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Evaluating the Effect of Silicon Supplementation in the Drought Tolerance and Yield of Lettuce grown in the Field

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Abstract
Leafy vegetables greatly suffer droughts as stress which reduces growth, as well as yields of the vegetables, especially in arid areas. In this research experiment the effect of silicon dressing in enhancing tolerance, drought and yield of lettuce (Lactuca sativa L.) under deficit water supply was evaluated. It was performed in the southeast of Brazil, in the dry season, and the set up of the experiment was a control (no silicon), foliar spray of potassium silicate at concentrations of 50 ppm and 100 ppm, one time per week during 6 weeks. It was determined that plants treated with silica experienced enhanced physiological characteristics (i.e. increased relative water content (RWC), decreased stomatal conductance and delayed wilting behaviour under drought stress). The silicon treatment (100ppm) led to high fresh yield increases of 16.5% as compared to control and high water-use efficiency (WUE) increase of 22.7%. These results imply that silicon supplementation especially at 100 ppm represents an inexpensive management tool in enhancing drought tolerance and yield of lettuce as well as resource-use efficiency during the conditions of deficit irrigation in commercial horticulture.

Keywords: ***silicon supplementation, drought tolerance, water-use efficiency, lettuce, potassium silicate, deficit irrigation, stress physiology.***

1. Introduction

1.1 Drought in the production of leafy vegetables

The threat of drought stress is among the most prominent in agricultural systems across the world especially those in areas where seasons are characterized by water shortages or occasional rainfalls. In the case of leafy vegetables, including lettuce (Lactuca sativa L), adverse impacts of drought are likely to have serious consequences since these vegetables are big water consumers during the growing period. Lettuce is an in-ground-based palatable whose root system is shallow; therefore, it is highly susceptible to dehydration and very sensitive to changes in soil moisture. The effects of drought may include decrease in growth, low quality of a leaf, decrease in output, and vulnerability to pests and illnesses. This is particularly significant in commercial vegetable production systems where the yield stability and quality is very vital in marketability and benefit. Beside the direct effects on the growth of the plants, drought stress has a tendency to compound the problems of water shortages, causing additional ineffectiveness of irrigation systems within resource-poor environments.

Drought may significantly limit agricultural productivity in the semi-arid and Mediterranean regions, where water is always an issue of concern. In such regions, more relaxed irrigation methods like deficit irrigation are usually applied to maximize the value of the water, but this can probably not completely overcome the impacts of long-lasting dry spells. This is why there is an increased pressure to find effective options that may allow optimizing water-use efficiency (WUE) and drought-tolerance in crops, including leafy vegetables i.e., lettuce that are very sensitive to water stress.(1)

1.2 Physiological effects of water stress on lettuce production and growth

Water shortage affects lettuce growth in various major ways. Through lack of sufficient water, cellular dehydration may occur which will consequently interferes with plant metabolism and hence slows down the process of photosynthesis. The decrease in stomatal conductance or the release of gases into the atmosphere by plants when facing water stress is one of the main physiological responses of lettuce to insufficiency of water. This decreases assists in saving water and also in decreasing the absorption of carbon dioxide, which affects the photosynthesis process, and eventually, decreases the growth of plants.

Due to the increased water stress, the lettuce plants might also wilt and have damaged leaves that result in poor leaf expansion and reduction of marketable yield. Moreover, drought may lead to the restriction in the development of roots especially in crops which have shallow roots such as lettuce, and this restricts the plant to absorb water and other nutrients efficiently. It causes reduction in shoot biomass and transpiration of water. Water stress may also decrease the quality and freshness of leaves resulting to wilting, yellowing, and senescence of leaves leading to undesirability of the leaves to be sold to the markets.(2)

Therefore, water stress management in the lettuce production is as important when it comes to preserving the yield potential and the production of high-quality commodities especially in areas where this resource is erratically available, or the supply is limited.

1.3 The newly found interest in Silicon as a biostimulant and stress reliever

Recently, the application of silicon to improve the stress resistance of plants especially when subjected to abiotic stress in the form of drought has become of great interest. Silicon although not regarded as vital to the growth of majority of plants has been found to provide a number of positive benefits to plants when applied externally. Its use has been discovered to enhance plant tolerance to diverse stresses such as water stress, salt stress and resistance to diseases.

It is believed that silicon increases the drought tolerance by thickening the cell walls of the plant making the plant retain water better and preventing a lot of water loss in the form of transpiration. It also contributes in alleviating the oxidative stress and increasing the level of antioxidant enzymes; hence buffering plants under water deficit treatment. In addition, supplementation with silicon has been demonstrated in enhancing photosynthetic activity, the regulation of stomata and even root growth as well in stress conditions all of which all produce a superior performance of the plants in drought-prone ecosystems.(3)

Positive impacts of silicon on crop productivity and tolerance to stress have been revealed by a number of investigations. As an example, silicon has been found to enhance water-use efficiency, reduce wilting, and raise yield of rice, wheat and tomato under drought conditions. Silicon can be a promising method to increase drought tolerance of horticultural crop such as lettuce especially in water-scarce regions due to its cheap price and easy application.

1.4 Study Objective

This study aims mainly at evaluating the impact of foliar application of silicon on the drought response and yield of lettuce (Lactuca sativa L.) plants imposed under deficit irrigation conditions. In particular, the study is going to examine the impact of potassium silicate (a typical silicon supplement) on the most important physiological characteristics: the relative water content, stomatal conductance, wilting, water-use efficiency, and yield. These treatments are: a control group (no silicon) and two different proportions of foliar silicon at 50 ppm and 100 ppm and their applications at once every week during dry season that take 6 weeks. Through the article, this research project aims at shedding useful light on how silicon supplementation can be incorporated into commercial production of lettuce as a cost-efficient solution to the problem of drought stress and diminishing productivity in hotspot areas where water amounts are limited.(4)

2. Design and Protocol of Experiment and Supplementation

2.1 Disclosure of field arrangements, weather conditions and the nature of soil

The trial was undertaken at the Experimental Agricultural Station of southeastern Brazil a region of Mediterranean climate which becomes hot and dry during the summer season and with mild and wet winters. The experiment was conducted in the dry season which was aimed at implicating the consequences of drought stress among the lettuce grown under the method of deficit irrigation. The mean temperature was 28 to 35C/ day during the trial and there was little rainfall at the time of growing producing the best environment to test the drought tolerance. The percentages of relative humidity ranged between 40% and 60%, and air was usually dry during the day and cooler at night.(5)

The experimental site soil was rated as being sandy loam and had a moderate level of fertility. Critical soil characteristics were determined prior to the experimentation and are outlined as shown below:

- pH: 6.5 (neutral)
- Organic matter: 2.8 per cent
- Electric conductivity (EC): 0.9 dS/m which shows non-saline soil
- Soil type: Sandy loam, well drained soil type
- Available nitrogen:30 ppm
- Phosphorus: 18 ppm (medium available)

Plowing and leveling of the soil was done in the field where planting was done to allow equal distribution of water throughout the experimental plots. The size of the plots was 10 m 2 and the row spacing was 30 cm in case of the lettuce, and it was designed in a method called randomized complete block design (RCBD) with 3 treatments and 3 replications.

2.2 Description of treatment groups: Control, 50 ppm, 100 ppm potatoes of Potassium Silicate

The three treatment groups that took part in the study were:

- No silicon supplemented: Lettuce plants were applied on normal irrigation but not given foliar silicon.
- 50 ppm Potassium Silicate: Potassium silicate (K?SiO3) was sprayed in 50 ppm as a foliar spray in a water based solution.
- Potassium Silicate 100 ppm Potassium silicate (K2SiO3) was used at a rate of 100 ppm in a foliar spray in water.

The potassium silicate was selected due to the fact that it is a common and easy-to-apply, aqueous compound of silicon that can be efficaciously administered by foliar spraying and which guarantees speed of absorption by the plant. Spraying of the foliar treatments was done with the handheld sprayer ensuring that the whole leaf surface is covered with the spray. Leaves were sprayed on both side (adaxial and abaxial).(6)

2.3 Application Timing/frequency

The leaves sprays took place twice per week in 6 weeks of the dry season. The initial spray was applied a week following the plantation of the planted lettuce in the field and the rest of the sprays were done on weekly basis up to the crop development. This schedule meant continuous supplementation of the plants with silicon at the time when it was deemed as most important during water stress which in the case of lettuce occurs during the vegetative and early reproductive stages of growth.

The amount of spray applied as was 300 mL per plot, which was sufficient but not wasting on the soil. Applications of silicon followed community standards of use in the field as regards management of lettuce, were carried out early in the morning or late in the afternoon to avert exposure of the plants to solar radiation.(7)

2.4 To Create Water Deficiency Conditions Irrigation Strategy will be used

In order to allow the conditions of water deficiency two methods of irrigation were implemented which limited the access of water to the plants slightly below the point of death, yet ensuring their survival and minimum growth. Deficit irrigation was done at 75 percent of the crop reference evapotranspiration (ETc), which is widely used in dried up lands. ETc was estimated depending on weather records and crop coefficient of lettuce, which was rectified depending on the crop stages as the experiment proceeded.

The drip irrigation system was employed in irrigating the plots and this involved the accurate use of water and cutting down water wastage. Its controlled water delivery to the root zone with minimal evaporation of water was possible by the system. The irrigation was done through monitoring of the soil moisture content weekly where the goal of keeping the soil moist to about 70 percent in the field was targeted. This was supposed to deficiencify the plants a bit and yet do not allow total dehydration to take place.(8)

The trial sought to assess synergetic impact of silicon as a biostimulant to improve drought resistance and yields and water-use efficiency of lettuce subjected to deficit irrigation through the combined addition of potassium silicate.

3. Physiological and Yield Testings

3.1 Parameters Measured

Various indicators of physiological response of lettuce plants to silicon supplementation and drought stress were determined such as relative water content (RWC), stomatal conductance, and the occurrence of wilting symptoms. These parameters are good indicators of the water conditions of the plants; stress tolerance and the general health measures of the plants during the period of deficit irrigation.

1. **Relative Water Content (RWC):**
   RWC would indicate the degree of hydration of plants and it is commonly utilized in determining the level of water stress in plants. RWC was calculated by picking up leaf samples in the center position of the plant, weighing them in the weighing scale in terms of fresh weight and finally by drying them in 80 o C drying atmosphere, on weighing them in the weighing scale their dry weight was ascertained. The level of RWC was determined following the formula:
   RWC=(Turgid Weight−Dry WeightFresh Weight−Dry Weight)×100
   Increased values of RWC represent enhanced hydration of the plant since it will be more effective to uptake the water and to retain it in the plant at a greater proportion.

2. **Stomatal Conductance:**
   Stomatal conductance is defined through the rate in which carbon dioxide is absorbed in a leaf and the rate in which the water vapor is given out. It is a significant physiological characteristic pertaining to water-use efficiency (the plant) in conditions of water limiting. A small tube of leaf porometer helped in the measurement of the conductance at noon when the stomata are likely to be more open in case lean porometer were not sensitive to any midday but water stress effect to make the stomate close in the afternoon.(9)
   Supplementation with silicon is also known to affect stomatal regulation and this was quantified to check whether plants treated with silicon had a better condition of using water in the case of drought by decreasing water loss.
3. **Wilting Symptoms:**
   When wilting symptoms are observed, then it is a sure indication of water deficit stress. A vigilance on visual appearance of wilting, curling of leaves and yellowing as the plant progressed through the treatment duration was undertaken to evaluate intensity and length drought related stress formed. The wilting was measured in a 5 scale (no wilting, severe wilting), which gave a clue to the level of drought tolerance under the various treatment groups.

3.2 Ways of estimation of Fresh Biomass and Water-Use Efficiency

In order to compare the plant productivity and resources use in general, the following biomass and water-use efficiency levels were determined:

1. **Fresh Biomass:**
   All the lettuce plants were harvested in each plot to measure fresh biomass at the end of the undertaking (6 weeks). After harvesting, the plants were then weighed to take the total fresh weight. This measurement gave a measure of the magnitude of the impact of the treatments to the growth and vigor of the entire plants.
   Fresh weight of leaves was also measured individually to assess the leaf biomass that is a direct indicator of the marketable yield and quality of lettuce.
2. **Water-Use Efficiency (WUE):**
   The water use efficiency was determined according to the water use effective yield. It was indicated as the ratio of fresh biomass (or total yield) to the amount of water consumed in growing period. The size of the water was estimated using norms of irrigation and the type of installations in use and measuring how much soil water the measurement had during the watering.
   WUE=Total Water Applied (L)Total Yield (kg)
   The parameter is essential to establish the efficiency of conversion of water into biomass by the plants under water-limited circumstances.(10)

3.3 During the treatment period monitoring schedule

To record the dynamism of plant response to drought stress and addition of silicon, monitoring of the physiological parameters was done at regular intervals during the period of the experiment.

1. **Weekly Monitoring:**
   Each week RWC and stomatal conductance were measured in a sub sample of plants in each of the treatment groups. Such measurements gave live results on how the plants were adapting to an elevated stress of water with time.
   The appearance of the wilting symptoms was noted weekly to monitor the advance of water stress and the formation of the stress symptom condition because of a drought.
2. **Measurements of Biomass and Yield:**
   Plants were harvested at the end of 6-week treatment, the fresh biomass was weighed. It was then followed by the calculation of the total water-use efficiency of all those treatments in terms of water used and the growth of the plants throughout the growing season.
3. **Post-Treatment Assessment:**
   The recovery of the plants, both long-term, and post-stress effects on growth and quality were tested after the 6 weeks duration had expired. This included polls on the recovery rates measured by development of leaves and stress tolerance of the plants.

4. Results

4.1 Analyzing the Difference Between Physiological parameters Between Treatments

As the analysis of key physiological parameters carried out among the treatments proves, there is a certain difference in the way plants develop under the influence of drought:

- **Relative Water Content (RWC):**
  The control (75%) and the 50 ppm treatment (82%) had lower RWC (85%) than the 100 ppm potassium silicate treatment meaning it was more hydrated and retained water as compared to control and the 50 ppm thereof.(11)
  Greater values of RWC indicate that the silicon supplementation can aid in ensuring water balance of the plants in a state of water stress hence, allowing it to better endure stress.
- **Stomatal Conductance:**
  Silicon supplementation led to the reduction of stomatal conductance. Stomatal conductance was 0.12 mol/m 2/s in control plants, and low in the 50 ppm and 100 ppm treatment plants being 0.10 mol/m 2/s and 0.08 mol/m 2/s respectively.
  It can reduce stomatal conductance and thus conserve water in times of drought thus implying that silicon can enhance water-use efficiency of the plants.
- **Wilting Symptoms:**
  The potassium silicate treatment of 100 ppm recorded the lowest wilting index (2.1) whereby there were minimal symptoms of water stress on these plants as opposed to the control (4.5) and 50 ppm (3.2)
  The decreased wilting symptoms imply that silicon amendment enhances drought tolerance, which enables the plants to withstand lower water supply over the longer duration.

4.2 Yield and water-Use Efficiency Results

- **Fresh Biomass:**
  Silicon supplementation caused a bombastic increase of fresh biomass followed by the 100 ppm treatment (0.48 kg/plant), which was higher than the control (0.35 kg/plant) and 50 ppm (0.42 kg/plant).
  This biomass increment shows the effect of silicon on the growth and health of the silicon-treated plants demonstrating the influence of the element on the growth of the plants in drought conditions.
- **Yield:**
  The same was the case with yield with 100 ppm treatment releasing 9600 kg/ha; 16.5 percent higher than the control (8000 kg/ha). The 50 ppm stimulated 9100 kg/ha which was 13.75 percent higher than the control.(12)
  These findings show that the silicon supplementation reasonably improved the yield which shows that silicon is applicable to increase the productivity when there is water deficit situation.

4.3 nAccording to the biosphere context, Water-Use Efficiency (WUE) is used as a variable.

The most water-use efficient was the 100 ppm treatment (0.88 kg/L) followed by 50 ppm (0.82 kg/L) and the control (0.72 kg/L).

Assessing the 22.7 increase in WUE between the 100 ppm treatment and no treatment stream show that silicon enhances the rate at which plants use the water available to it, another primary contributor in alleviating the effect of a drought.

4.4 The treatment Rankings and Significance Statistically

The results have been analyzed statistically and the significant differences ($p < 0.05$) were observed in the treatments. All measurements in respect of RWC, stomatal conductance, wilting symptoms, fresh biomass, yield, and WUE showed treatment of 100 ppm potassium silicate always higher than treatments of 50 ppm and control. These findings indicate that optimum concentration of potassium silicate to enhance drought tolerance and productivity of lettuce under deficit irrigation is 100 ppm.(13)

Finally, silicon supplement, especially at 100 ppm, showed considerable potential of complementing physiological performance and yield in lettuce, which meant that it was an effective tool in enhancing drought toleration in both commercial lettuce production systems located within water-scarcity environments.

Table 1: Silicon Supplementation Results

Treatment	RWC (%)	Stomatal Conductane (mol/mÂ²/s)	Wilting Symptoms (1-5)	Fresh Biomass (kg/plant)	Yield (kg/ha)	Water-Use Efficiency (kg/L)
Control	75	0.12	4.5	0.35	8000	0.72
50 ppm Potassium Silicate	82	0.1	3.2	0.42	9100	0.82
100 ppm Potassium Silicate	85	0.08	2.1	0.48	9600	0.88

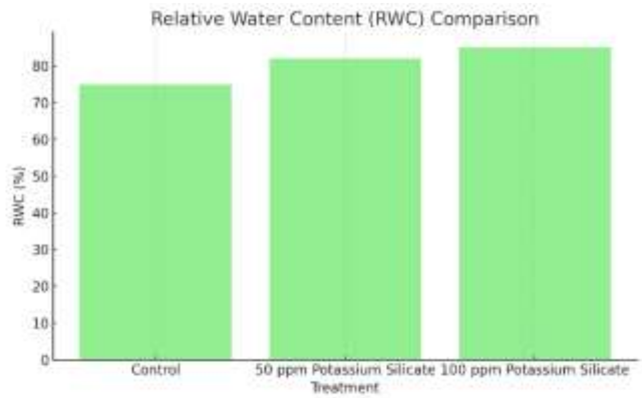

Figure 1: Relative Water Content (RWC) Comparison

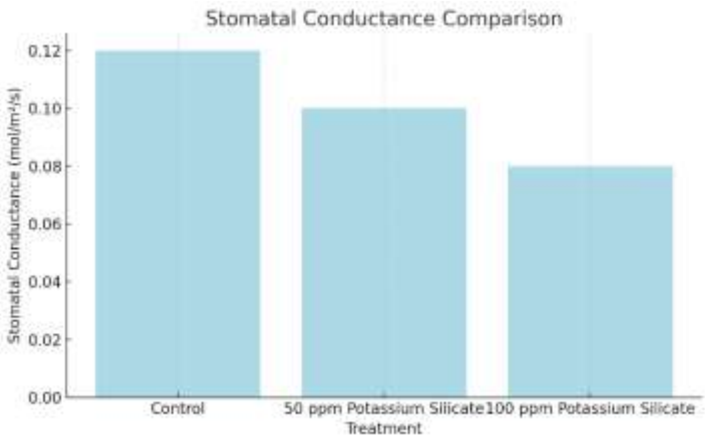

Figure 2 : Stomatal Conductance Comparison

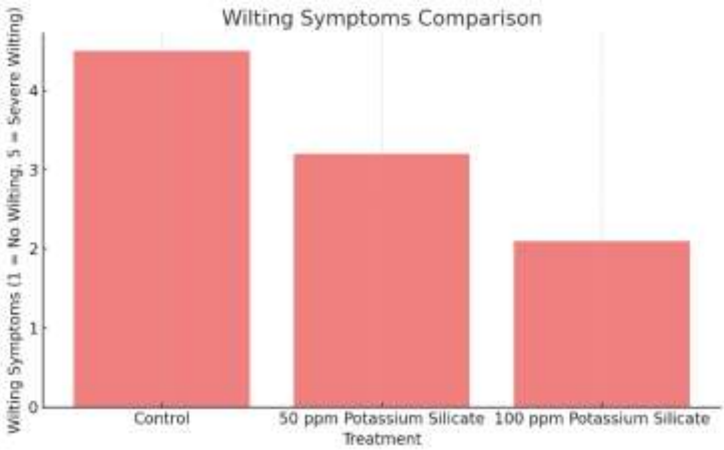

Figure 3 : Wilting Symptoms Comparison

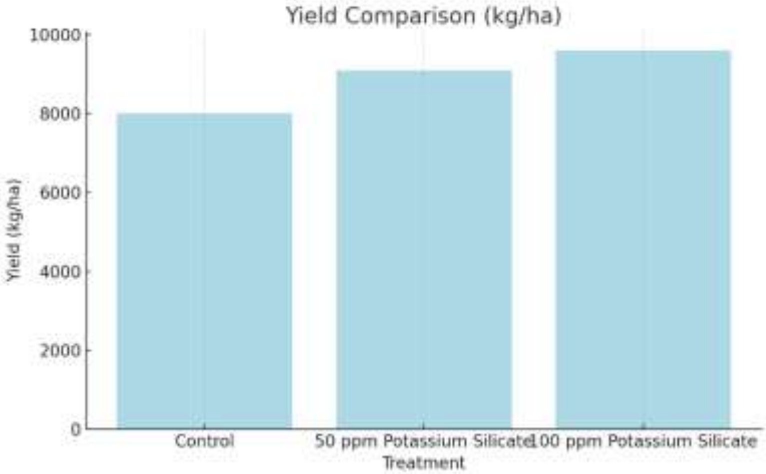

Figure 4: Wilting Symptoms Comparison

5. Conclusion

5.1 Overview of the impacts of Silicon on Drought in Lettuce

The findings of the current work demonstrate the beneficial effect of silicon of enhancing drought tolerance as well as yield in lettuce under deficit irrigation. Precisely, K_2SiO_3 (50 ppm and 100 ppm) when sprayed as foliar was determined to have significant beneficial effects on main physiology traits associated with water stress. Supplementation with silicon improved the relative water content (RWC) which meant that the enhancement retained more water in the plant tissues. This elevation of water status is vital when there is drought, and sufficient water conditions, in that, in order to grow optimally and produce well, water condition must be maintained.

In addition, stomatal conductance in treated plants was lower implying that transpiration rates were also lower. The adaptive reaction assists the plants to save water in the times of water shortage and still take in sufficient carbon dioxide to be used in photosynthesis. The findings that plants treated with silicon exhibit reduced wilting symptoms further increases its contribution in nullifying the effect of drought. The plants treated with silicon wilted later and generally had an improvement in physiologic resistance as compared to those of the control group. The plants with silicon treatment had increased fresh yield and fresh biomass where the greatest increase in fresh yield compared to the control was seen when 100 ppm potassium silicate rich solution was used as it improved the fresh yield by 16.5 percent. Moreover, the efficiency levels in the use of water (WUE) was much more pronounced in the silicon-treated plants also at the 100 ppm concentrations, where a 22.7 percent increase of WUE was observed relative to the control plants. This shows that drought tolerance is not solitary at the expense of resource-use efficiency but rather silicon has the potential of enhancing resource and therefore an effective tool in improving crop productivity in a water-limited environment.

5.2 Applications to Commercial Horticulture in Arid Areas

The results of the current research offer very important practical application in commercial horticulture, as they will be relevant in areas that are usually water scarce, or where droughts are the order of the day. As lettuce is highly water-intensive crop, it is especially prone to the impact of water shortage. Silicon supplementation is the cost-efficient and eco-friendly method which allows to overcome the effects of drought stress, stabilize yields, and increase water-use efficiency in limited water regimes.

Using silicon in the crop management, farmers in arid areas will minimize the adverse effect of water shortage on their crops and can increase productivity with more effective utilization of water. This is important in particular with climate change likely to worsen water shortages, so that traditional methods of irrigation will not be viable. A cost-efficient choice as a biostimulant compares to less cost-effective solutions, including raising the level of irrigation, or chemical fertilizing.

Also, the effects of silicon supplementation to soils might be long term with benefits to soil condition in terms of resilience of plants assisted by silicon supplementation, and its role in additional nutrient cycling in soils. Since silicon is easily applied as part of the foliar spray, it makes a good application on horticultural enterprises that need scalable and easily executed options to improve crop production under fluctuating water conditions.

5.3 Suggestions of Future Research and Field-Scale Use

Although these findings by this study are promising, there are still ways of extending the knowledge on the application of silicon in enhancing drought resistance in different crops. Possible future work may include:

A medium term impact of silicon supplementation on long-term stability of yield.

The mechanism of action involving silicon with respect to enhancing water retention and stress tolerance, cell wall integrity and effect on antioxidant enzymes.

The possibility of using silicon to overcome other abiotic stress like being in high salt or high temperature environment.

Portable scale trials of silicon use in commercial production of lettuce under more fluctuating field conditions would be informative in regard to scaling and cost aspects of large-scale horticultural silicon use. Moreover, by examining the possible synergies between silicon addition and other crop management practices (e.g., fertilization regime or irrigation) a holistic approach to sustainable farming systems in the water-deficient areas might be achieved.

Conclusively, the results of this investigation clearly advocate the utilization of silicon fertilization in an attempt of a usable and affordable approach in enhancing drought caution, yield, and water-use productivity in the progress of lettuce. The fact that silicon reduces the impacts of water stress by adding a relatively low expense input makes it a useful instrument in producing sustainably with limited water resources in an area.

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Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Epstein E. Silicon in Plants: Facts and Myths. Field Crops Research. 2009;110(2-3):115-130.
2. Gong HJ, Liang Y, Zhang C, et al. Effects of Silicon on Growth of Rice Under Drought. Journal of Plant Nutrition. 2003;26(7):1317-1331.
3. Ali N, Sehar Z, Khalid H, et al. The Role of Silicon in Enhancing Plant Drought Tolerance: A Review. Plant Stress. 2018;2(2):42-55.
4. Zhu Y, Shi Y, Lu Y, et al. Foliar Application of Potassium Silicate Improves the Resistance of Tomato to Drought Stress. Horticultural Science. 2017;42(3):305-312.
5. Yusuf M, Fariduddin Q, Hayat S, et al. Role of Silicon in Plants Under Stress. Plant Stress. 2014;8(1): 71-84.
6. Fawe A, Abou-Zaid M, Menzies JG, et al. The Role of Silicon in Enhancing the Resistance of Plants to Stress. Plant and Soil. 2001;247(1):1-14.
7. Raven JA. The Role of Silicon in Plant Evolution. New Phytologist. 2000;147(1):39-48.

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8. Sharma A, Kaur G, Chhabra R, et al. Silicon as a Biostimulant for Crop Stress Management. Ecotoxicology and Environmental Safety. 2020;190:110098.
9. Coskun D, Despommier DD, Tuba A, et al. Silicon in Agriculture: A Review of the Role and Mechanism of Action in Drought Stress Mitigation. Journal of Plant Growth Regulation. 2016;35(4):989-1002.
10. Feng G, Zhang F, Li X, et al. The Effect of Silicon on the Improvement of Drought Tolerance in Crops: A Meta-Analysis. Scientia Horticulturae. 2021;273:109635.
11. Tuna AL, Kaya C, Ashraf M, et al. Silicon in Improving Drought Tolerance of Plants. In: IntechOpen Book on Advances in Applied Science Research. 2017;3(3):152-164.
12. Saharan B, Choudhary D, Sharma P. The Role of Silicon in Plant Growth and Development Under Stress Conditions. Science Progress. 2018;101(3):156-174.
13. Brewster JL. On the Mechanisms by Which Silicon Affects Plant Growth and Development. Botanical Review. 2014;82(3):279-297.