.267	23.122
	Si$_{100}$-I$_{1.00}$	15.957^{bcd}	16.792	36.202	15.647	2.722	3.563^{c}	51.990	22.852
	Si$_{100}$-I$_{0.75}$	15.672^{cde}	16.417	36.107	14.925	2.500	3.209^{d}	51.675	22.705
	Si$_{100}$-I$_{0.50}$	15.262^{de}	16.177	36.002	14.820	2.455	3.180^{d}	51.480	22.502
	Si$_{100}$-I$_{0.25}$	15.225^{de}	15.895	35.662	14.740	2.415	3.010^{de}	51.150	22.040
	Si$_{50}$-I$_{1.00}$	15.047^{e}	15.720	35.342	14.232	2.292	2.773^{ef}	51.027	21.787
	Si$_{50}$-I$_{0.75}$	15.010^{e}	15.255	35.122	14.137	2.157	2.743^{f}	50.782	21.627
	Si$_{50}$-I$_{0.50}$	14.947^{e}	15.070	34.982	13.967	2.082	2.540^{fg}	50.625	21.455
	Si$_{50}$-I$_{0.25}$	14.152^{f}	14.437	34.885	13.600	1.660	2.458^{gh}	50.565	21.215
	Si$_{0}$-I$_{1.00}$	14.117^{f}	14.252	34.745	13.465	1.090	2.457^{gh}	50.350	20.725
	Si$_{0}$-I$_{0.75}$	13.645^{f}	14.207	34.597	12.727	1.077	2.271^{hi}	49.675	20.707
	Si$_{0}$-I$_{0.50}$	12.020^{g}	13.510	34.487	12.387	1.072	2.122^{i}	49.665	20.405
	Si$_{0}$-I$_{0.25}$	11.395^{g}	13.267	34.422	12.032	0.840	1.412^{j}	48.230	19.697
	LSD (0.05)	0.745	-	-	-	-	0.279	-	-
	P (probability)	0.0022^{**}	^{ns}	^{ns}	^{ns}	^{ns}	0.0001^{**}	^{ns}	^{ns}

In the second year of the study (2023), Si$_{100}$ and Si$_{150}$ applications gave the highest plant crown diameter of 15.89 and 16.00 mm respectively. The highest plant diameter obtained in irrigation applications was 17.71 mm in the treatment with a coefficient of I$_{1.00}$ and it increased by 3.5% compared to the lowest plant crown diameter, Si$_{0}$-I$_{0.25}$ (13.26 cm) treatment.

In both experiment years, only irrigation coefficients related to plant stem diameter were found to be significant ($P < 0.01$). The highest plant stem diameter values were found to be 36.78 and 36.54 mm from the I$_{1.00}$ treatment respectively with an increase of 5.8% compared to the lowest value Si$_{0}$-I$_{0.25}$ (34.53 mm) treatment. Silicon doses and irrigation coefficients on stem length of cauliflower were found significant in both experimental years ($P < 0.01$). In 2022, the highest body length was obtained with Si$_{150}$ dose and I$_{1.00}$ treatments with 15.58 and 15.70 cm respectively. The similar situation was 15.13 and 15.88 cm respectively in 2023 and it increased by 24.9% compared to the lowest value Si$_{0}$-I$_{0.25}$ (12.72 mm) treatment. The interactions of Si doses, irrigation coefficients and Si doses × Irrigation coefficients on cauliflower crown weight were significant ($P < 0.01$) only in the first year of the study (2022). The highest plant crown weight (2.71 kg) was obtained with Si_{150}-$I_{1.00}$ application and the lowest (0.91 kg) in Si_0-$I_{0.25}$ applications and increased by 216%. The interactions of Si doses, irrigation coefficients and Si doses × Irrigation coefficients on the marketable yield of cauliflower were significant in both experimental years ($P < 0.01$). In both experiment years, the highest marketable yield was obtained in Si_{150}-$I_{1.00}$ application with 4.61 and 4.48 t ha^{-1} respectively. In both experiment years, the lowest marketable yields were 1.12 and 1.41 t ha^{-1} from Si_0-$I_{0.25}$ respectively with an increase of 310%. Silicon doses and irrigation coefficients on cauliflower leaf length were significant ($P < 0.05$) in the first experiment year. The effect of treatments on the leaf length of cauliflower in 2022-2023 the highest values were obtained from Si_{150}-$I_{1.00}$ (52.69 cm) and Si_{150}-$I_{1.00}$ (52.41 cm) treatments and the lowest values were 47.53 cm and 48.23, respectively, for Si_0-$I_{0.25}$.

In many studies, it was reported that plant growth parameters were positively affected by Si applications. Olle and Schnug (2016) and Zhu and Gong (2014) determined that the most important effects of Si are steeper growth, hard and durable plant head structure in lettuce. Chang et al. (2024) reported that Si application has positive effects on growth and physiological parameters on rice. Lettuce yield and average fruit weight show parallelism especially with increasing water content. The Si may contribute to increased water homeostasis to protect plants against drought stress as a result of greater accumulation of the element in lettuce leaves and may be the main factor in maintaining biomass in water-deficient lettuce plants. As a matter of fact, this positive effect of Si on the water balance has been observed in other studies and a better hydraulic conductivity has been observed (Cao et al., 2017; Chen et al., 2018; Rafi et al., 2020). In investigations in which Si was applied to the soil conducted in north-eastern China in the years 2005-2006, cucumber yields grew by 9.35%-26.60% (on average by 13.7%) in comparison with the control treatment (Liang et al., 2015).

According to Wang et al. (2024), Si treatments on tomato fruit quality under typical growth conditions improved the nutritional value and mature green, breaker, and red ripening stages of tomato fruit appearance. Also, it was determined that addition of Si improved the nutritional quality of tomato by significantly increasing soluble sugars, soluble solids, soluble proteins, and vitamin C contents, promoting the accumulation of carotenoids (lycopene and lutein), and increasing the total amino acid content of tomato fruits. Wenneck et al. (2023) analyzed water use efficiency in cauliflower cultivation under a protected environment with varying levels of water and Si supply. Their study found that the application of Si positively impacted water productivity, drought tolerance, and the water mass conversion rate. Notably, even under a 30% water deficit, the results were comparable to or better than those of the control group, suggesting that Si plays a significant role in enhancing the resilience of cauliflower plants to water stress conditions.

CONCLUSIONS

As a result of the applications of Si doses (100 and 150 kg ha^{-1}), the effect on yield and yield components in cauliflower at 75% and 100% (full irrigation) irrigation treatments were at the same level of importance. It was found nonsignificant effect of Si doses on 25% irrigation level. According to the results of the study, it is thought that the recommendation of 50 and 100 kg ha^{-1} Si at low irrigation levels in cauliflower will be beneficial in terms of improving yield in water-limited agriculture. Silicone application in cauliflower cultivation can be considered as an economical water management strategy to protect limited water resources in semi-arid regions.

Author contribution

Conceptualization: Ç.Y., B.A., K.N. Developing methodology: Ç.Y., B.A., K.N. Collecting data: Ç.Y. Statistical analyses: B.A. Visualization: K.N. Writing-review & editing: Ç.Y., B.A., K.N. Writing-original draft: Ç.Y., B.A., K.N. Supervision: Ç.Y. All authors reviewed and commented on the final version and approved the manuscript before submission.

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