Pak. J. Agri. Sci., Vol. 59(1), 83-92; 2022
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/22.1404
http://www.pakjas.com.pk

The role of silica fertilizer on morphological traits of sorghum forage under drought stress

Ehsan Rezaei, Hamidreza Larijani, Pourang Kasraie, Hamidreza Tohidi Moghadam and Farshad Ghooshchi

Department of Agronomy, Varamin-Pishva Branch, Islamic Azad University, Varamin, Iran.
*Corresponding author's e-mail: larijani2004@yahoo.com

Evaluate silica fertilizer's effect on the quantitative and qualitative yield of forage sorghum (*Sorghum bicolor* L.) under drought stress. A split-plot experiment was implemented in a randomized block design with three replications in two cropping years, 2017-2018, in a farm located in the Varamin - Iran. The treatments included irrigation at three levels of 60, 120 and 180 mm of evaporation from class A's evaporation pan level. The main factor was silica fertilizer as non-consumption (control), foliar application and silica irrigation fertilizer as a secondary factor. Based on the obtained results, the treatment containing total chlorophyll, RWC and stomatal conductance was obtained from the 60 mm evaporation treatment and silica fertilizer use in irrigation water. The use of silica fertilizer as irrigation water reduced the Hydrogen cyanide content by 4%. The highest amount of crude protein was estimated to be 12.60 from 180 mm stress treatment and the use of silica fertilizer in irrigation water, which were 19% higher than the control treatment, respectively. The best sorghum dry forage yield was obtained from 60 mm evaporation irrigation and silica irrigation fertilizer with an average of 82.22 ton ha^{-1}, which was 52% higher than the 180 mm evaporation stress treatment.
Keywords: Auxin hormone, crude protein, irrigation, silica fertilizer, sorghum and hydrogen cyanide.

INTRODUCTION

The quantity and quality of forage plants are beneficial and useful due to their role in animal husbandry, reproduction and other livestock products (Hayes *et al*., 2013; Gonulal, 2020). Due to the scarcity of water resources, drought as a significant non-biological stressor is the most severe threat to world food security and is responsible for many plant shortages (Farooq *et al*., 2009). Sorghum (*Sorghum bicolor* L.) is the fifth most crucial grain globally after wheat, rice, corn and barley (De Morais *et al*., 2017). Sorghum can devote itself to adverse environmental conditions (Getachew *et al*., 2016). Therefore, it is mostly grown in hot and dry areas that are not suitable for growing other forage plants such as corn (Jahanzad *et al*., 2013; Rizal *et al*., 2014; Hadebe *et al*., 2017). Morphological and physiological traits of plants together cause changes in relative leaf water content, relative water content lost, chlorophyll content, proline accumulation, osmotic regulation and other parameters such as stomatal exchange (CO_2) are related (Ghaderi *et al*., 2018). In general, water stress reduces photosynthesis and ultimately reduces plant growth and yield by reducing leaf area, closing pores, reducing pore conductivity, dehydrating chloroplasts and other parts of the protoplasm, and reducing protein and chlorophyll production (Khalilzadeh *et al*., 2012; Hejazi *et al*., 2013). It has been stated that the use of silica by increasing the ability to absorb water can be useful to improve drought tolerance of sorghum, sorghum can with the help of silica extract more water from dry soil and maintain more stomatal conductance (Ghanem *et al*., 2019). Silica increases the fresh, dry weight by improving leaf and flower morphological characteristics such as leaf area increase, leaf thickness, flower diameter, petal surface and petal thickness (Tofighi Alikhani *et al*., 2020). Silica increases photosynthetic pigments, Rubisco enzyme and photosynthetic capacity, reduces oxidative stress and protects macromolecules such as proteins and chloroplast membranes in the cell (Enteshari *et al*., 2011). In another report, it was stated that silica increases the trigger pressure by improving water use efficiency and relative leaf water content (Kalteh *et al*., 2014). Other studies the effect of silica on sorghum plant showed that silica treatment increased the resistance and amount of soluble carbohydrates compared to silica-free treatments under stress (Yin *et al*., 2013; Hattori *et al*., 2009). They were reported with wheat plants (Pei *et al*., 2010). Therefore, considering the importance of drought stress in agriculture and its increasing extent and the need to produce

Rezaei, E., H. Larijani, P. Kasraie, H. T. Moghadam and F. Ghooshchi. 2022. The role of silica fertilizer on morphological traits of sorghum forage under drought stress. Pakistan Journal of Agricultural Sciences. 59: 83-92.
[Received 17 Nov 2020; Accepted 1 Feb 2022; Published 18 Mar 2022]

high-quality fodder, this study aims to (1) understand the nutritional dynamics of silica in sorghum leaves and roots its effect on morphological and physiological parameters designed. (2) Does silica improve drought tolerance in sorghum, and (3) Does silica fertilizer under drought stress conditions affect the plant's quantitative and qualitative characteristics?

MATERIALS AND METHODS

This experiment was carried out in 2017-2018 in Varamin - Iran, located at latitude 35.21E and longitude: 51.38N and at an altitude of 927 above sea level. This region's climate is arid and semi-arid, and the average rainfall of the last 38 years has been 251 mm. The average annual air temperature is 16.5 C, the average soil temperature is 15.5 c, and the evaporation rate from the surface of the annual evaporation pan is 2607 mm (Figures 1 and 2).

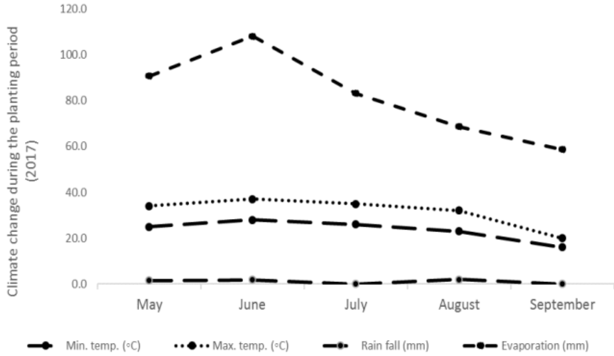

Figure 1. Temperature, average rainfall and transpiration in Varmint 2017.

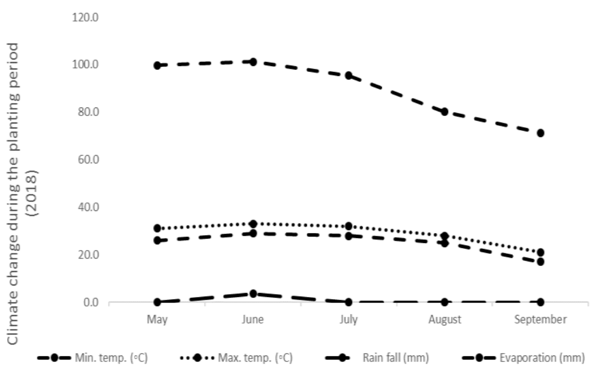

Figure 2. Temperature, average rainfall and transpiration in Varmint 2018.

Before conducting a field experiment to determine the soil's physical and chemical properties, sampling was done from a depth of 0-30 cm. The results of the analysis of the physical and chemical properties of soil are shown in Table 1. The experiment was performed as a split-plot based on randomized complete blocks in three replications. The studied treatments included three levels of drought stress as the main factor (irrigation after 60, 120 and 180 mm evaporation from the class A pan) and silica fertilizer as a secondary factor, including not using silica (control) solution. Silica spraying with a ratio of three per thousand and silica irrigation fertilizer at the rate of 10 litres per hectare was considered in three stages.

Up to the four-leaf sorghum stage, all plots were irrigated uniformly, and different levels of drought stress were applied after this stage. The irrigation of this experiment was drip irrigation, and the diameter of each irrigation strip was 16 mm, the distance of each dropper was 15 cm, and the flow rate was 2 litres per hour. Its duration in each irrigation step was 3 hours. The time of applying silica fertilizer from potassium silicate source (K_2O -10%, SiO_2 - 20%) was performed in three stages, including the five-leaf stage and before the first flowering and the next stage 20 days after the first harvest of sorghum. The test site was prepared for planting each year by plowing, disc and trowel. 150 $kg.ha^{-1}$ ammonium phosphate fertilizer and 100 $kg.ha^{-1}$ urea fertilizer were used as primary fertilizer. Farrow and the experimental map created planting lines. The distance between the lines was 60 cm, and each treatment consisted of four lines with a length of five meters. According to the experimental plan, 10 $kg.ha^{-1}$ sorghum seeds were sown manually at the time of sowing. During the growing season, operations were carried out, including weeding, irrigation, thinning and weeding, weeding and irrigation. All the parameters studied in this experiment were measured at the flowering stage of sorghum. Leaf area index (LAI) was obtained from the relation A = L * W * 0.75, in which L: leaf length (cm), W: largest leaf width (cm) and A: total leaf area in terms of (cm) (Huang *et al.*, 2015). Relative leaf water content (RWC) was measured using the Levitt (1980) formula (Formula 1).

Formula (1): $\mathrm{RWC} = (\mathrm{FW} - \mathrm{DW}/\mathrm{SW} - \mathrm{DW}) \times 100$

In this experiment, FW is fresh weight, DW is dry weight, and SW is the sorghum forage weight. Leaf orifice conductivity was measured using the Mk3 T-Delta Porometer (Model AP3, made in the USA) at 25 ° C and 40% relative humidity at 11 to noon. To measure ion leakage in terms of ($\mu s\ Cm^{-1}$) and according to the method described by Zhao *et al.* (2009) was

Table 1. Physical and chemical characteristics of farm soil.

TEXTURE	SAND (%)	SILT (%)	CLAY (%)	pH (1-14)	EC (dS.m)	Depth (cm)	
Clay	25	22	53	7.3	3.8	0-30	
N (ppm)	**K (ppm)**	**P (ppm)**	**Cu (ppm)**	**Mn (ppm)**	**Zn (ppm)**	**Fe (ppm)**	**OC (%)**
1.1	210	10	2.2	2.5	1.1	1.5	0.8

evaluated. Total chlorophyll was measured using (mg g^{-1} FW) by Lichtenthaler (1987) method. The dry and the fresh weight of sorghum forage was calculated from two forage harvests per crop year. Accordingly, by removing the margins, an area of two square meters was harvested from each plot, and immediately the relevant sample was weighed. The amount of fresh forage yield per ton per hectare was calculated. Then, to measure the dry weight of forage, a one kg sample was randomly prepared from each treatment and dried for 48 hours in an oven at 85 ° C. Then, the dry forage yield was calculated per hectare per ton. After calculating each sorghum batch's dry weight to determine the quality characteristics of sorghum, from a total of two harvesting stages, a 500 g sample of dry forage was randomly selected and used to determine digestible dry matter (DMD), crude protein (CP). For this measurement, the Near-Infrared Spectrometer (NIR) (Model Inframatics 8620, Sweden) was used. The device was calibrated using SESAME software based on data related to forage grasses. After calibration, the NIR device was performed according to the method proposed by (Jafari *et al*., 2003). At full flowering, sorghum auxin (IAA) in terms of (nmol/g of protein) was obtained by Shengjie *et al*. (2008) and Hydrogen cyanide in terms of (ppm) by titration (Nejad *et al*., 2014). Statistical calculations were performed using SAS statistical software (version 9.4) and mean comparison with the test (LSD).

RESULTS

***Leaf Area Index (LAI)*: ** Leaf area index is one of the components of plant growth rate that increase or decrease directly affects changes in plant growth rate (Gul *et al*., 2015). The variance analysis (Table 2) showed that in addition to simple effects was significant, the interaction effect of drought stress in silica fertilizer on leaf area index ($p \leq 0.01$). The highest leaf area index with an average of 4.49 evaporated at the time of 60 mm irrigation. It was obtained using silica fertilizer in irrigation water, which was 46% higher than the irrigation treatment of 180 mm of evaporation and no use of silica fertilizer (Table 3). It seems that drought stress reduces the leaf area index by making leaf water potential and cell divisions and not providing the assimilates needed for leaf growth. However, the use of silica leads to its accumulation in the leaves and leaves more tensile strength against water stress. Similar results have been reported by other researchers regarding the positive effect of silica on drought stress conditions (Malhotra and Kapoor, 2019; Törnros and Menzel, 2014).

***Relative water content (RWC)*: ** The relative content of leaf water is one of the mechanisms of drought tolerance, and the more RWC the plant has, the more tolerance to drought stress (Nouri *et al*., 2011). The analysis of variance in (Table 2) showed that in addition to simple effects was significant, the interaction effect of drought stress in silica fertilizer on the relative water content ($p \leq 0.01$). Based on this study (Table 3), the highest relative leaf water content was obtained from irrigation treatments of 60 mm evaporation and application of silica as silica irrigation fertilizer 88.03% and foliar spraying 87.62%. On the other hand, the lowest content Relative leaf water was obtained from irrigation treatment of 180 mm evaporation and non-application of silica fertilizer with an average of 53.67%. Another significant result was the use of silica fertilizer as irrigation water in 120 mm evaporation irrigation treatment with an average of 77.96% with 60 mm evaporation irrigation treatment and no silica fertilizer with an average of 80.19% were in a statistical group. The result shows the importance of silica fertilizer in maintaining moisture in drought-stress conditions. In this regard, there is a positive effect of silica fertilizer on the relative water content under drought stress (Othmani *et al*., 2020; Nabizadeh *et al*., 2010).

Table 2. Analysis of variance of leaf area index, relative leaf water content, ion leakage, stomatal conductance and total chlorophyll

Source	DF	Leaf Area Index	Relative water content	Ion leakage	Stomatal guidance	Complete chlorophyll
		M.S.				
Year	1	7.601**	85.950n.s	35703.85**	0.9645**	0.0460**
Rep(year)	4	1.196**	125.120**	28849.48**	0.126*	0.005n.s
Drought	2	18.213**	3310.510**	596322.80**	6.982**	4.995**
Year × drought	2	0.260n.s	0.67284	8.45n.s	0.0015n.s	0.0449**
Eror a	8	1.162	151.930	4517.12	0.029	0.002
Silicon	2	3.547**	1399.466**	82693.98**	3.287**	0.222**
Year × silicon	2	0.421n.s	9.376n.s	33.89n.s	0.0002n.s	0.002n.s
Drought × Silicon	4	1.312**	466.580**	15871.47**	0.5881**	0.024**
Year×Drought×silicon	4	0.117n.s	1.765n.s	22.38n.s	0.001n.s	0.0009n.s
Error b	132	0.235	22.501	967.81	0.037	0.003
CV (%)		12.51	6.25	6.32	9.73	7.65

n.s. = Non-significant * = Significant at 5% level ** = significant at %1 level

***Ion leakage*:** Ion leakage was significantly ($p \leq 0.01$) affected by the interaction of drought stress and silica fertilizer (Table 2). This study (Table 3) showed that under drought stress, the ion leakage of sorghum cells was increased. The application of silica fertilizer reduces the amount of damage to cells under stress so that the least amount Ionic leakage from 60 mm irrigation treatment evaporation and application of silica fertilizer as irrigation fertilizer with average (356.07 μs Cm^{-1}) 72% of the highest ion leakage from 180 mm evaporation irrigation treatment was obtained and no application of silica fertilizer with average (614.05 μs Cm^{-1}). As this experiment shows, the occurrence of drought stress by increasing ion leakage leads to a decrease in photosynthetic capacity. On the other hand, through its deposition in the cell membrane, silica makes the cell harder and ultimately reduces the amount of ion leakage. In this regard, research results on sorghum showed that ion leakage with increasing drought stress increased significantly compared to the control (Abdelaal *et al*., 2020).

***Stomatal guidance*:** In this study, stomatal conductance was significantly ($p \leq 0.01$) affected by the interaction of drought stress and silica fertilizer (Table 2). The results of comparing the mean interaction of drought stress in silica fertilizer on stomatal conductance showed that the maximum stomatal conductivity evaporates when irrigation is 60 mm and with the application of silica fertilizer in irrigation water (2.37 cm s^{-1}) and foliar application (2.35 cm s^{-1}) silica was obtained applying 180 mm of evaporation irrigation and not using silica fertilizer, the lowest orifice conductance with an average (1.13 cm s^{-1}) (Table 3). It seems that silica fertilizer prevents pores' closure under stress, which leads to increased and maintained CO_2 assimilation. Similar results have been reported regarding the reduction of plant stomatal conductivity under drought stress and its increase with silica fertilizer (Avila *et al*., 2019).

***Complete chlorophyll*:** In this study, the interaction effect of drought stress in silica fertilizer had a significant effect ($p \leq 0.01$) on total chlorophyll content (Table 2). Comparing the mean interaction of drought stress and silica fertilizer on total chlorophyll showed that silica fertilizer in all irrigation cycles affected the chlorophyll content of sorghum so that the highest amount of total chlorophyll evaporated from 60 mm irrigation treatments and fertilizer application. Silica was obtained as irrigation fertilizer (1.82 mg g^{-1} FW). The lowest total chlorophyll content was obtained from the non-application of silica fertilizer and 180 mm evaporation irrigation (0.72 mg g^{-1} FW) (Table 3). About these results, it seems that silica fertilizer, reducing the destructive effect of drought stress, has prevented the production of lipid peroxidation and H_2O_2 content and has maintained the chlorophyll content. These results are consistent with the findings of other researchers about wheat (*Triticum aestivum* L.) (Maghsoudi *et al*., 2016) and sorghum (Saad *et al*., 2018).

***Digestible dry matter (DMD)*:** The variance analysis (Table 4) showed that in addition to simple effects was a significant interaction effect of drought stress in silica fertilizer on DMD ($p \leq 0.01$). Silica fertilizer reduces the percentage of DMD in different irrigation conditions. Therefore, the lowest amount of this trait was obtained by 54.41% of the 60 mm irrigation treatment evaporated and silica fertilizer as irrigation fertilizer. On the other hand, the highest amount of DMD was obtained in non-consumption conditions. Silica was observed from 120 mm irrigation treatments of 72.83% evaporation and 180 mm evaporation treatments of 72.88% evaporation (Table 5). Stem development, which has a higher percentage of lignin and cellulose than other plant organs, increases the digestibility of dry matter in the sorghum plant. On the other hand, the use of silica fertilizer in irrigation water and foliar application due to increased vegetative growth of sorghum leads to a decrease in DMD percentage. Similar reports have suggested that increasing the amount of silica fertilizer in the plant environment reduces digestible dry matter in forage (Tolentino *et al*., 2016; Shewmaker *et al*., 1989).

Table 3. Interaction of drought stress and silica fertilizer on leaf area index, relative leaf water content, ion leakage, stomatal conductance and total chlorophyll

Drought stress	Silicon	Leaf area index	Relative water content (%)	Ion leakage (μs Cm^{-1})	Stomatal guidance (cm s^{-1})	Complete chlorophyll (mg g^{-1} FW)
60 mm	Control	4.31b	80.19b	391.47e	2.27ab	1.41c
60 mm	Foliar	4.19b	87.62a	379.08e	2.35a	1.68b
60 mm	Fertigation	4.79a	88.03a	356.01f	2.37a	1.82a
120 mm	Control	3.41c	62.52cd	567.93bc	1.69d	0.93f
120 mm	Foliar	4.13b	80.24b	551.33c	2.13b	1.08e
120 mm	Fertigation	4.22b	77.96b	437.61d	2.18b	1.15d
180 mm	Control	3.07d	53.67e	614.05a	1.13e	0.65h
180 mm	Foliar	3.48c	63.98c	575.44b	1.84c	0.72g
180 mm	Fertigation	3.26cd	60.58d	551.32c	1.87c	0.76g
LSD value		0.33	3.19	22.79	0.14	0.06

Value given in table is mean of four replicates; Values followed by same letter did not differ significantly from LSD test at 5% significance

***Crude protein content (CP)*:** The variance analysis results in (Table 4) showed that the interaction effect of drought stress and silica fertilizer on the percentage of crude protein was significant. Other interactions were not significant for this trait. Based on the results of the mean comparison (Table 5), application of silica fertilizer in the form of foliar application and irrigation water leads to an increase in forage protein so that the highest percentage of crude protein with the application of silica fertilizer in irrigation water from irrigation treatments 180 and 120 Evaporation mm was obtained with an average of 12.60% and 12.21% and the lowest amount of Cp obtained from irrigation treatment was estimated at 60 mm of evaporation and no silica fertilizer, which was 20% different from the highest amount of this trait in drought stress conditions. In this regard, it was reported that the application of silica fertilizer increases the soluble protein content, free amino acids and total nitrogen, phosphorus, potassium, and ultimately increase crop production (Suriyaprabha *et al*., 2014; Li *et al*., 2012).

***Auxin Hormone Content (IAA)*:** One of the causes of plant growth disorders under stress is the imbalance of hormones, especially auxin (Bielach *et al*., 2017). Based on the results of the analysis of variance (Table 4), the content of the auxin hormone was significantly ($p \leq 0.05$) affected by the interaction of drought stress in silica fertilizer. This study showed that the use of silica fertilizer in all drought stress treatments had the highest amount of auxin compared to non-silica fertilizer treatments the highest concentration in 60 mm irrigation conditions evaporated and the use of silica fertilizer as fertilizer. Irrigation was obtained with an average (129.66 nmol g of protein^{-1}) and silica foliar application (126.65 nmol g of protein^{-1}). In addition, the lowest amount of auxin was recorded (44.93 nmol g of protein^{-1}) from the irrigation treatment of 180 mm of evaporation and no silica (Table 5).

Table 4. Analysis of variance of digestible dry matter, crude protein, hydrogen cyanide, wet and dry yield of sorghum forage

urce	DF	Digestible dry matter	Crude protein content	Auxin Hormone Content	Hydrogen cyanide	Fresh weight sorghum forage	Dry weight sorghum forage
		M.S.					
ar	1	2664.501**	13.6938**	980.260**	485.368$^{n.s}$	102.139$^{n.s}$	7.416*
p(year)	4	15.756$^{n.s}$	0.265$^{n.s}$	32.441$^{n.s}$	456.696$^{n.s}$	99.188$^{n.s}$	12.745*
ought	2	2976.956**	22.327**	70518.042**	119989.053**	36804.639**	1527.942*
ar×drought	2	2.740$^{n.s}$	2.023$^{n.s}$	31.858$^{n.s}$	344.027$^{n.s}$	33.232$^{n.s}$	42.471*
or a	8	43.713	0.867	129.671	304.397	38.269	3.713
icon	2	751.439**	37.180**	5716.779**	3146.349**	1571.767**	156.049*
ar×silicon	2	0.501$^{n.s}$	0.001$^{n.s}$	0.635$^{n.s}$	221.818$^{n.s}$	709.284**	43.387*
ought × Silicon	4	95.015*	9.173**	677.681**	1020.953$^{n.s}$	246.559**	27.283*
ar×Drought×silicon	4	1.462$^{n.s}$	0.089$^{n.s}$	1.2191$^{n.s}$	93.205$^{n.s}$	92.573$^{n.s}$	8.851$^{n.}$
or b	132	29.952	2.609	44.523	542.38	66.552	4.693
' (%)		8.51	14.41	7.39	12.49	11.22	12.48

n.s. = Non-significant * = Significant at 5% level ** = significant at %1 level

Table 5. Interaction of drought stress and silica fertilizer on digestible dry matter, crude protein, auxin, fresh weight and dry weight of sorghum forage

Drought stress	Silicon	Digestible dry matter (%)	Crude protein content (%)	Auxin hormone content (nmol g of protein^{-1})	Fresh weight sorghum forage (ton ha^{-1})	Dry weight of sorghum forage (ton ha^{-1})
60 mm	Control	57.65e	10.08d	115.43b	90.94b	21.40b
60 mm	Foliar	55.71ef	10.58c	126.56a	94.72a	22.03a
60 mm	Fertigation	54.41f	10.82c	129.66a	95.11a	22.82a
120 mm	Control	72.83a	10.13d	74.70d	69.51d	16.44d
120 mm	Foliar	68.36b	11.58b	104.17c	76.06c	18.30c
120 mm	Fertigation	60.74d	12.21a	105.04c	87.37b	20.62b
180 mm	Control	72.88a	10.788c	44.93f	39.13f	10.92f
180 mm	Foliar	70.67ab	11.80b	54.62e	47.52e	12.67e
180 mm	Fertigation	66.03c	12.60a	56.52e	49.49e	12.77e
LSD value		2.59	0.61	4.85	4.42	0.61

Value given in table is mean of four replicates; Values followed by same letter did not differ significantly from LSD test at 5% significance

According to the results, it can be said that the destruction of cell membranes due to drought stress and increased ion permeability due to increased solubility and peroxidation of membrane fats in sorghum cause disruption in the structure and function of cell membranes. On the other hand, the application of silica fertilizer in these conditions shows a factor in reversing abiotic stresses. Similar results of this discussion showed that drought stress reduces the IAA concentration in response to control treatment, while silica fertilizer deviated to improve this trait (Helaly *et al*., 2017; Ryu *et al*., 2015; Kazan, 2013). On the other hand, according to the results, Zn^+ is required for IAA synthesis. After adding silica fertilizer to the culture medium, the amount of Zn^+ in the plant increases (Singh *et al*., 2011). According to another report, the addition of silica fertilizer to increase IAA synthesis in rice (*Oryza sativa* L.) by increasing Zn^+ uptake also maintains plant growth under stress (Tripathi *et al*., 2012).

***Hydrogen cyanide (HCN*)**: The variance analysis (Table 4) showed that only the main effects of drought stress and silica fertilizer ($p \leq 0.01$) on Hydrogen cyanide content were significant. This study showed that increasing drought stress on the HCN content increased so that the highest amount with an average (225.21 ppm) was obtained from the 180 mm evaporation irrigation treatment and this rate was about 41% higher than the 60 mm evaporation treatment. (Figure 3). In this regard, other researchers have reported that if the plant grows in stressful conditions such as long-term dehydration, it will increase the concentration of HCN in sorghum (Sher *et al*., 2016). Regarding the effect of silica fertilizer on HCN content, the results showed that if silica fertilizer was not used, the highest amount of this trait was obtained with the average (193.91 ppm) and the application of silica fertilizer as a foliar application with the average (186.66 ppm) Reduced by 4% and application of silica fertilizer as irrigation fertilizer reduced the content of Hydrogen cyanide by 8% (Figure 4). According to Oracz *et al*. (2008), Hydrogen cyanide in plants, in addition to inducing cyanide and pentose phosphate-resistant airways in the plant, is the precursor amino acid asparagine and stimulates ethylene production in plants in non-toxic concentrations. In cyanide, hydrogen is produced as an accompanying substance in the biosynthesis pathway of ethylene. In this reaction, the enzyme ACC Oxidase converts the compound 1-amin ocyclo-propane-1-carboxylic acid to ethylene and HCN (Fujita *et al*., 2006). The role of hydrogen cyanide as a by-product in ethylene's production in the plant is in response to environmental stresses. Hydrogen cyanide is produced in equal amounts with ethylene in response to biotic and abiotic stresses in the plant and therefore the production of this the seemingly toxic and dangerous element is not useless in response to stress and acts as a defence factor against stress in plants (Ahmadi *et al*., 2015).

On the other hand, it was reported that the application of silica in sorghum increases the plant's tolerance to stress and increases the level of polyamine (PA) and decreases the concentration of ethylene precursor, ACC (1-amin ocyclo-propane). 1- carboxylic acid) (Yin *et al*., 2016). Ethylene and PA synthesis pathways are considered competitors (Li *et al*., 2004). In other words, the use of silica fertilizer under stress conditions decreased the precursor of HCN production. As a result, its concentration in the plant decreases under stress conditions, which is consistent with this study's findings.

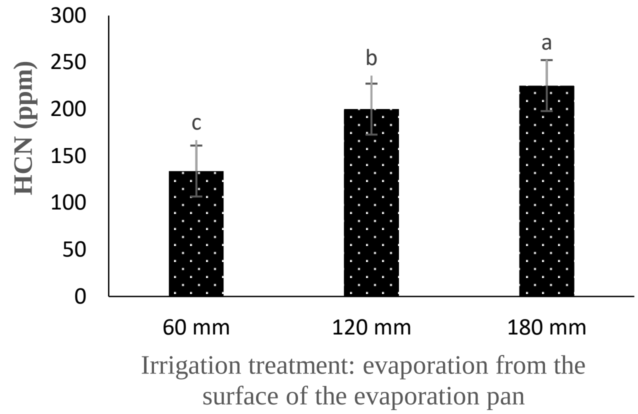

Figure 3. Simple effect of drought stress on sorghum forage Hydrogen cyanide (LSD value: 7.74)

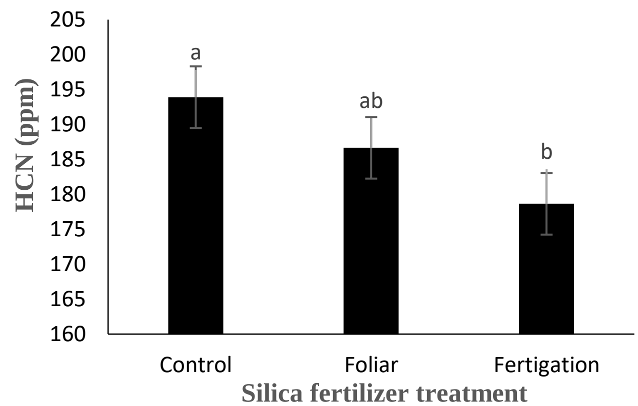

Figure 4. Simple effect of silica fertilizer on Hydrogen cyanide of sorghum forage (LSD value: 9.28)

***The fresh and dry weight of sorghum forage*:** The results of this study showed that the interaction effect of drought stress and silica fertilizer had a significant effect on the fresh weight of sorghum forage ($p \leq 0.01$) and dry weight of sorghum forage ($p \leq 0.01$) (Table 4). The use of silica fertilizer with the highest fresh weight of sorghum with an average of 95.11 and 94.72 ton ha^{-1} was estimated from 60 mm evaporation irrigation treatment and silica fertilizer irrigation fertilizer and foliar application. The lowest fresh weight of sorghum with an average of 39.13 ton ha^{-1} was obtained from 180 mm of evaporation irrigation treatment and no silica fertilizer application, which showed a difference of 58% with the maximum fresh weight of forage (Table 5). Similar to the results of the present study has been reported the improvement of plant growth under drought stress due to the application of silica on wheat (Neu *et al*., 2017; Martin *et al*., 2017) and corn (*Sorghum bicolor* L.) (Flores *et al*., 2018).

Also, regarding the dry weight of sorghum forage, this study's results stated that (Table 5) application of silica fertilizer in all drought stresses led to a reduction in stress damage and increased yield compared to the control treatment. The highest dry weight of sorghum forage was obtained from 60 mm evaporation irrigation treatment using silica fertilizer as irrigation fertilizer 22.82 ton ha^{-1} and foliar spraying 22.03 ton ha^{-1}, respectively. The lowest dry weight of sorghum, with an average of 10.92 ton ha^{-1}, was obtained from the treatment of severe drought stress and non-application of silica fertilizer. The trend of changing and reducing drought stress damage and improving the dry weight yield of sorghum using silica fertilizer was more evident in drought stress conditions so that in 120 mm irrigation conditions, the dry weight of sorghum evaporated using silica fertilizer as irrigation fertilizer with an average of 20.62 ton ha^{-1} with dry weight yield of sorghum in optimal irrigation conditions and no silica fertilizer with an average of 20.70 ton ha^{-1} were in a statistical group. Also, the use of silica as an irrigation fertilizer in 180 mm evaporation treatment was achieved with a 14% increase in yield compared to the conditions of not using silica fertilizer (Table 5). It is argued that the use of silica in drought stress conditions due to increasing and improving the relative water content and reducing ion leakage, maintaining plant leaf area index, chlorophyll content and stomatal conductivity leads to increased sorghum forage yield. Which indicates That is silica fertilizer under stress can be a good option in reducing drought damage. Other similar results have been reported in that the application of silica under drought stress conditions of maize (*Zea mays* L.) (Amin *et al*., 2018) and barley (*Hordeum vulgare* L.) (Balakhnina *et al*., 2012) Increases photosynthesis and reduces transpiration improves growth and function. These results are also consistent with Artyszak (2018) finding on the effectiveness of silica fertilizer on plant yield.

***Conclusion*:** This experiment showed that the occurrence of drought stress through direct impact on LAI, RWC, ion leakage, reduced stomatal conductance, and total chlorophyll indices lead to a fresh and dry weight loss of sorghum forage. On the other hand, Silica fertilizer application by affecting morphological traits and maintaining IAA production reduced drought stress significantly. It improved the yield of sorghum forage plants. Silica fertilizer under drought stress decreased DMD but, on the other hand, increased Crude protein content and also decreased Hydrogen cyanide in forage production. Another noteworthy point is that silica fertilizer can increase the yield and dry weight of sorghum. However, the changes in the use of silica fertilizer were more noticeable under drought stress, so that in 120 and 180 mm irrigation treatments, respectively. Evaporation with the application of silica fertilizer in irrigation water showed a 20 and 14% increase in sorghum dry forage yield compared to no silica fertilizer treatment. While in 60 mm irrigation, the evaporation ratio was only six percent. According to the results, it can be recommended that silica fertilizer be considered by farmers to maintain the natural growth and development of sorghum forage plants, especially in drought-prone areas. However, its widespread use in other farm crops needs to be investigated.

***Conflicts of Interest*:** The Authors declare that they have no conflict of interests.

***Authors' Contribution Statements*:** ER carried out the experiment, ER and HL wrote the manuscript and PK supervision. HT and FG Methodology and Conceptualization, all authors have read and agreed to the published version of the manuscript

***Acknowledgement*:** The research was financed by Department of Agronomy, Varamin-Pishva Branch, Islamic Azad University,Varamin, Iran. The authors declare that they have no conflict of interest.

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