FOLIAR APPLICATION OF SILICON HAS LITTLE EFFECT ON HYDROPONICALLY GROWN BARLEY (*HORDEUM VULGARE* L.)

FOLIARNO DODAJANJE SILICIJA IMA MALO UČINKA NA HIDROPONSKO GOJEN JEČMEN (*HORDEUM VULGARE* L.)

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ABSTRACT

Foliar application of silicon has little effect on hydroponically grown barley (*Hordeum vulgare* L.)

Silicon is an element widely distributed on the earth's crust. It can ameliorate stress in plants grown in unfavorable conditions. Barley is an important cereal used as a staple food. In our experiment, barley was grown on a floating hydroponics system in a greenhouse. Plants were stabilized in pots containing rockwool. Half of the plants were sprayed with potassium silicate (0.25 ml 6% K_2SiO_3 L^{-1}) every ten days for 35 days. The vitality of plants during their growth was monitored by measuring the potential photochemical efficiency of photosystem II. After 16 and 35 days of silicon application, shoot length, root length, and fresh and dry biomass were measured. At the end of the experiment, the number of leaves and shoots, specific leaf area, leaf optical properties, and lipid peroxidation were determined as well. The potential photochemical efficiency of photosystem II was close to 0.8 and unaffected by the addition of silicon, indicating a good condition of the plants. Results showed lower leaf reflectance for silicon-treated plants in UVA, UVB, and blue light wavelengths, possibly due to a layer of potassium silicate on leaves. After 16 days, silicon-treated plants' fresh shoot weight and root length were higher than in control plants. Results showed that additional foliar application of silicon does not cause stress in the barley plant.

Keywords: potassium silicate, barley, *Hordeum vulgare*, hydroponics, foliar application, silicon

IZVLEČEK

Foliarno dodajanje silicija ima malo učinka na hidroponsko gojen ječmen (*Hordeum vulgare* L.)

Silicij je pogost element v zemljini skorji in lahko znižuje stres rastlin, ki rastejo v neugodnih razmerah. Ječmen je za ljudi pomembno žito, saj spada med osnovna živila. Poskus smo izvedli na plavajočem hidroponskem sistemu v rastlinjaku na Biotehniški fakulteti. Rastline so bile ukoreninjene v lončkih s kameno volno. Polovico rastlin smo škropili s kalijevim silikatom (0,25 ml 6% K_2SiO_3 L^{-1}) vsakih deset dni. Med rastjo smo spremljali vitalnost rastlin z merjenjem potencialne fotokemične učinkovitosti fotosistema II. Po 16 in 35 dneh nanašanja Si, smo izmerili velikost poganjkov, dolžino korenin ter svežo in suho biomaso. Na koncu poskusa smo prešteli število listov in poganjkov, določili specifično listno površino, optične lastnosti listov in stopnjo lipidne peroksidacije. Potencialna fotokemična učinkovitost fotosistema II je bila v vseh tretmajih blizu 0,8, kar je nakazovalo na dobro stanje rastlin. Rezultati so pokazali nižjo odbojnost listov pri rastlinah, škropljenih s Si v UVA, UVB in modrem spektru valovnih dolžin, najverjetneje zaradi nastale plasti kalijevega silikata na listih. Po 16 dneh so imele s Si tretirane rastline večjo svežo maso poganjkov in daljše korenine kot rastline brez dodanega Si. Rezultati so pokazali, da škropljenje s silicijem ne povzroča stresa v ječmenu.

*Ključne besede***:** kalijev silikat, ječmen, *Hordeum vulgare*, hidroponika, foliarni nanos, silicij

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1 INTRODUCTION

Silicon (Si) is an abundant element in the earth's crust. It is not essential for most plants, but some accumulate more silicon than others. One of the silicon accumulators is barley (*Hordeum vulgare* L.), an important species in agriculture. Silicon enters the cell through the pores in a way that depends on the plant species. Different plant species contain different concentrations of Si in their tissues, and it ranges between 0.1 and 10% of dry weight of the plant (Hodson et al. 2005). Despite generally high silicon levels in soils, continuous crop harvesting has led to a depletion of the soil pools of plant-available silicon, and crops will require silicon application in the future to maintain their yields. Furthermore, silicon is only accessible to plants in the form of monosilicic acid, the concentration of which in the soil is highly dependent on the physical and chemical properties of the soil (Katz et al. 2021). Plants that grow in silicon-deficient soils are less mechanically robust, consequently more sensitive to various disorders and abiotic stressors, and more vulnerable to various diseases. Some researchers suggested that added silicon can mitigate the negative effects of a variety of environmental factors, especially drought. The beneficial effects due to silicon are closely correlated with silicon accumulation levels in plants. Seven of the ten most abundant crops in the world are silicon accumulators (Guntzer et al. 2012). These include barley, a very important crop in temperate climate zones. Barley itself is not entirely drought-resistant, but it has effective mechanisms enabling it to avoid drought (Dawson et al. 2015). According to literature (Newton et al. 2011) its yield is expected to remain more reliable than other important crops, such as wheat. The beneficial effects of silicon in plants are based on a protective silicon layer deposited at the leaf surface, the co-localisation of the absorbed silicon with metal ions and other compounds, and the metabolic functions of silicon in plants, exposed to stress conditions. Silicification of leaf tissues limits herbivory and pathogen infections, increasing plant shoots' rigidity. It has a similar effect on plant stiffness to that of lignin, but at a 10-20-fold lower energy cost (Schoelynck et al. 2010). In grasses, silicon is a key structural element that prevents lodging and shading of leaves. Hosseini et al. (2017) showed that silicon accumulation in shoots delays osmotic stress-induced leaf senescence in barley. It was recently reported, that the addition of silicon in the form of K_2SiO_3 significantly affected the concentration of minerals, such as Si, K, Ca, Cl, S, Mn, Fe and Zn, in the roots and leaves of barley plants (Mavrič Čermelj et al., 2022).

Our work aimed to find out the response of hydroponically grown barley to foliar addition of silicon at physiological and morphological levels.

2 MATERIALS AND METHODS

2.1 Experimental set-up

In the experiment, barley plants were grown on a floating hydroponics system that lasted 35 days. We germinated seeds of barley var. Wilma (*Hordeum vulgare* L.) in germination trays with peat substrate. After nine days, we transferred the seedlings to plastic hydroponic net pots and embedded with rockwool. Plants of barley were grown in a greenhouse at 15 °C (day) and 10 °C (night) under light panels with a 16/8 light regime with average radiation of 300 μmol/m^2 s). Plants were grown in nutrient solution for barley from Podar (2013). We sprayed half of the plants with potassium silicate (0.25 ml 6% K_2SiO_3 L^{-1}, with Si concentration 3.5 mM) every ten days (Figures 1 and 2). Control plants are marked in the tables and figures with Si0, and treated plants with Si+. The experiment was set up in five replicates (plots) and measurements were made on from 1 to 12 plants per each plot, depending on the measured parameter.

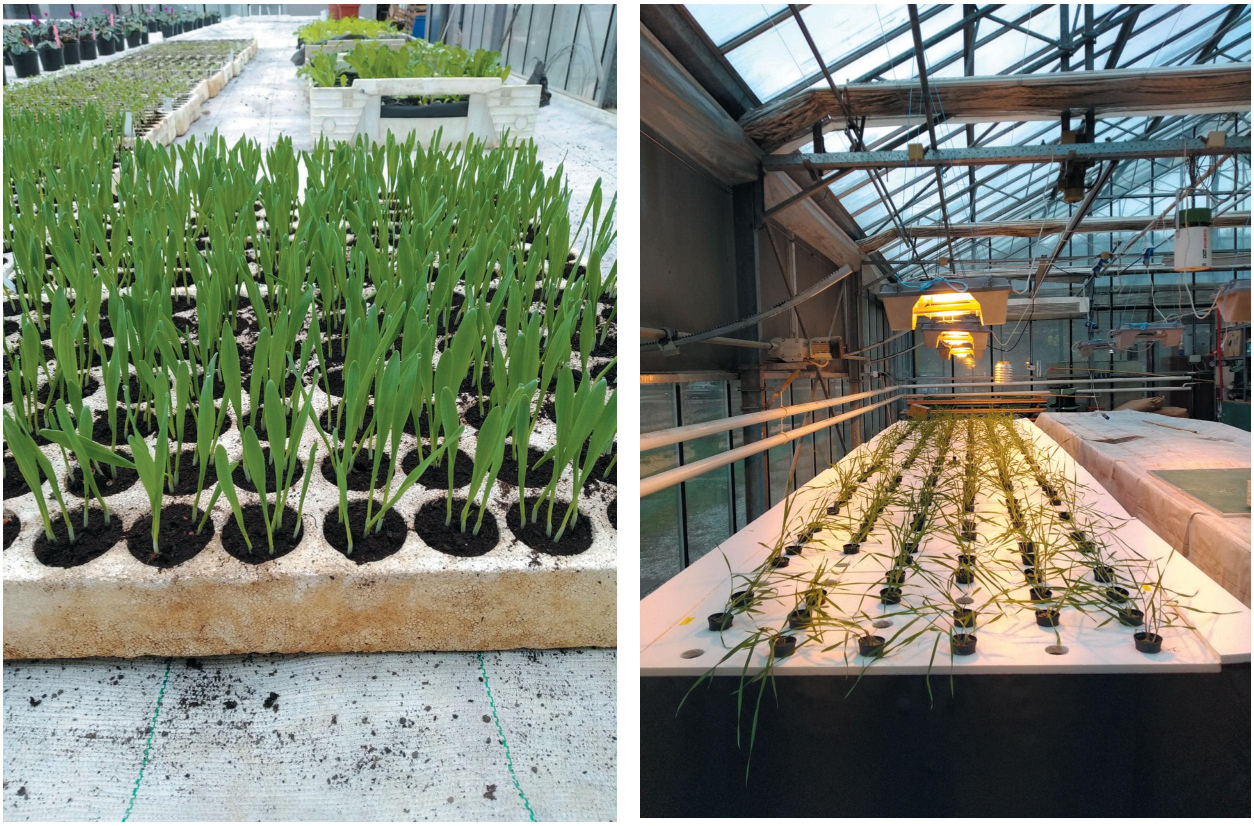
2.2 Physiological and morphological parameters

Chlorophyll fluorescence was monitored with a portable chlorophyll fluorometer (PAM-2500; Walz, Germany). The potential photochemical efficiency of photosystem (PS) II (Fv/Fm) was evaluated according to Schreiber et al. (1996).

After 16 and 35 days of silicon application, shoot length, root length, and fresh and dry biomass were measured. After 35 days, the number of leaves and shoots, specific leaf area, leaf optical properties, and lipid peroxidation were determined.

2. 3 Optical measurements

The reflectance and transmittance spectra of fresh barley leaves were measured in the laboratory immedi-



Figures 1 and 2: Experimental setup in the department of Agronomy, Biotechnical Faculty.

ately after their collection in the growing chamber. The procedure is described in Klančnik et al. (2012). The measurements were made from the range of 300 nm to 820 nm, at every ~1.3 nm, with a portable spectrophotometer (Jaz Modular Optical Sensing Suite; Ocean Optics, Inc., Dunedin, USA), that was connected to an optical fiber (QP600-1-SR-BX; Ocean Optics, Inc.) and an integrating sphere (ISP-30-6-R; Ocean Optics, Inc.). During measurements, the samples were illuminated with a UV-VIS-near infrared light source (DH-2000; Ocean Optics, Inc.).

2.4 Lipid peroxidation

Lipid peroxidation was estimated according to protocol by Hodges et al. (1999). Five leaves per treatment replication were frozen in liquid nitrogen and saved at -80 °C until used to determine malondialdehyde (MDA) as an index of general lipid peroxidation.

2.5 Statistical analysis

Statistical analysis was made using the statistical software XL Stat for Excel (Version 2112, Addinsoft, Paris, France). The normal distribution of data was checked with Shapiro–Wilk test. Upon confirmation of normal distribution, data were further analyzed with a t-test to distinct between the control and treatment. Visual representation of results was created with the use of MS Excel. The level of significance was accepted at $p < 0.05$.

3 RESULTS AND DISCUSSION

The potential photochemical efficiency of PS II was unaffected by the addition of silicon. Values were close to the theoretical optimum (0,78) (Table 1). The absence of the effect of silicon on photochemical efficiency of PS II and values close to the theoretical optimum indicated that plants were not under stress and that the photosynthetic apparatus was not damaged (Schreiber et al., 1996).

Table 1: Photochemical efficiency of photosystem II in the middle (day 15) and final sampling (day 35) of the experiment for Si0 and Si+ treated plants.

Day	Si0	Si+
Day 15	0.77 ± 0.01a	0.77 ± 0.01a
Day 34	0.79 ± 0.01a	0.78 ± 0.02 a

Data are means ± SD, n= 25. Letters indicate significant differences (p≤0.05, Duncan test).

Results showed lower leaf reflectance for silicon-treated plants in UVA, UVB, and blue light wavelengths. The difference in the reflectance may be caused by a layer of potassium silicate on leaves (Figure 3). The results differ from those of Golob et al. (2017), who observed a positive correlation between the amount of phytoliths on leaf surface of wheat and the reflectance spectrum in the UVB part. With Si or Ca incrusted surfaces of leaves present the first barrier to UV rays that reach the leaf surface (Klančnik & Gaberščik, 2016), and can affect their optical properties.

Statistically significant differences were also found on the 16th day after the first silicon application when roots were longer in Si treated plants compared to control plants. The shoot fresh weight of silicon-treated plants was higher than in control plants (Figure 4), indicating the positive effect of Si on plant growth. Similarly, biomass significantly increased in non-stressed wheat with foliar application of sodium silicate at tillering or anthesis stage (Maghsoudi et al. 2016). On the contrary, Habibi (2016) found no differences in

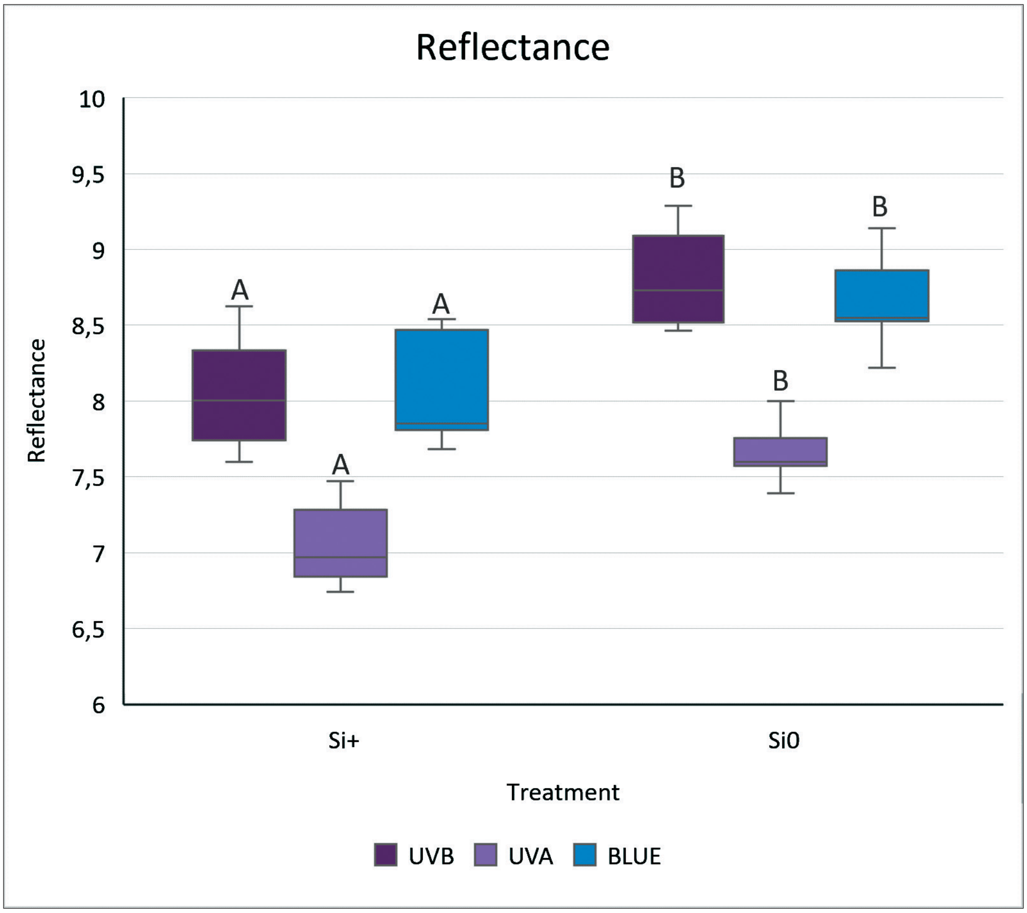


Figure 3: Reflectance in blue, UVA and UVB wavelengths for silicon-treated (Si+) and untreated plants (Si0).

fresh and dry shoot mass after application of potassium metasilicate on non-stressed maize. Foliar application of silicon is important at drought stress, with Si application increases shoot fresh and dry weight of barley (Mahmoud et al. 2021). We found no differences in other analyzed characteristics of treated and untreated barley plants (Table 2). We confirmed in our experiment that additional foliar application with Si concentration 3.5 mM does not cause stress in the barley plants and not significantly affect plant growth.

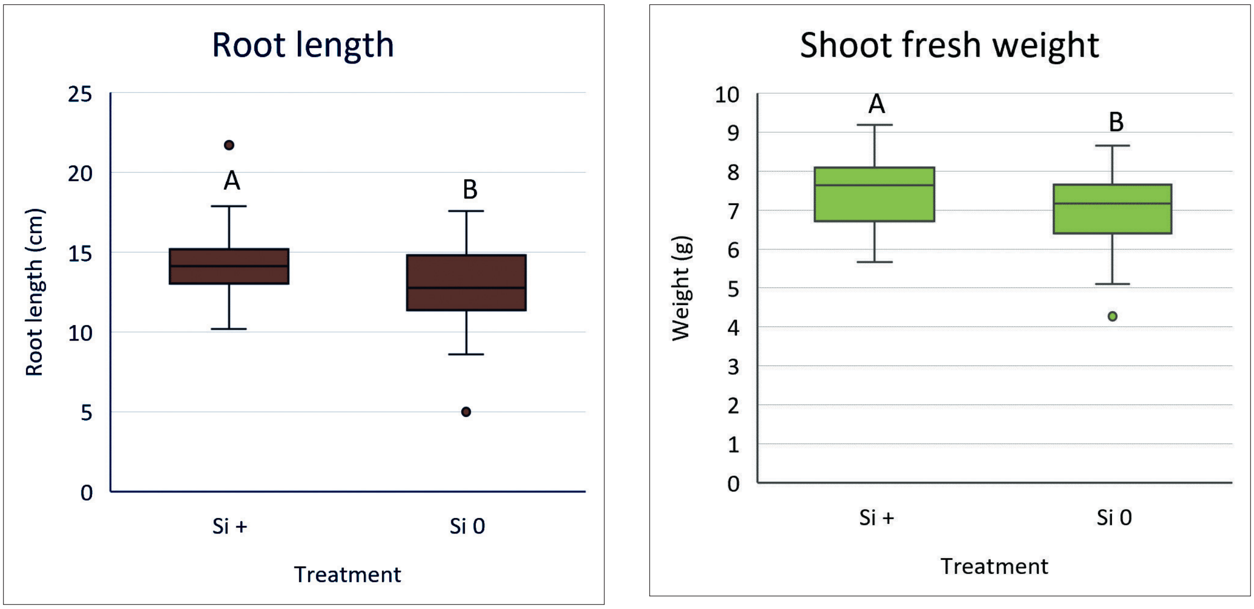


Figure 4: Fresh shoot weight and root length of silicon treated (Si+) and untreated plants (Si0) on day 16.

Table 2: Analyzed parameters in the middle (day 16) and at the end (day 35) of the experiment for Si0 and Si+ treated plants.

Day	Plant organ	Parameter	Unit	Si0	Si+
Day 16	Root	Length	cm	12.8 ± 2,8 b	14.3 ± 2.4 a
		Fresh weight	g	5.2 ± 0.5 a	5.2 ± 0.7 a
		Dry weight	g	0.4 ± 0.1 a	0.4 ± 0.0 a
	Shoot	Length	cm	40.5 ± 4.2 a	39.7 ± 2.0 a
		Fresh weight	g	6.9 ± 1.2 b	7.5 ± 0.9 a
		Dry weight	g	1.0 ± 0.2 a	1.1 ± 0.2 a
	Root	Length	cm	11.5 ± 1.3 a	11.9 ± 1.9 a
		Fresh weight	g	24.3 ± 9.0 a	18.2 ± 6.7 a
		Dry weight	g	2.2 ± 0.5 a	1.8 ± 0.6 a
	Shoot	Length	cm	58.8 ± 3.2 a	59.3 ± 2.8 a
		Fresh weight	g	25.8 ± 4.8 a	26.6 ± 4.2 a
		Dry weight	g	3.6 ± 0.8 a	3.9 ± 0.9 a
		Number of shoots	no. per pot	12 ± 2 a	12 ± 2 a
		Number of leaves	no. per pot	16 ± 2 a	16 ± 2 a
		Speficic leaf area	cm^2 g^-1	13.5 ± 0.9 a	13.1 ± 2.0 a
		Lipid peroxidation	nmol MDA g^-1	37.2 ± 7.6 a	38.8 ± 7.2 a
		Transmitance			

Day 35	Leaf	UV-B	/	0.04 ± 0.11 a	0.07 ± 0.27 a
		UV-A	/	0.05 ± 0.06 a	0.08 ± 0.15 a
		Blue	/	0.26 ± 0.09 a	0.31 ± 0.14 a
		Green	/	6.98 ± 0.50 a	7.46 ± 0.52 a
		Yellow	/	6.31 ± 0.63 a	6.78 ± 0.44 a
		Red	/	14.12 ± 0.35 a	14.50 ± 0.59 a
		NIR	/	59.76 ± 1.29 a	58.83 ± 0.84 a
		Reflectance			
		UV-B	/	8.79 ± 0.29 a	8.03 ± 0.34 b
		UV-A	/	7.66 ± 0.20 a	7.06 ± 0.27 b
		Blue	/	8.66 ± 0.32 a	8.07 ± 0.36 b
		Green	/	13.42 ± 0.66 a	12.50 ± 0.84 a
		Yellow	/	12.39 ± 0.67 a	11.54 ± 0.77 a
		Red	/	17.24 ± 0.64 a	16.68 ± 0.95 a
		NIR	/	45.09 ± 1.53 a	47.59 ± 8.09 a

Data are means ± SD. n= 5-60. Letters indicate statistically significant differences (p≤0.05, Duncan test).

4 CONCLUSIONS

Silicon did not have negative effects on the vitality of barley plants. The potential photochemical efficiency of photosystem II was close to the maximal value of plants, which are not exposed to stress conditions. Lower leaf reflectance for silicon-treated plants in UVA, UVB, and blue light wavelengths, is possibly the consequence of a layer of potassium silicate on leaves. We can conclude that additional foliar spraying of silicon did not negatively affect the barley plant.

5 POVZETEK

Silicij je za rastline koristen element in rastline ga v svoja tkiva nalagajo v različnih koncentracijah. Privzemajo ga lahko le v obliki monosilicijeve kisline, katere koncentracija v tleh je odvisna od fizikalnih in kemijskih lastnosti tal (Katz et al., 2021). Rastline, ki rastejo na s silicijem revnih tleh, so bolj občutljive na različne bolezni ter stres, ki ga povzročajo abiostki dejavniki. Silicij je tudi pomemben strukturni element, ki preprečuje poleganje in senčenje listov pri travah. Silicij se nalaga v različnih strukturah na površini listov, kar omeji objedanje rastlinojedcev in okužbe s patogeni ter poveča trdnost rastlinskih poganjkov. Koristni učinki silicija na rastline so tesno povezani z ravnmi kopičenja silicija v rastlinah. Med akumulatorje silicija spada navadni ječmen (*Hordeum vulgare* L.), ki je agronomsko pomembna rastlinska vrsta. Nalaganje silicija v ječmenu zakasni staranje listov zaradi osmotskega stresa (Hosseini et al., 2017). Dodajanje silicija v obliki kalijevega silikata vpliva na elementno sestavo listov in korenin ječmena (Mavrič Čermelj et al., 2022). Namen naše raziskave je bil določiti vpliv foliarnega dodajanja silicija pri hidroponsko gojenem navadnem ječmenu na njegove fiziološke in morfološke lastnosti.

Razkužena semena navadnega ječmena sorte Wilma smo nakalili v šotnem substratu ter kalice po devetih dneh presadili v plastične mrežaste hidroponske lončke s kameno volno, ki je omogočala ukoreninjenje rastlin ter jih postavili na plavajoč hidroponski sistem. Povprečna temperatura v rastlinjaku je bila 15 °C podnevi in 10 °C ponoči ter režim osvetljenosti 16 ur (noč)/ 8 ur (dan). Vsakih 10 dni smo polovico rastlin (Si+) škropili po listih s kalijevim silikatom s koncentracijo 3,5 mM Si. Druge polovice rastlin nismo škropili s Si (Si0). Za vsak tretma smo imeli pet ponovitev.

Med poskusom smo merili potencialno (Fv/Fm) fotokemično učinkovitost II. Rastline smo vzorčili med poskusom (16. dan) in na koncu poskusa (35. dan). Pri obeh vzorčenjih smo izmerili dolžino poganjkov, dolžino korenin ter svežo in suho biomaso. Na koncu poskusa smo prešteli število listov in poganjkov, določili specifično listno površino, optične lastnosti listov in stopnjo lipidne peroksidacije.

Ugotovili smo, da škropljenje s silicijem ni imelo vpliva na potencialno fotokemično učinkovitost fotosistema II pri rastlinah. Vrednosti so bile blizu teoretičnega optimuma (0,78), kar kaže na to, da rastline niso bile podvržene stresu in fotosintezni aparat ni bil poškodovan. Odboj svetlobe od listov je bil pri Si+ rastlinah pri valovnih dolžinah UVA, UVB in modre svetlobe nižji od odboja pri ostalih skupinah. Razlike v odbojnosti bi lahko povzročila plast kalijevega silikata na površini listov. Pri vmesnem vzorčenju so imele Si+ rastline daljše korenine in višjo svežo maso poganjka kot rastline, ki jih nismo škopili s Si, kar nakazuje na pozitivni vpliv Si na rast rastlin. V ostalih izmerjenih lastnostih nismo našli statistično značilnih razlik med tretmajema. Ugotovili smo, da škropljenje rastlin s kalijevim silikatom nima negativnega vpliva na vitalnost rastlin, vpliva pa na odbojnost svetlobe v določenih delih svetlobnega spektra.

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