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Effects of Nano Silicon on Growth and Physiological Properties in Deficit Irrigated Pepper (*Capsicum Annuum* L.)

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Abstract **–** Pollution and reduction of water resources have led to the production of different alternative searches in agriculture where water is consumed the most. The deficit irrigation approach, in which less water is supplied to the plants, has been accepted as a prominent practice. However, growth and so yield significantly reduced in deficit irrigation approach compared to full irrigation, constitute an important problem. Therefore, there is a need for practical actions to improve the reduced growth in the deficit irrigation approach. Nano silicon, which is produced as a result of nanotechnologies that have emerged in recent years, is mentioned as a nano fertilizer that improves growth and physiology by protecting the plant from biotic and abiotic stress factors. Thus, in this study, the effects of nano silicon applications (0 ppm, 50 ppm, and 100 ppm) on the soil of pepper plants (*Capsicum annuum* L.) growing in different irrigation levels (100%: full irrigation, 75%: deficit irrigation at 25% of full irrigation, and 50%: deficit irrigation at 50% of full irrigation) on the properties of the plant were investigated. While many properties of pepper (number of leaves and fruits, plant height, stem diameter, plant fresh weight, chlorophyll content, leaf relative water content, and electrolyte leakage) which decreased by increasing drought, nano silicon applications influenced positively the number of leaves, plant height, plant fresh weight and chlorophyll content. According to these results, a 100 ppm dose of nano silicon was found to be effective in improving some properties of plants in pepper cultivation at the decreasing irrigation water level, but investigating the effectiveness of nano silicon applications at different rates and continuing field studies on this subject were found to be advisable in the results of this study.

Keywords – Pepper, Deficit Irrigation, Drought, Nano Fertilizer, Silicon

I. INTRODUCTION

Changing world conditions, especially climate change, cause pollution and decrease in water resources. This situation mostly affects the agricultural sector. Because the agriculture sector is the sector where water is consumed the most with a ratio of approximately 70% compared to urban and industrial activities (Moghaddam et al., 2017). Thus, the importance of effective management of water resources in agricultural irrigation comes to the fore. Among the effective management plans, the deficit irrigation approach, in which less water is supplied to the plant, is considered a good alternative (Ektiren and Degirmenci, 2018). With this approach, it is possible to increase product diversity with less water and to improve water use efficiency by producing. In addition, since water saving is of great importance in sustainable irrigation, the deficit irrigation approach is considered a prominent strategy (Gokkur, 2016). However, since the yield of the plant decreases in the deficit irrigation, there is a need for practical actions to improve the decreased yield in the deficit irrigation approach.

Silicon, which is found in the highest amount in the earth's crust after oxygen, protects the plant from various biotic and abiotic stress factors (Haghighi and Pessarakli, 2013). Although the protective effect of silicon and its behavior on plant physiology are not fully understood (Horuz et al., 2017), silicon regulates the plant's water consumption, improves the structure of leaf organelles, and increases the yield and quality of the plant through the activation of plant defense systems and attenuation of specific ions (Parveen and Ashraf, 2010).

Silicon is applied to the soil or plant in the forms of calcium silicate, sodium silicate, magnesium silicate, and silicic acid, especially potassium silicate (Tantawy et al., 2015; Horuz et al., 2017; Tuna and Eroglu, 2017; Abdelaal et al., 2019; Oral et al., 2020; Badawy et al., 2021; Ismail et al., 2022). However, studies on the use of nano silicon, which is one of the nano fertilizers produced as a result of nanotechnologies that have emerged in recent years, are very limited. Nano fertilizers can be defined as nanomaterials that offer one or more nutrients to the plant more effectively and promote plant growth and development (Benzon et al., 2005). Nano fertilizers, together with their slow dissolution feature, can hold on to the soil for longer periods without being washed from the soil, to remain more effective in the soil without binding to structures such as organic matter, clay and lime, and without turning into useless forms, and thus, they can be taken more easily by plants (Mukherjee et al., 2015). In addition, according to synthetic fertilizer applications, nano fertilizers do not have a negative effect on the environment and are defined as environmentally friendly applications (Yaghubi et al., 2019).

Therefore, by hypothesizing that nano silicon would be effective in improving the decreased growth under deficit irrigation conditions, the effects of nano silicon applications at varying rates to the soil in increased drought conditions on growth and physological properties of pepper plants (*Capsicum annuum* L.) were investigated.

II. MATERIALS AND METHOD

A completely randomized factorial experiment was designed in a plastic-covered greenhouse located in the experimental area of Van Yuzuncu Yil University, Faculty of Agriculture. The study, which was carried out in 4-liter pots with 3 replications, was designed usnig 3 different irrigation water levels (100%: full irrigation, 75%: deficit irrigation at 25% of full irrigation, and 50%: deficit irrigation at 50% of full irrigation) and nano silicon applications (0 ppm, 50 ppm, and 100 ppm) in a total of 27 pots. During the study period, the mean daily temperature and humidity of the greenhouse measured by the automatic weather device (HOBO, Campbell Scientific, USA) were 27.7±4.8°C and 42.6±7.1%.

The seedling stage plant material (*Capsicum annuum* L.) and nano silicon used in the study were obtained commercially. Study soil with a texture of sandy loam (sand: 57%, silt: 25%, clay: 18%) in USDA classification was brought to the experimental area and some analyses were made. As a result of these analyses, it was determined that the electrical conductivity, pH, organic matter and total nitrogen content of the study soil were 0.29 dS m^{-1}, 8.27, 1.76%, and 0.115%.

The air-dried soil, which were passed through a 4 mm sieve, were transferred to pots and then, after the pepper seedlings were planted in the pots, all the pots were irrigated with equal irrigation quantitiy to complete the field (pot) capacity. With the first irrigation at this stage, nano silicon applications (0 ppm, 50 ppm, and 100 ppm) were carried out on the soils, and then irrigation applications were started with different irrigation levels (100%, 75%, and 50%). The field (pot) capacity was determined by saturating the pots without nano silicon (0 ppm) with capillarity and then weighing after draining of the water above the field capacity. Irrigation time was determined to be approximately once every three days, which was equal to 30% of the available water capacity consumed in the control application.

Pepper plants were harvested when they reached marketable yield and some measurements were made. While the number of leaves and fruits in the harvested plants was determined by counting, plant height and stem diameter were determined by measuring with a ruler and digital caliper, respectively. Plant fresh weight was obtained by weighing the harvested plants. Chlorophyll content was determined by making five readings from the leaves of each plant with the SPAD 502 chlorophyllmeter device (Tunalı et al., 2012). Leaf relative water content (LRWC) was calculated with the help of Equation 1 by determining the turgor weights (TW) of the fresh weights (FW) taken from the leaf samples in distilled water for 4 hours, and then keeping them in an oven at 65ºC for 48 hours and determining their dry weight (DW) (Kaya, 2011). Disc samples taken from the leaves of each plant were kept in 30 ml of ionized water in 50 ml tubes for 24 hours, the EC value was measured (EC1) and then the same samples were kept in a water bath at 95°C for 20 minutes, cooled to room temperature, the EC value (EC2) was measured and finally electrolyte leakage (EL) was determined by calculating with Equation 2.

$$LRWC = (FW - DW) / (TW - DW) \times 100 \quad (1)$$

$$EL = (EC1 / EC2) \times 100 \quad (2)$$

Statistical evaluation of the data obtained in the study was carried out in the SPSS statistical program (Ver. 21). The data were analyzed with the General Linear Model and the significant means were separated at the 5% significance level with the Duncan Multiple Range Test.

III. RESULTS AND DISCUSSION

While the effect of irrigation treatments on the whole properties of pepper examined in this study (number of leaves and fruits, plant height, stem diameter, plant fresh weight, chlorophyll content, leaf relative water content, and electrolyte leakage) was significant ($p<0.01$), the effect of nano silicon treatments was significant for number of leaves ($p<0.05$), plant height, plant fresh weight and chlorophyll content ($p<0.01$) but the effect of nano silicon treatments on number of fruits, stem diameter, leaf relative water content and electrolyte leakage was found to be insignificant (Table 1 and Fig. 1).

The decrease in the number of leaves and fruits, plant height, stem diameter, plant fresh weight of the pepper under deficit irrigation conditions can be explained by the weakening of the physiological functions of the plant against the increased moisture deficit in the soil as an expected effect. Decreased moisture in the soil negatively affects the vital functions of pepper (Pellitero et al., 1993). Thus, the plant, which is exposed to stress, limits some of its physical properties to survive (Gencoglan, 2006). The first affected organs of the plant grown in arid conditions usually appear as physical characteristics such as height, diameter, weight, number of leaves, number of fruits, and area (Sultan, 2021).

The decrease in the chlorophyll content of pepper with the decreasing irrigation water level can be explained by the limitation of photosynthetic activity as a result of closing the stomata of the plant under insufficient soil moisture conditions. The chlorophyll content of the plant is considered a clear indicator of water stress (Bauerle et al., 2004). Thus, the chlorophyll development of the plant, which provides insufficient water flow from the soil, decreases (Yerli et al., 2023). The decrease in the physical development of the plant under increasing drought conditions further limits the growth functions of the plant, further reducing the chlorophyll content of the plant (Guo et al., 2015). The decrease in the leaf relative water content of the pepper under deficit irrigation conditions can be evaluated by the decrease in water storage in the leaves as a result of the plant's inability to get enough water in the decreasing soil moisture. In drought conditions, plants close their stomata to resist stress, and then they lose water from their leaves with the increase in leaf temperatures due to increased drought (Yildirim et al., 2022). In addition, Omami and Hammes (2016) explained the decrease in the leaf relative water content of the plant with the decrease in the osmotic potential at the decreasing irrigation water level. In drought conditions, the closure of the stomata, the increase in leaf temperatures, and the decrease in the leaf relative water content lead to deterioration of the functionality of the cell membrane system, and membrane damage occurs (Ozturk, 2015). Thus, in this study, the reason for the increase in electrolyte leakage of pepper at the decreasing irrigation water level can be explained. Therefore, it can be said that the increasing effect of water stress on electrolyte leakage is due to the decrease in the leaf relative water content. The negative correlation ($p<0.01$) between electrolyte leakage and leaf relative water content also supports this situation (Table 2). In addition, Wild and Kabay (2018) and Kusvuran et al. (2020) also reported that the electrolyte leakage of pepper grown in arid conditions increased.

The nano silicon applications increase the number of leaves and plant height of pepper can be explained by the fact that nano silicon regulates the transpiration rate of the plant and protects the water content of the plant. Silicon is defined as an element that regulates the water content of the plant and increases the physical development of the plant under stress conditions (Reezi et al., 2009). Haghighi and Pessarakli (2013) stated that silicon plays an important role in maintaining moisture in the plant body by the reducing transpiration rate under stress conditions.

Table 1. Variance analysis results in some properties of pepper in irrigation and nano silicon treatments

Parameter	Variance source	Mean square	F	P	Parameter	Variance source	Mean square	F	P
NL	**I**	641.926	38.861	0.000	***NF***	**I**	5.481	7.048	0.005
	N	67.704	4.099	0.034		**N**	0.259	0.333	0.721
	I × N	0.481	0.029	0.998		**I × N**	0.093	0.119	0.974
	Error	16.519				**Error**	0.778		
PH	**I**	247.815	25.934	0.000	***SD***	**I**	15.945	29.386	0.000
	N	65.815	6.888	0.006		**N**	1.103	2.032	0.160
	I × N	1.093	0.114	0.976		**I × N**	0.035	0.065	0.991
	Error	9.556				**Error**	0.543		
PFW	**I**	4 564.037	93.710	0.000	***CC***	**I**	344.333	44.271	0.000
	N	370.481	7.607	0.004		**N**	65.333	8.400	0.003
	I × N	2.593	0.053	0.994		**I × N**	0.667	0.086	0.986
	Error	48.704				**Error**	7.778		
LRWC	**I**	380.481	9.314	0.002	***EL***	**I**	1 138.778	206.356	0.000
	N	8.259	0.202	0.819		**N**	16.778	3.040	0.073
	I × N	0.926	0.023	0.999		**I × N**	2.889	0.523	0.720
	Error	40.852				**Error**	5.519		

NL: Number of leaves, NF: Number of fruits, PH: Plant height, SD: Stem diameter, PFW: Plant fresh weight, CC: Chlorophyll content, LRWC: Leaf relative water content, EL: Electrolyte leakage, I, N, and I × N represent irrigation water levels, nano silicon treatments, and interaction of I and N, respectively

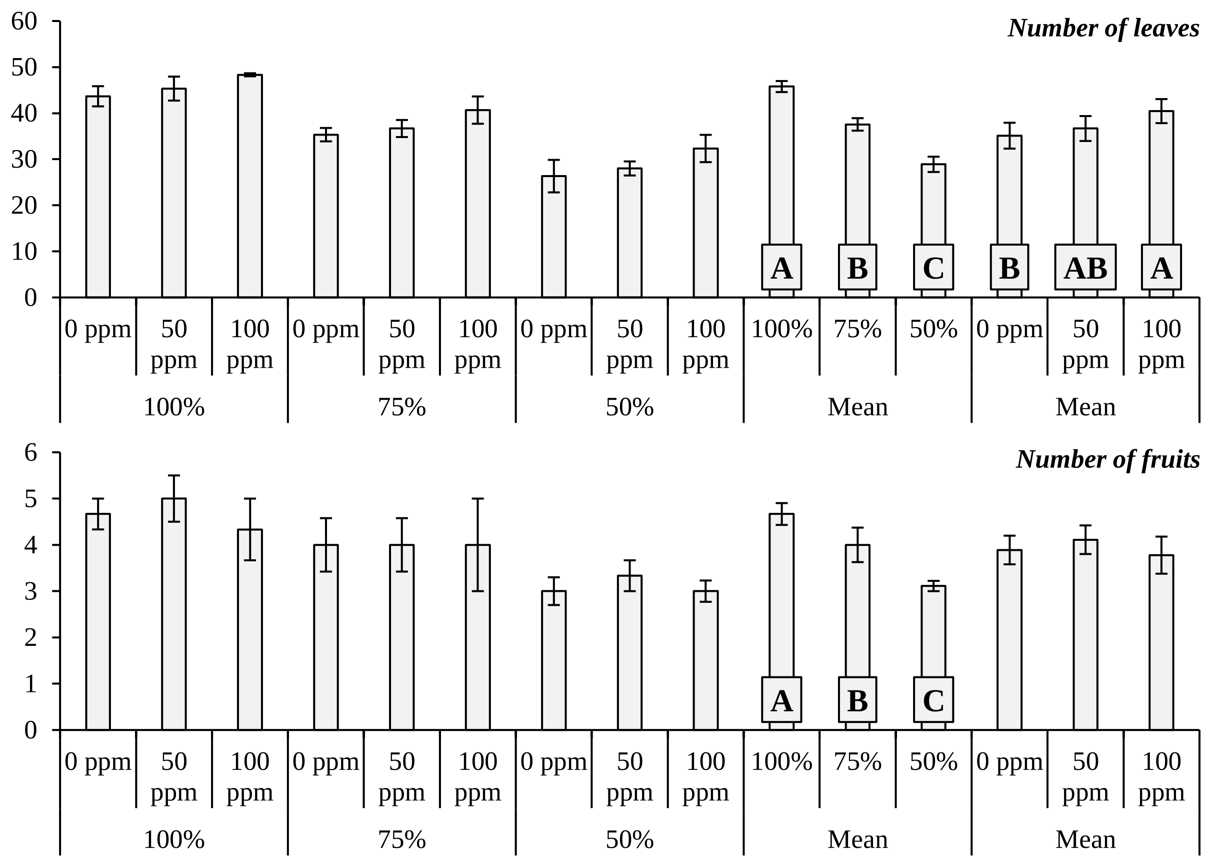

Fig. 1 Changes in some properties of pepper in irrigation and nano silicon treatments
While 100%, 75%, and 50% represent irrigation water levels, 0 ppm, 50 ppm, and 100 ppm represent nano silicon treatments

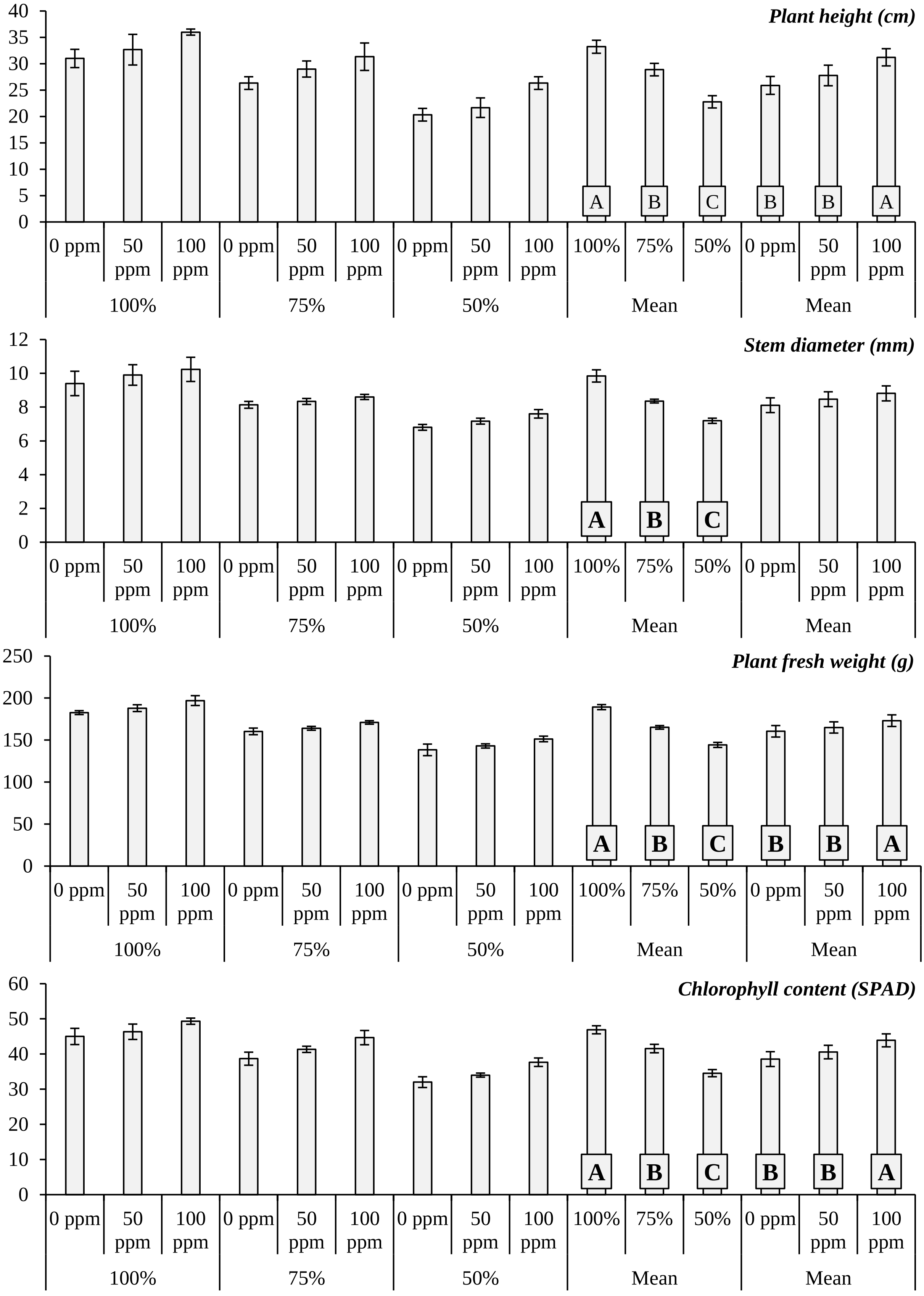

Fig. 2 Changes in some properties of pepper in irrigation and nano silicon treatments (continue)
While 100%, 75%, and 50% represent irrigation water levels, 0 ppm, 50 ppm, and 100 ppm represent nano silicon treatments

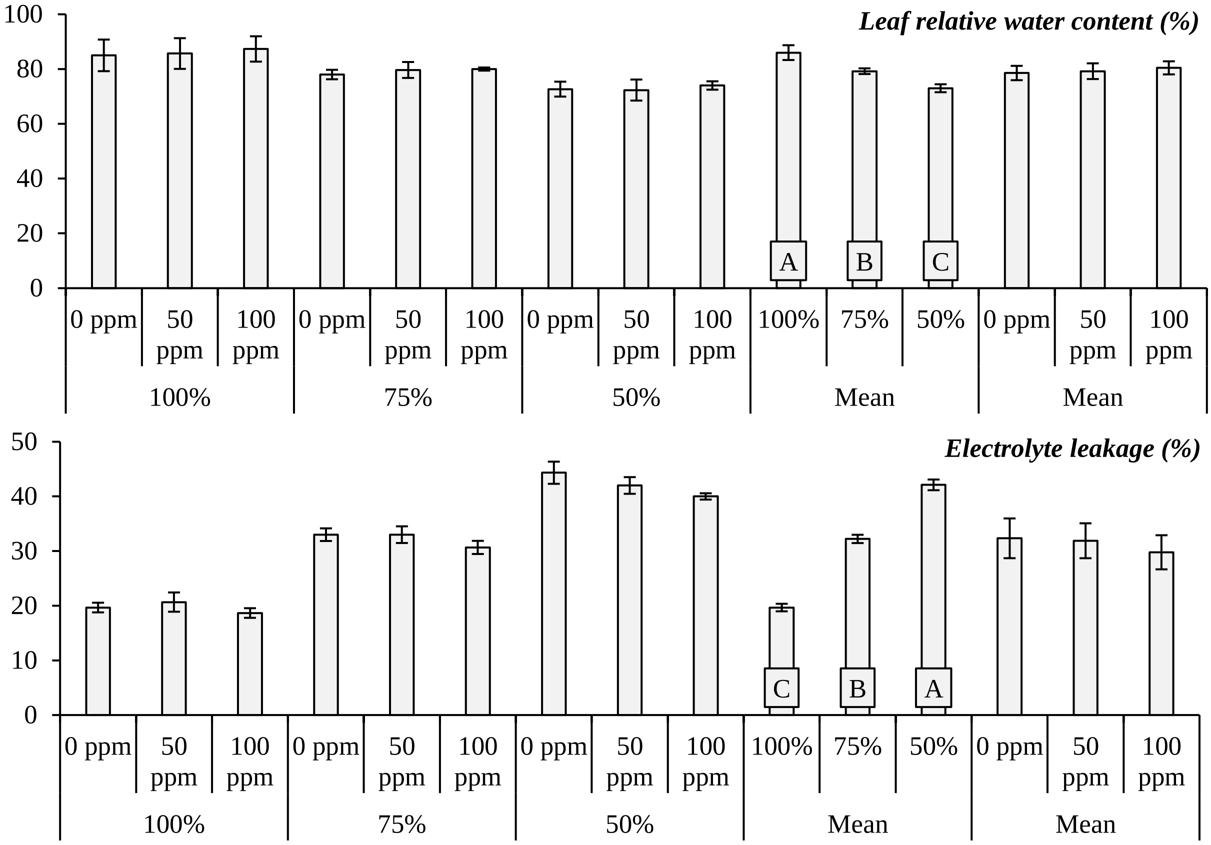

Fig. 3 Changes in some properties of pepper in irrigation and nano silicon treatments (continue)
While 100%, 75%, and 50% represent irrigation water levels, 0 ppm, 50 ppm, and 100 ppm represent nano silicon treatments

Table 2. Correlation relations among some properties of pepper in irrigation and nano silicon treatments

	NF	***PH***	***SD***	***PFW***	***CC***	***LRWC***	***EL***
NL	0.554**	0.783**	0.801**	0.816**	0.781**	0.630**	-0.890**
NF		0.608**	0.505**	0.655**	0.552**	0.433*	-0.605**
PH			0.786**	0.845**	0.866**	0.519**	-0.797**
SD				0.871**	0.840**	0.528**	-0.839**
PFW					0.902**	0.669**	-0.923**
CC						0.552**	-0.834**
LRWC							-0.678**

NL: Number of leaves, NF: Number of fruits, PH: Plant height, SD: Stem diameter, PFW: Plant fresh weight, CC: Chlorophyll content, LRWC: Leaf relative water content, EL: Electrolyte leakage, **: p<0.01, and *: p<0.05

The slow dissolution and retention properties of nano silicon in the soil for longer periods without being washed out of the soil increase its effectiveness under stress conditions according to silicon (Mukherjee et al., 2015). Nano silicon significantly increases the strength of the cell wall under stress conditions, and 1 gram of nano silicon particles provides an absorption surface equal to 400 m2 (Kalteh et al., 2018). Thus, nano silicon particles significantly improve xylem water transmission and water translocation, increasing the plant's water use under stress conditions (Wang and Naser, 1994). The increase in plant fresh weight of pepper by nano silicon applications can be evaluated due to the increase in the number of leaves and plant height of pepper in nano silicon applications. The positive correlations ($p<0.01$) of plant fresh weight with number of leaves and plant height also supports this situation (Table 2). In addition, Haghighi and Pessarakli (2013) stated that nano silicon applications increased the fresh and dry weight of tomatoes, while Siddiqui et al. (2015) reported that nano silicon application to squash grown under stress conditions improved the physical properties of squash. Similarly, in a different study, attention was drawn to the effects of nano silicon application against stress in rose cultivation to improve the physical properties that affect the yield (Reezi et al., 2009).

The nano silicon applications increase the chlorophyll content of pepper can be explained by the fact that nano silicon regulates the transpiration rate of the plant and protects the water content of the plant, as well as increasing the chloroplast development of the plant. Photosynthesis, which is the main energy source for plants, is directly related to leaf structure (Asmar et al., 2013). Therefore, the absorption of nano silicon from the soil and its accumulation in the leaves directly increase chloroplast development and provide a better chlorophyll content (Avestan et al., 2021). Under stress conditions, silicon reduces the weakening of chlorophyll content by helping to heal the leaf epidermis and other tissue thicknesses (Ju et al., 2017). In addition, changes in the nutrient intake of the plant with nano silicon application may also support the increase in chlorophyll content (Reezi et al., 2009). In addition to all these, the positive correlation ($p<0.01$) between the chlorophyll content and the number of leaves determined in this study (Table 2) may be a different approach explaining the increase in the chlorophyll content of pepper in nano silicon applications. In addition, similar to the findings of this study, it has been reported in many studies that nano silicon applications increase the chlorophyll content of different plants (Bao-Shan et al., 2004; Reezi et al., 2009; Haghighi and Pessarakli, 2013; Avestan et al., 2019; Avestan et al., 2021).

IV. CONCLUSION

In light of the results obtained, 100 ppm dose of nano silicon application was found to be effective in improving some properties of plants in pepper cultivation at the decreasing irrigation water level, but investigating the effectiveness of nano silicon applications at different rates and continuing field studies on this subject were found to be advisable in the results of this study.

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