ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol. Hortorum Cultus, 22(4) 2023, 3–12
https://czasopisma.up.lublin.pl/index.php/asphc ISSN 1644-0692 e-ISSN 2545-1405 https://doi.org/10.24326/asphc.2023.5004

ORIGINAL PAPER

Accepted: 8.12.2022
First published online: 27.07.2023
Issue published: 31.08.2023

EFFECTS OF DIFFERENT IRRIGATION LEVELS AND VARYING DOSES OF SILICON APPLICATIONS ON YIELD AND SOME PHYSIOLOGICAL PARAMETERS IN LETTUCE CULTIVATION

Yusuf Çelik ✉

Silifke Vocational School, Department of Plant and Animal Production, Mersin University, 33940 Silifke Mersin, Turkey

ABSTRACT

The study was repeated for two years to reduce the effects of water scarcity and drought stress in lettuce cultivation. The irrigation problem was created by applying 25% (I_{25}), 50% (I_{50}), 75% (I_{75}) and 100% (I_{100}) of the evaporation amounts formed in the class-A evaporation vessel. Si_0 (0 kg ha^{-1}), Si_{40} (40 kg ha^{-1}), Si_{80} (80 kg ha^{-1}) and Si_{120} (120 kg ha^{-1}) silicon fertilisation was applied at four different doses. Head length, head diameter, head weight, root length, and leaf fresh and dry weight were measured in harvested plants. According to the data of 2020–2021, the best results in the effect of different doses of Si applications on plant head height, head diameter, head weight and root length at different irrigation levels were recorded from $I_{75} \times Si_{80}$, $I_{75} \times Si_{120}$, $I_{100} \times Si_{80}$, $I_{100} \times Si_{120}$ applications with the same severity level. While the Si_{40} dose gave good results at I_{75} and I_{100} irrigation levels, its effect decreased at I_{25} and I_{50} irrigation levels. At different irrigation levels where different doses of silicon were applied, I_{25} irrigation had the lowest leaf chlorophyll and relative moisture content and the most severe membrane damage, while I_{50} irrigation had a moderate effect. Leaf chlorophyll and moisture content increased, and membrane damage decreased in $I_{75} \times$ 80 kg ha^{-1} Si, $I_{75} \times$ 120 kg ha^{-1} Si, $I_{100} \times$ 80 kg ha^{-1} Si and $I_{100} \times$ 120 kg ha^{-1} Si applications. As a result, when the effects of the applications covering two years on plant growth and yield were evaluated, the most successful irrigation levels were determined as I_{75}, I_{100}, and the most successful silicon doses; were determined as 80 kg ha^{-1} and 120 kg ha^{-1}.

Key words: lettuce, silicon doses, irrigation amounts, yield

INTRODUCTION

Due to dense population and urbanisation, the need for water, a limited resource, of rapidly developing agricultural systems is increasing daily. In this case, it is necessary to use water effectively and economically. In addition, due to the increasing global warming problem and possible climate changes, it is thought that the economic use of water will be a much more critical issue in the coming years. However, increasing food demand is shifting agricultural production to more marginal areas with scarce water resources. Limited water applications become very important economically in places where water is scarce. One of the main abiotic factors threatening agricultural productivity is the gradual widening of the water deficit in different world areas. Therefore, water stress is one of the most important factors limiting plant growth and development [Pour-Aboughadareh et al. 2019]. Today, scientific studies are generally possible by applying and removing valuable water from the soil in different ratios and determining the response of plants un-

✉ ycelik3334@gmail.com

der limited irrigation regimes. One of the main abiotic factors threatening agricultural production is the gradual widening of water deficits in different parts of the world. Therefore, water stress is one of the most important factors limiting plant growth and development [Pour-Aboughadareh et al. 2019]. Plants are subject to water stress when there is a restriction in the water supply to the roots or when the transpiration rate is too high, so the most frequent drought events are in arid or semi-arid regions [Nemeskéri and Helyes 2019]. The intensity and duration of droughts are expected to increase with climate change due to higher global temperatures [Kørup et al. 2018]. Water deficit negatively affects plant growth and production and changes morphological, biochemical and molecular properties [Balestrini et al. 2018]. Due to climate change, the weather is getting hotter and drier every day, and the weather has a stress effect on plants. In this case, interest in plant species resistant to environmental stress increases daily [Pradhan et al. 2015]. Abiotic stress conditions cause significant yield losses, especially in agriculture. Among the abiotic stress factors, salinity and drought stress cause the most yield loss [Singh et al. 2008]. The use of silicon (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 unfavourable physical-chemical soil conditions [Souza et al. 2015, Weerahewa and Somapala 2016, Jadhao et al. 2020]. Si source alleviates stress conditions and improves crop performance, increasing yield and post-harvest quality in water deficiency conditions and N toxicity [Barreto et al. 2017, Lozano et al. 2018, Nunes et al. 2019]. Inadequate irrigation in lettuce cultivation reduces plant growth and yield. This study, repeated over two years in field conditions, evaluated the effects on lettuce growth, physiology and water stress tolerance grown under different irrigation levels and varying silicon (Si) doses.

MATERIALS AND METHOD

Materials

Plant material used in the study. Lital lettuce variety was used. It is included in the group of navel salads. The plant shape is crunchy and upright. The leaves are long, light green, delicate, crisp, broad and oval. It has a very dense and upright belly structure. The umbilical cord is perfect. The belly part is yellow. It is a medium early variety resistant to cold and heat. It can be easily grown in all regions of our country. It is a long day vegetable. It requires more than 10–15 h of light during the day. It is a cool climate plant and is partially resistant to cold, and needs moist air. Since it likes a moist environment, vegetative development is shortened in hot and arid regions, and the plant goes to seed. In addition, lettuces become karts. Growing it in summer on cool plateaus (1000–1500 m altitude) is possible. Lettuces are very resistant to frost when they have 6–10 leaves. It is slightly resistant when approaching maturity. In severe frosts, the plant is damaged [https://www.tarimtedarik.com/lital--marul-25gr].

Soil properties of the trial area. Soil characteristics of the field where the study was carried out. The soil pH was 6.97, salinity 0.10%, lime 1.7%, organic matter 2.1%, and soil texture sandy/loamy (Tab. 1).

Fertiliser materials used in the research. The study used $(NH_4)_2SO_4$ as nitrogen fertiliser, P_2O_5 as phosphorus source fertiliser, and K_2SO_4 as potassium fertiliser source. Silica applications were carried out at doses of 0, 40, 80 and 120 kg ha^{-1} using a commercial product, AgriSilTM (98% of SiO_2), in the form of a wettable powder.

Method. This study was conducted in open field conditions in Mersin University Silifke Vocational High School application and research lands to be applied in two fall semesters between 2020–2021. Soil analysis was carried out at Alata Horticultural Research Institute. According to soil analysis results, the recommended amount of fertiliser in the study was determined as 20 kg ha^{-1} N, 15 kg ha^{-1} P and 24 kg ha^{-1} K. Irrigation was applied according to 4 irrigation levels at 4-day intervals. It was formed by giving 25% (I_{25}), 50% (I_{50}), 75% (I_{75}), and 100% (I_{100} control application) of the water vapour formed in the A-class evaporation vessel. Irrigations were made when the amount of water evaporating from the class-A evaporation pan was equal to or greater than 25 mm. Irrigation was done with controlled drip irrigation. The local lettuce variety was used in the study. The seedlings grown per the procedure were planted in 3–5 leaves, approximately 10–12 cm in length, and the experiment was terminated after approximately 70 days. In the

Table 1. Some climate data of the Silifke Centre (2020–2021)

Specification	Month												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average
Max. temp. (°C)	24.6	26.3	30.3	35.0	28.3	41.3	42.4	42.4	40.0	37.0	31.9	28.5	34.8
Min. temp. (°C)	–1.4	–1.9	–0.3	2.8	9.4	13.0	18.0	18.0	12.8	7.8	1.8	0.7	6.4
Avg. temp. (°C)	10.2	10.9	13.7	17.3	21.4	25.4	28.1	28.1	25.6	21.5	15.5	11.6	19.1
Avg. Moisture (%)	56.8	57.5	63.1	63.1	64.6	64.5	64.6	64.6	58.5	54.6	55.1	57.3	60.2
Avg. rain (mm)	106.6	81.0	31.3	31.3	24.5	8.1	2.2	0.9	5.2	36.7	84.6	120.1	534.26*

* Annual total

study, which was arranged in a four-replication plan according to the random blocks trial design, the planting frequency was 25 cm in rows and 30 cm between rows in the experiment, in which a total of 5 × 10 × 10 × 4 = 2000 plants were planted in 5 applications and 10 plants in each row in each application.

Data analysis. Statistical analysis; the data obtained in the study, organised in four replication plans according to the randomised blocks trial design, were evaluated according to the analysis of variance (ANOVA) test using the demo version of the "IBM SPSS Statistics 28" statistical program. Duncan's ($p = 0.05$) multiple comparison tests were used to compare the differences between the means.

Class-A evaporation pan (class-A pan) and precipitation measurements. The class-A evaporation pan (class-A pan) was placed on a 10 cm high grid in the trial area. The water height in the class-A evaporation vessel was measured with tape at 09:00 every day. The daily pan evaporation was calculated by taking the difference from each other. During the 2021–2022 lettuce growing season, the total amount of evaporation from the class-A evaporation pan was measured. The amount of precipitation was measured using a pluviometer (rain gauge). The measurements after each precipitation were recorded in the relevant tables and accounted for in the irrigation water amount calculation. The measured four-day total evaporation amount was applied as irrigation water. The total amount of precipitation in the said period was measured in mm.

Irrigation system. The dripper spacing is 50 cm, and the dripper flow rate is 2.3 L h^{-1}. Soil moisture observations were made in the first layer of the soil profile (0–20 cm) by gravimetric method and between 20–60 cm by a neutron-meter method in 20 cm increments and continued until the harvest period.

Calculation of the amount of irrigation water to be applied. The amount of irrigation water was calculated according to the method given by Gençoğlan et al. [2006] using open-water surface evaporation and plant-pan coefficients. These measured values were used to calculate the amount of irrigation water. The amount of water to be given to the irrigation plots was calculated with the help of the equation given below.

$$IR = Ep * P * kcp \text{ (mm)}$$

$$V = A * IR$$

where: IR – irrigation water amount (mm), Ep – pan evaporation (mm), P – cover ratio, kcp – plant pan coefficient (selected as 0.40, 0.60, 0.80 and 1.00), V – water volume (L), A – plot area (m^2). Calculated irrigation water amounts were applied to irrigation subjects by passing water hours.

Determination of plant water consumption (evapotranspiration). The water balance equation given by Gençoğlan et al. [2006] was used:

$$ET = I + P - DP - RO + CR \pm \Delta SF \pm \Delta SW$$

where: ET – crop water consumption (mm), I – irrigation amount (mm), P – precipitation (mm), RO – runoff, DP – deep percolation (mm), CR – capillary rise (mm), ΔSF – change in groundwater flow (mm), ΔSW – change in soil water content (mm).

Surface flow losses ($I = mm/h > q = L/h$) are neglected because the deep infiltration losses are controlled in the equation, and the dripper flow rate (q) is chosen to be lower than the infiltration rate (i) of the soil.

Irrigation water and water usage efficiency. The irrigation water (IWUE, kg/mm) and water usage efficiency (WUE, kg/mm) values were calculated according to the irrigation water applied to the trial subjects, the measured plant water consumption and the lettuce yields obtained with the help of the following equations [Zhang et al. 2004].

$$WUE = Ey / ET$$

$$IWUE = Ey / IR$$

where: Ey – lettuce yield (kg/da), IR – irrigation water amount (mm), ET – evapotranspiration (mm).

The relationship between proportional yield decrease (1 – Ya / Ym) and proportional plant water consumption (1 – ETa / ETm)

The yield response factor (ky) is crucial for irrigation planning and indicates water deficiency during the growing season. The fact that this value is less than 1 indicates that the plant is more resistant to water deficiency in the soil, and the decrease in unit lettuce yield is smaller than the applied unit water decrease. Regression analyses were performed to determine the first-order relationship between the applied irrigation water and plant water consumption (evapotranspiration) and yield. Doorenbos [1979], yield response factor (ky), which determines the relationship between the proportional water consumption gap and the proportional yield decrease, was found from the equation below.

$$(Ya / Ym) = Ky\ (1 - (Eta / ETm)$$

where: actual yield (kg/ha), Ym – maximum yield (kg/ha), ETa – actual plant water consumption (mm), ETm – maximum plant water consumption (mm), ky – the plant yield response factor.

Physiological parameters examined in the study

Cell membrane stability. The stability of cell membranes was determined by performing the electrolyte loss test [Soloklui et al. 2012]. For this purpose, 0.3 g of fresh plant material was weighed, cut into pieces, washed lightly with deionised water, placed in a test tube, added 30 mL of deionised water, and vortexed for 1 min. The initial conductivity (EC1) was measured using a conductivity meter (Cond 8; XS Instruments,

Table 2. Soil properties of trial areas

Parameters	Values
pH	6.97
Lime (%)	34,4
Salt (%)	0,42
Clay (%)	11.3
Sand (%)	43
Organic matter (%)	2,1
Total N (%)	1.2
P (mg kg^{-1})	2.02
K (mg kg^{-1})	397.2
Ca (mg kg^{-1})	3945
Mg (mg kg^{-1})	381
Fe (mg kg^{-1})	3.84
Mn (mg kg^{-1})	3.13
Zn (mg kg^{-1})	3.93
Cu (mg kg^{-1})	1.76

Italy). The tubes were then kept in a water bath at 100°C for 20 min to extract the released electrolytes and cool to room temperature. Subsequently, the final conductivity (EC2) was measured. The percentage of electrolyte loss was calculated using the following formula:

$$(EC1 / EC2) \times 100.$$

Relative Water Content (%). The fresh weights (YA) (g) of the leaf samples from 4 sample plants selected from each replication and each plot were determined and placed in Petri dishes with lids. Then, the leaves were kept in distilled water for 4 hours to become turgorized, and after 4 h, the turgor weights (TA) were measured (g). Then, they were kept in an oven at 80°C for 48 h, and their dry weights (KA) were measured (g).

Chlorophyll amount (SPAD). Relative chlorophyll content was measured with a SPAD instrument (SPAD-502 Chlorophyll Meter; Konica Minolta, Tokyo, Japan) in the middle parts of the 5 plants representing the average from each replication and each plot, without coming into the midrib of the upper leaf.

Fresh and dry weight. Four leaves, consisting of 4 and 5 leaves, were taken from the inside of the 4 heads of lettuce that did not have an edge effect from the application plots, and their fresh weights were measured, then these leaves were kept in the open air in the laboratory for 2 days and then kept in an oven at 65°C for 48 h and their dry weights were weighed.

RESULTS AND DISCUSSION

At the end of the study, the effects of different irrigation levels and varying Si doses applied according to the measurement made on the selected samples were found to be significant on vegetative growth parameters (Tab. 3). Si_{40}, $Si_{80,}$ and Si_{120} applications increased in the effect of silicon doses on lettuce head length, head diameter, and leaf fresh and dry weight at the I_{25} irrigation level of lettuce cultivation in the fall period of 2020–2021 compared to Si_0 application but all applications were at the same level of importance. While Si_0 (0.7 kg – 0.9 kg) was the most negligible

Table 3. The effects of different silicon and irrigation levels on yield parameters (2020)

Irrigation level	Silicon (kg ha^{-1})	Head length (cm)	Head diameter (cm)	Head weight (kg)	Root length (cm)	Leaf fresh weight (g)	Leaf dry weight (g)
I_{25}	0	28.9 ±1a	29.5 ±0.9b	0.7 ±0.1c	6.7 ±0.4b	119.6 ±6.2b	8.9 ±0.7b
	40	29.7 ±0.3a	30.1 ±0.5a	0.9 ±0.1b	10.3 ±0.3a	120.3 ±2.5a	10.4 ±0.2a
	80	30.6 ±0.5a	31.4 ±0.4a	1.1 ±0.1a	8.8 ±0.5ab	123.2 ±4.1a	10.5 ±0.4a
	120	31.8 ±0.6a	32.2 ±0.6ab	1.1 ±0.1a	7 ±1.9b	125.6 ±3.1a	10.6 ±0.4a
I_{50}	0	30.1 ±0.7b	30.2 ±0.3b	1.2 ±0.1b	6 ±0.3b	120.6 ±3.2a	9.9 ±0.5a
	40	31.7 ±0.8ab	32.4 ±0.5a	1.3 ±0.1a	9.4 ±0.5a	130.4 ±6.4a	10.5 ±0.5a
	80	31.3 ±0.5ab	32.6 ±0.3a	1.4 ±0.1a	9.6 ±0.4a	128.7 ±3.5a	10.4 ±0.4a
	120	32.8 ±0.6a	32.8 ±0.4a	1.4 ±0a	9.4 ±0.5a	131.4 ±1.9a	10.6 ±0.5a
I_{75}	0	32.7 ±0.7b	33.3 ±0.4b	1.4 ±0b	6.1 ±0.2c	119.3 ±3.9a	9.8 ±0.4b
	40	33 ±0,2a	34 ±0.2a	1.5 ±0.1a	10.4 ±0.5a	138.5 ±6.5a	11.9 ±0.6a
	80	33.3 ±0.6a	34.4 ±0.5a	1.6 ±0.1a	9.6 ±0.5a	133.9 ±9.3a	11.6 ±0.6a
	120	33.1 ±0.4a	34.6 ±0.7a	1.5 ±0.1ab	9.8 ±0.5a	135.1 ±6.9a	11.8 ±0.6a
I_{100}	0	33 ±0.8ab	33.1 ±0.5b	1.4 ±0.1a	7.2 ±0.4b	120.5 ±1.9a	9.7 ±0.4b
	40	33.2 ±1.1ab	34.8 ±0.4ab	1.5 ±0.1a	10.6 ±1.1a	135 ±10.3a	11.4 ±0.5a
	80	33.4 ±0.8a	35.2 ±0.7a	1.6 ±0.1a	9.7 ±0.6a	134.4 ±9.2a	11.2 ±0.4a
	120	33.3 ±0.7ab	35.1 ±0.3a	1.6 ±0.1a	10.7 ±0.9a	136.7 ±8a	11 ±0.6a

The averages containing the same letter are not statistically different according to Duncan's test (p = 0.05)

Table 4. The effects of different silicon fertilisation and irrigation level on yield parameters (2021)

Irrigation level	Silicon (kg ha^{-1})	Head length (cm)	Head Diameter (cm)	Head Weight (kg)	Root Length (cm)	Leaf fresh weight (g)	Leaf dry weight (g)
I_{25}	0	29.4 ±0.7b	28.5 ±0.3c	0.9 ±0d	9.6 ±0,4ab	111.3 ±6.2b	8.9 ±0.7b
	40	30.2 ±0.2a	30.7 ±0.5a	1.2 ±0.1c	10.3 ±0.3a	1224 ±2.5a	9.6 ±0.2a
	80	30.6 ±0.3a	31.9 ±0.3a	1.1 ±0a	7.6 ±1.9b	128.7 ±4.1a	10.5 ±0.4a
	120	31.7 ±0.4a	31.6 ±0.4a	1.1 ±0.1ab	8.8 ±0.5ab	126.2 ±3.1a	10.2 ±0.4ab
I_{50}	0	33.6 ±0.5a	31.3 ±0.4c	1.2 ±0b	8.7 ±0.7b	122.6 ±4a	9.7 ±0.5a
	40	33.2 ±0.3a	33.2 ±0.2ab	1.3 ±0a	9.8 ±0.2a	132.3 ±3.8a	10.6 ±0.5a
	80	33.5 ±0.3a	33.6 ±0.3ab	1.4 ±0.1a	9.4 ±0.4a	131.5 ±3.8a	10.9 ±0.4a
	120	33.4 ±0.4a	33.9 ±0.1a	1.4 ±0.1a	9.7 ±0.2a	132.7 ±6.2a	11.1 ±0.6a
I_{75}	0	32.4 ±1b	33.8 ±0.2c	1.4 ±0b	7.2 ±0.5b	123.3 ±4.8a	11.1 ±0.4a
	40	33.1 ±0.4ab	34 ±0,2a	1.5 ±0.1a	10.5 ±0.5a	132.2 ±5.5a	11.5 ±0.2a
	80	33.6 ±0.6a	34.6 ±0.3a	1.6 ±0.1a	10.6 ±0.3a	133.9 ±7.1a	11.4 ±0.8a
	120	34.6 ±0.4a	34.8 ±0.4a	1.6 ±0.1a	10.7 ±0.3a	136.2 ±6.7a	11.3 ±0.2a
I_{100}	0	33.8 ±0.8ab	34 ±0.2c	1.4 ±0.1b	6.6 ±0.4b	126.1 ±3.3a	10.7 ±0.3b
	40	34.2 ±0.2a	34.5 ±0.3a	1.5 ±0.1a	9.8 ±0.4a	135.3 ±8a	12.4 ±0.4ab
	80	34.6 ±0.4a	35.4 ±0.3a	1.6 ±0.1a	10.4 ±0.4a	134.8 ±8.8a	12.1 ±0.8ab
	120	34.5 ±0.4a	35.5 ±0.5a	1.6 ±0.1a	10.3 ±0.5a	139.5 ±6.8a	13 ±0.7a

The averages containing the same letter are not statistically different according to Duncan's test (p = 0.05)

value in the effect of the applications on the average plant head weight of the applications in both periods, the highest value was found in the Si_{80} – Si_{120} (1.1 kg – 1.1 kg) applications. The effect of increasing the dose of Si was found to be insignificant.

The highest results in the effects of Si applications at I_{50} irrigation level on lettuce head length, head diameter, leaf fresh and dry weight in lettuce cultivation repeated in the two fall semesters of 2020–2021. It was taken from Si_{40}, Si_{80} and Si_{120} applications, and Si_0 application got the lowest value. While Si_0 (1.2 kg – 1.2 kg) was the most negligible value in the effect of the applications in both periods on the average plant head weight, the highest value was found in Si_{80} and Si_{120} (1.4 kg – 1.4 kg) applications. Si_0 has the lowest value in the effect of applications on plant root length, and Si_{40}, Si_{80} and Si_{120} applications have the highest value at the same level of importance. In the lettuce cultivation repeated in the two fall semesters of 2020–2021, the highest results were obtained from Si_{40}, Si_{80} and Si_{120} applications in the effect of Si applications on lettuce head length, head diameter and dry weight at I_{75} irrigation level, while Si_0 application received the lowest value. The effect of applications on leaf fresh weight was found to be insignificant. While Si_0 (1.4 kg – 1.4 kg) was the most negligible value in the effect of the applications on the average plant head weight of the applications in both periods, the highest value was obtained from the Si_{80} and Si_{120} (1.5 kg – 1.6 kg) applications. Si_{80} and Si_{120} applications received the highest value at the same level of importance. Barker et al. (2007). They reported an increase in vegetative growth head weight in lettuce due to the increase in the concentration of Si in the nutrient solution [Resende et al. 2007]. In a study in which different silicon varieties were applied, it improved the productivity and quality of the plants as it provided more nutrients to the vegetables, less water loss by the plant due to more swelling in the leaves, and reduced water loss because the nutrients are stored in the leaf epidermis and act as a barrier.

The highest results in the effects of Si applications on lettuce head length, head diameter, dry weight and root length at I_{100} irrigation level in lettuce cultivation

Table 5. Effects of different silicon fertilisation and irrigation levels on cell membrane damage (year 2021)

Irrigation level	Silicon fertilisation			
	Si_0 (0 kg ha^{-1})	Si_{40} (40 kg ha^{-1})	Si_{80} (80 kg ha^{-1})	Si_{120} (120 kg ha^{-1})
I_{25}	67.6 ±1.1a	53.2 ±2.1a	52.7 ±2.1a	53.5 ±0.1a
I_{50}	51.5 ±2.1b	39.7 ±0.8b	34.7 ±0.1b	34 ±0.1b
I_{75}	35.4 ±0.5c	34.5 ±0.8c	34.5 ±0.1b	34.6 ±0.7b
I_{100}	36.4 ±0.1c	35.2 ±0.7c	33.8 ±0.1b	34.4 ±0.3b
Average	47.75	40.65	38.92	39.12

The averages containing the same letter are not statistically different according to Duncan's test (p = 0.05)

repeated in the two fall semesters of 2020–2021. Si_{40} was taken from Si_{80} and Si_{120} applications, and Si_0 application got the lowest value. The effect of applications on leaf fresh weight was found to be insignificant. While Si_0 (1.4 kg – 1.4 kg) was the most negligible value in the effect of the applications in both periods on the average plant head weight, the highest value was found in Si_{80} and Si_{120} (1.6 kg – 1.6 kg) applications. Lettuce yield and average fruit weight show parallelism, especially with increased water. Si can contribute to increasing water homeostasis to protect plants against drought stress due to the further accumulation of the element in lettuce leaves and may be the main factor in maintaining biomass in lettuce plants exposed to water deficiency. This positive effect of Si on the water balance was also observed in other studies, and a better hydraulic conductivity was observed [Cao et al. 2017, Chen et al. 2018, Rafi et al. 2020].

The effects of different silicon doses at different irrigation levels in lettuce cultivation on cell membrane damage were examined. The highest rate of cell membrane damage was obtained in the $I_{25} \times Si_0$ (67.5%) interaction, while the lowest rate was obtained in the $I_{100} \times Si_{80}$ (33.8%) – Table 5. According to the interaction results of $I_{25} \times Si_{40}$ (53.2%), $I_{25} \times Si_{80}$ (52.7%), and $I_{25} \times Si_{120}$ (53.7%) in irrigation with 75% water restriction, membrane damage occurred at low irrigation level, while increasing silicon applications reduced this damage. According to the interaction between $I_{50} \times Si_0$ (51.5%), $I_{50} \times Si_{40}$ (39.7%), $I_{50} \times Si_{80}$ (34.7%) and $I_{50} \times Si_{120}$ (34%) applications at the irrigation level with 50% water restriction, the increase in irrigation level and silicon doses decreased membrane damage. Since membrane damage did not occur at 75% (I_{75}) and 100% (I_{100}) irrigation levels, the effect of silicon doses was found to be insignificant. Under adverse conditions, such as water stress, maintaining cell membrane integrity and low levels of ROS generation is crucial to plant survival [Sanchez-Rodríguez et al. 2010, De la Torre-González et al. 2018]. In this sense, it was shown that the application of Si, K, or P decreased the loss of electrolytes in plants stressed by water deficit, indicating the possible protective role of these elements against membrane damage. In addition, they activate antioxidant defences that contribute to eliminating ROS in plants [Shen et al. 2010, Rejeb et al. 2014, Ahanger et al. 2017, Zhang et al. 2018]. When the effects of the applications on leaf chlorophyll contents were examined, the highest ratio was obtained by the interaction of $I_{100} \times Si_{120}$ (52.6%) and $I_{75} \times Si_{120}$ (51.4%), while the lowest ratio was obtained in the interaction of $I_{25} \times Si_0$ (34.2%). When the results of $I_{25} \times Si_{40}$ (38.4%), $I_{25} \times Si_{80}$ (41.8%), and $I_{25} \times Si_{120}$ (41.7%) applications were evaluated according to the interaction between irrigation levels of different silicon doses, silicon applications at the water-limited irrigation level increased the amount of leaf chlorophyll. According to the interaction between $I_{50} \times Si_0$ (34.2%), $I_{50} \times Si_{40}$ (47.4%), $I_{50} \times Si_{80}$ (48.9%) and $I_{50} \times Si_{120}$ (48.7%) applications at 50% irrigation level, the increase in irrigation level and silicon doses increased leaf chlorophyll contents (Tab. 6). When the effects of the applications on the relative water content of the leaves were examined, the highest ratio was obtained

Table 6. Effects of different silicon fertilisation and irrigation levels on leaf chlorophyll contents (2021)

Irrigation level	Silicon fertilisation			
	Si_0 (0 kg ha^{-1})	Si_{40} (40 kg ha^{-1})	Si_{80} (80 kg ha^{-1})	Si_{120} (120 kg ha^{-1})
I_{25}	34.2 ±0.5c	38.4 ±1.7b	41.8 ±0.6c	41.7 ±0.6c
I_{50}	34.9 ±0.3c	47.4 ±1.1a	48,9 ±1.1b	48,7 ±1.2b
I_{75}	43.4 ±1.1b	48.3 ±0.1a	51.3 ±0.9ab	51.4 ±1.4ab
I_{100}	40.9 ±0.9a	48 ±1.1a	52.6 ±0.8a	52.6 ±1a
Average	38.35	45.52	48.65	48.6

The averages containing the same letter are not statistically different according to Duncan's test (p = 0.05)

Table 7. Effects of different silicon fertilisation and irrigation levels on leaf water content (2021)

Irrigation level	Silicon fertilisation			
	Si_0 (0 kg ha^{-1})	Si_{40} (40 kg ha^{-1})	Si_{80} (80 kg ha^{-1})	Si_{120} (120 kg ha^{-1})
I_{25}	51.2 ±0.5b	54.7 ±0.8c	60.3 ±1.2b	60.5 ±1.5c
I_{50}	54.7 ±1.1b	61.3 ±1.5b	64.9 ±0.8b	65.8 ±0.8b
I_{75}	59.9 ±1.6a	64.2 ±0.7ab	70.2 ±0.6a	68.8 ±0.7ab
I_{100}	61.8 ±1.2a	65.4 ±1.1a	70.4 ±0.7a	70 ±0.8a
Average	56.9	61.4	66.45	66.27

The averages containing the same letter are not statistically different according to Duncan's test (p = 0.05)

by the interaction of $I_{100} \times Si_{80}$ (70.4%) and $I_{75} \times Si_{80}$ (70.2%), while the lowest ratio was obtained in the interaction of $I_{25} \times Si_0$ (51.2%) – Table 7. When the results of $I_{25} \times Si_{40}$ (54.7%), $I_{25} \times Si_{80}$ (60.3%), and $I_{25} \times Si_{120}$ (60.5%) applications were evaluated according to the interaction between irrigation levels and different silicon doses, silicon applications at the water-restricted irrigation level increased the leaf water content. According to the interactions of $I_{50} \times Si_0$ (54.7%), $I_{50} \times Si_{40}$ (61.3%), $I_{50} \times Si_{80}$ (64.9%) and $I_{50} \times Si_{120}$ (65.8%) at 50% irrigation level, the increase in irrigation level and silicon doses increased leaf chlorophyll contents. Leaf water decreases due to physiological drought stress caused by salt stress, and therefore, stomatal conductivity decreases due to stomatal closure and transpiration is prevented [Nemeskéri and Helyes 2019, Wang et al. 2019]. As a result of Si applications In lettuce plants, the stomata are opened more, thereby increasing the rate of photosynthesis [Cao et al. 2017, Chen et al. 2018].

CONCLUSION

In this study, in which varying silicon doses at different irrigation levels were tested, the effects on water consumption efficiency and yield components in lettuce were investigated. In this study, which was carried out in open field conditions for two consecutive years, when the data obtained based on years were evaluated, the effect of the applications did not differ much according to the years. According to the measurements made in the samples taken in both years, the effect of the applications on yield and yield elements in lettuce cultivation was found to be significant. An increase in lettuce yield was determined depending on the increase in Si doses and irrigation levels. As a result of silicon applications at low irrigation levels (I_{25}), leaf membrane damage increased, leaf water and chlorophyll contents decreased, and plant growth slowed down. As a result of the effect of increasing silicon doses (Si_{40}, Si_{80} and Si_{120}) in high irrigation subjects (I_{75}, I_{100}), the stress effect on plants decreased, and plant growth increased. The effects of silicon applications at appropriate doses on plant growth and some stress parameters were found to be significant in lettuce farming.

SOURCE OF FUNDING

This research received no external funding.

REFERENCES

Ahanger, M.A., Tomar, N.S., Tittal, M., Argal, S., Agarwal, R.M. (2017). Plant growth under water/salt stress: ROS production; antioxidants and significance of added potassium under such conditions. Physiol. Mol. Biol. Plants 23, 731–744. https://doi.org/10.1007/s12298-017-0462-7

Balestrini, R., Chitarra, W., Antoniou, C., Ruocco, M., Fotopoulos, V. (2018). Improvement of plant performance under water deficit with the employment of biological and chemical priming agents. J. Agric. Sci. 156, 680–688. https://doi.org/10.1017/ S0021859618000126

Barreto, R.F., Schiavon Jr, A.A., Maggio, M.A., Prado, R.D. (2017). Silicon alleviates ammonium toxicity in cauliflower and in broccoli. Sci. Hortic., 225(1), 743–750.

Cao, B., Wang, L., Gao, S., Xia, J., Xu, K. (2017). Silicon-mediated changes in radial hydraulic conductivity and cell wall stability are involved in silicon-induced drought resistance in tomato. Protoplasma, 254, 2295–2304. https://doi.org/10.1007/ s00709-017-1115-y

Chen, D., Wang, S., Yin, L., Deng, X. (2018). How does silicon mediate plant water uptake and loss under water deficiency?. Front. Plant Sci., 9, 281. https://doi.org/10.3389/fpls.2018.00281

De la Torre-González, A., Montesinos-Pereira, D., Blasco, B., Ruiz, J.M. (2018). Influence of the proline metabolism and glycine betaine on tolerance to salt stress in tomato (*Solanum lycopersicum* L.) commercial genotypes. J. Plant Physiol. 231, 329–336. https://doi.org/10.1016/J.JPLPH.2018.10.013

Doorenbos, J. (1977). Guidelines for predicting crop water requirements, FAO, Roma (Italia).

Gençoğlan, C., Altunbey, H., Gençoğlan, S. (2006). Response of green bean (*P. vulgaris* L.) to subsurface drip irrigation and partial rootzone-drying irrigation. Agric. Water Manag., 84(3), 274–280.

Jadhao, K.R., Bansal, A., Rout, G.R. (2020). Silicon amendment induces synergistic plant defense mechanism against pink stem borer (*Sesamia inferens* Walker.) in finger millet (*Eleusine coracana* Gaertn.). Sci. Rep., 10, e4229.

Kørup, K., Laerke, P.E., Baadsgaard, H., Andersen, M.N., Kristensen, K., Münnich, C., Didion, T., Jensen, E.S., Mårtensson, L.-.M., Jørgensen, U. (2018). Biomass production and water use efficiency in perennial grasses during and after drought stress. GCB Bioenergy, 10, 12–27. https://doi.org/10.1111/gcbb.12464

Lozano, C.S., Rezende, R., Hachmann, T.L., Santos, F.A.S., Lorenzoni, M.Z., Souza, Á.H.C. (2018). Yield and quality of melon under silicon doses and irrigation management in a greenhouse. Pesqui. Agropecu. Trop., 48(2),140–146. https://doi.org/10.1590/1983-40632018v4851265

Nemeskéri, E., Helyes, L. (2019). Physiological responses of selected vegetable crop species to water stress. Agronomy, 9(8), 447. https://doi.org/10.3390/agronomy9080447

Nunes, A.M.C., Nunes, L.R.L., Rodrigues, A.J.O., Uchoâ, K.S.A. (2019). Silício na tolerância ao estresse hídrico em tomateiro [Silicon in the tolerance of the water stress in tomatoes]. Rev. Cient. Rur., 21(2), 239–258 [in Portuguese]. https://doi.org/10.30945/rcr-v21i2.2658

Pradhan, A., Naik, N., Sahoo, K.K. (2015). RNAi mediated drought and salinity stress tolerance in plants. Amer, J. Plant Sci., 6, 1990–2008.

Pour-Aboughadareh, A., Omidi, M., Naghavi, M.R., Etminan, A., Mehrabi, A.A., Poczai, P., Bayat, H. (2019). Effect of water deficit stress on seedling biomass and physio-chemical characteristics in different species of wheat possessing the D genome. Agronomy 9, 522. https://doi.org/10.3390/agronomy9090522

Singh, A.K., Ansari, M.W., Pareek, A., Singla-Paree, S.L. (2008). Raising salinity tolerant rice: recent progress and future perspectives. Physiol. Mol. Biol. Plants, 14, 137–154.

Rejeb, K. Ben, Abdelly, C., Savouré, A. (2014). How reactive oxygen species and proline face stress together. Plant Physiol. Biochem. 80, 278–284. https://doi.org/10.1016/J.Plaphy.2014.04.007

Sánchez-Rodríguez, E., Rubio-Wilhelmi, M., Cervilla, L.M., Blasco, B., Rios, J.J., Rosales, M.A., Romero, L., Ruiz, J.M. (2010). Genotypic differences in some physiological parameters symptomatic for oxidative stress under moderate drought in tomato plants. Plant Sci., 178(1), 30–40. https://doi.org/10.1016/J.Plantsci.2009.10.001

Shen, X., Zhou, Y., Duan, L., Li, Z., Eneji, A.E., Li, J. (2010). Silicon effects on photosynthesis and antioxidant parameters of soybean seedlings under drought and ultraviolet-B radiation. J. Plant Physiol., 167, 1248–1252. https://doi.org/10.1016/J.JPLPH.2010.04.011

Souza, L.C., Melo, N.C., Siqueira, J.A.M., Silva, V.F.A., Oliveira Neto, C.F. (2015). Comportamento bioquímico no milho submetido ao déficit hídrico e a diferentes concentrações de silício [Biochemical behavior in grass subjected to drought and different concentrations of silicon]. Revista Agrarian, 8(29), 260–267 [in Portuguese].

Soloklui, A.A.G., Ershadi, A., Fallahi, E. (2012). Evaluation of cold hardiness in seven Iranian commercial pomegranate (*Punica granatum* L.) cultivars. HortScience, 47(12), 1821–1825. https://doi.org/10.21273/Hortscı.47.12.1821

Zhang, Z.S., Wei, X.H., Li, X.R., Wang, X.P., Xie, Z.K. (2004). Analysis on investment and benefit of harvested rainwater utilization in the northwest loess Plateau. Adv. Water Sci., 6, 022.

Zhang, F., He, J.-D., Ni, Q.-D., Wu, Q.-S., Zou, Y.-N. (2018). Enhancement of drought tolerance in trifoliate orange by mycorrhiza: changes in root sucrose and proline metabolisms. Not. Bot. Horti Agrobot. Cluj-Napoca, 46, 270–276. https://doi.org/ 10.15835/nbha46110983

Wang, Y., Gao, S., He, X., Li, Y., Li, P., Zhang, Y., Chen, W. (2019). Growth, secondary metabolites and enzyme activity responses of two edible fern species to drought stress and rehydration in northeast China. Agronomy, 9, 137. https://doi.org/10.3390/agronomy9030137

Weerahewa, D., Somapala, K. (2016). Role of silicone on enhancing disease resistance in tropical fruits and vegetables: a review. OUSL J., 11(1), 135–162.