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Role of Silicon in Mitigating Effects of Deficit Irrigation on Production of Sorghum (Sorghum Bicolor L.) Under Arid Land Conditions

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***Abstract:*- Growth of sorghum under irrigation water stress i.e. under reduction of irrigation water from 100% to 60% ETc resulted in significant reduction in growth components of sorghum. Plant height, number of tillers and total fresh forage yield decreased with decrease in irrigation water from 100% to 80% and 60% ETc. Folliar application of silicon mitigated and alleviated the harsh conditions created by drought stress on sorghum plant growth. Silicon when applied at concentration of 2 kg/ha with water stress level 2 (80%ETc) gave the maximum plant height (109.0 cm) and the maximum fresh forage yield (44.00 t/ha) compared to control treatment (100% ETc). Root volume was maximum (0.031 m3) under 60% ETc and 2 kg ha-1 Si treatments compared with control (100% ETc). For production of sorghum fodder under the arid land environmental conditions of Saudi Arabia deficit irrigation with (80% and 60% ETc) with application of 2 kg ha-1 silicon (Si) as foliar spray seems a reasonable option than irrigating the crop with 100% ETc due to scarcity of irrigation water in this country. It gives higher yields than 100% irrigation and optimum moister level in the root zoon.**

Key words: Sorghum bicoloeL., drought stress, silicon foliar spray

I. INTRODUCTION

Saudi Arabia demands for green forage is ever increasing due to the rapidly expanding livestock industry particular in dairy animals. Sorghum bicolor L forage crop may be one of the solutions to this problem for it is a drought resistant crop and can grow in limited irrigation water, to give very low cost fodder. (Marsalis et al., 2009). It is an animal fodder cereal crop and also human food belonging to Poaceae family and is cultivated in all around the world particularly in arid regions. Plants mostly suffer from drought stress more than from any other factor, and drought stress on crop production is more harmful as compared to other environmental stresses (Dreesen et al., 2012; Rollins et al., 2013). The decrease in rainfall events, continuous water losses, high ambient air temperature and bad irrigation practices during growing season causes drought stress in a specific region (Lobell et al., 2011; Vadez et al., 2011; 2012; Wahid et al., 2007; Trenberth, 2011). Leaf area index (LAI) and shoot to root ratio are greatly reduced due to drought stress which ultimately results in reduction of whole plant growth and development (Anjum, et al., 2011b). Due to drought stress, the diffusion of carbon dioxide from the atmosphere decreases in plants which causes in low photosynthetic activity (Keenan, et al., 2010). In plants, Si concentration varies from 0.1 to 10% of dry weight according to genotypes (Hodson et al., 2005). Si regulates the nutrients uptake in many crops particular under environmental stresses (Wallace, 1993; Ma and Takahasi, 2002). When applied, in proper amount, Si mitigates the drought stress and improves production. Sonobe et al., (2017) studied the positive effects of Si on sorghum root response to drought stress, they found that the roots of plants treated with Si absorbed more water compared with control which increased the dry weight and reduced the osmotic potential in the roots. Deposited Si in the plants prevents the compression of xylem during high transpiration rate under drought stress (Mitani and Ma, 2005). In a pot experiment silicon Si (ml/L of K_2SiO_3 per kilogram of soil) was used in two concentrations (100) and Si (200). Si (200) treatment improved chlorophyll content, leaf area index, root dry weight, leaf dry weight, shoot dry weight, total dry weight and specific leaf weight compared to untreated plants (Ahmad et al., 2011b). The application of Si enhances morphological characters and net yield in sorghum when applied under drought condition (Kaya et al., 2006). Coskun et al., 2016 examined the productive role of Si in many crop plants under drought and salinity stress, the results indicated that silicon mitigated drought and salinity stresses and increased the yield. This study investigates the mitigation role of silicon Si on the harsh environmental drought stresses in this arid land of Saudi Arabia.

II. MATERIALS AND METHODS

The research experiment was conducted in the Research Station of the Faculty of Meteorology, Environment and Arid Land Agriculture at Hada Al-Sham. The design used in this research was split plot design with main plots and subplots with three replications. The experimental area was divided into three main plots and three subplots. The irrigation was applied as main plots and Si was applied as subplots. The irrigation treatment levels are percentage of crop evapotranspiration's (ETc), and silicon treatments as (0 kg Si ha-1 1 kg Si ha-1 , 2 kg Si ha-1). Surrounding the experimental plots, a buffer of two meter (2m) wide was also cultivated with the same sorghum crop to make a fetch to reduce uneven weather and wind effects on the experimental plots.

The total number of plots were twenty seven (3*3*3=27). The dimension of each experimental plot was (4m x 2m) in size with one meter clearance between each plot to prevent inter-plot water flow. The experimental area was irrigated then ploughed twice, and levelled.

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Plots irrigation system

Four plastic tanks (6000 litters capacity of each) were installed, and all the tanks were interconnected and connected with irrigation pump. Bubbler irrigation system was used. Each plot was provided with eight bubblers of Rain Bird pressure compensating full circle trickle pattern 0.5 GPM discharge. The bubblers within each plot were mounted on two Poly Ethylene (PE) laterals pipelines of one inch size at one meter spacing. The bubblers were mounted using saddle of 1 inch*1/2 inch size (female threads) and six inch long PE risers. Each bubbler had built-in strainer to filter course sand and debris. Each PE lateral line supplied irrigation to three sub-plots running from east to west by applying same irrigation amount. The main and sub-main lines used were two inch PE pipe running from north to south outside the plots (flowmeter). Electrical pressure control valve was used at delivery of pump to deliver even pressure and prevent damage to the pump or lines while keeping bubblers' discharge constant. Flow rate was measured with seven bubblers in each plot and larger capacity pump and found to be very close to the standard discharge with small variation. Four pressure gauges were installed to check the operating pressure at pump, in the main line, in the sub main lines and in the laterals lines.

Method used in irrigation:

The water balance irrigation scheduling method involves estimation of the soil water balance by measuring the amount of rainfall, irrigation and then estimating the soil water depletion by calculating water consumed by the crop. It is a flexible method and can forecast irrigation needs in future depending upon weather forecast. The procedure of water balance irrigation scheduling is as follows:

AWSC = FC – PWP

Where

AWSC: is the available water storage capacity of the soil (mm/m).

FC: is the field capacity (volumetric moister content (%) (Upper limit).

PWP: is the permanent wilting point (volumetric moister content (%) (Lower limit).

Evapotranspiration (ET) is the combination of two separate processes (Evaporation and Transpiration) whereby water is lost from the soil surface by evaporation and from the crops by transpiration.

Planting of sorghum:

Sorghum fodder local variety Jizani was sown. After installation of irrigation system and levelling Sorghum crop was sown manually in all plots. The spacing between rows kept at 30cm. Seeds were placed at 5cm depth and then covered manually. Six rows were sown in each plot. Six rows were also sown as buffer area at the same time. Seed rate of 60 kg/ha was used.

The crop was sown on 13th March 2017 and the 3rd cut was harvested on 30th September 2017. The duration of 1st cut was 61 days (Sowing date 13th March and Harvesting date 13th May).

Application of silicon treatments

Irrigation and Si treatments were applied after proper germination and crop establishment period at five leaves stage. treatments (1 kg/ha= 0.1 gram/m2 and 2 kg/ha= 0.2 gram/m2)

III. RESULTS

IV. ANALYSIS OF VARIANCE (ANOVA) FOR STUDIED SORGHUM CROP PARAMETERS DURING GROWING SEASON 2017.

The ANOVA table (Table 1) indicated highly significant differences in results of the studied growth parameters of sorghum (number of tillers per square meter, plant height, fresh forage yield, and root volume) between irrigation treatments (100%, 80% and 60% of ETc) and Si foliar treatments (0, 1 and 2 kg/ha) at ($P \leq 0.01$) during all cuts.

TABLE 1. THE ANALYSIS OF VARIANCE FOR NUMBER OF TILLERS/M2, PLANT HEIGHT, FRESH FORAGE YIELD, DRY FORAGE YIELD, ROOT VOLUME AND IRRIGATION WATER USE EFFICIENCY (IWUE) FOR SORGHUM CROP UNDER THE EFFECT OF IRRIGATION AND SILICON TREATMENTS AND THEIR INTERACTION DURING 2017 CROP SEASON.

	Source of variance	df	parameters			
			Number of tillers/m2	Plant height (cm)	Fresh forage Yield (t/ha)	Root Volume (m3)
1st Cut	Replication	2	129.33 NS	7.14 NS	4.48 NS	x
	Irrigation(Irri)	2	82.33 NS	791.81**	164.73**	x
	Error (a)	4	319.83	1.42	0.99	x
	Silicon (Si)	2	217.44*	529.03**	291.27**	x
	Irri* Si	4	12.44 NS	11.98*	3.72*	x
	Error (b)	12	37.27	3.33	0.99	x
2nd cut	Replication	2	0.11 NS	3.37 NS	3.01 NS	x
	Irrigation(Irri)	2	315.11**	611.48**	133.73**	x
	Error (a)	4	0.88	1.06	0.83	x
	Silicon (Si)	2	137.44**	426.45**	232.99**	x
	Irri* Si	4	8.22 NS	8.98 NS	2.96 NS	x
	Error (b)	12	3.07	3.11	0.94	x
3rd cut	Replication	2	0.25 NS	5.48 NS	3.56 NS	0.0000014
	Irrigation(Irri)	2	226.81**	786.03**	158.88**	0.0000598**
	Error (a)	4	0.70	1.31	0.98	0.0000004
	Silicon (Si)	2	98.25**	529.59**	276.65**	0.000148**
	Irri* Si	4	5.87 NS	10.59 NS	3.52 NS	0.0000033*
	Error	12	2.27	3.48	1.11	0.00000092

Effect of irrigation and Si levels on number of tillers/m2 of Sorghum crop:

Analysis of variance:

Table (1) illustrates that during first cut no significant differences were observed by irrigation treatments on number of tillers per m2 in sorghum, but there were significant differences by irrigation treatments and Si treatments on number of tillers during second and third cuts. Means comparisons of number of tillers/m2 of sorghum crop.

Number of tillers per square meter was not affected very much by Si during the first cut. While during 2nd and 3rd cut the decrease in irrigation amount from 100% to 60% of ETc reduced the number of tillers per square meter by 11.2 % but tiller number increased by 10.11% by application of Si from 0-2 kg/ha, (Table 2). The interaction of irrigation and Si treatments shows no significant effect on number of tillers per square meter during all cuts.

TABLE 2. MEANS OF NUMBER OF TILLERS/M2 OF SORGHUM CROP UNDER THE EFFECT OF VARYING LEVELS OF IRRIGATION AND SILICON DURING 2017 CROP SEASON.

Treatments levels	Number of cuts of Sorghum crop		
	1st cut	2nd cut	3rd cut
Irrigation levels (% ETc)			
100	74.00 a	116.44 a	99.11 a
80	71.66 a	111.55 b	94.88 b
60	77.66 a	104.66 c	89.11 c
LSD (0.05)	23.41	1.23	1.09
Silicon levels (kg/ha)			
0	71.33 b	107.22 c	91.33 c
1	71.88 b	110.44 b	93.88 b
2	80.11 a	115.00 a	97.88 a
LSD (0.05)	6.27	1.80	1.55

* MEANS FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT ACCORDING TO LSD AT $P \leq 0.05$

Effect of irrigation and Si levels on plant height of Sorghum crop:

Means comparisons of plant height of Sorghum crop:

During 1st cut the decrease in irrigation amount from 100% to 60% of ETc reduced the plant height from 114.77cm to 96.22 cm (16.16%) while increased the level of Si from 0-2 kg/ha increased them from 97.00 cm to 112.33 cm (13.64%), the same trend was followed during 2nd cut, the decrease was 15.86% and increase was 13.56%, during 3rd cut the decrease was 15.43% and increase was 13.93% (Table 3).

TABLE 3. MEANS OF PLANT HEIGHT (CM) OF SORGHUM CROP UNDER THE EFFECT OF VARYING LEVELS OF IRRIGATION AND SILICON DURING 2017 CROP SEASON.

Treatments levels	Number of cuts of Sorghum crop		
	1st cut	2nd cut	3rd cut
Irrigation levels (% ETc)			
100	114.77 a	103.14 a	120.22 a
80	103.11 b	93.17 b	109.00 b
60	96.22 c	86.78 c	101.66 c
LSD (0.05)	1.56	1.35	1.50
Silicon levels (kg/ha)			
0	97.00 c	87.65 c	102.77 c
1	104.77 b	94.04 b	110.00 b
2	112.33 a	101.41 a	118.11 a
LSD (0.05)	1.87	1.81	1.91

* MEANS FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT ACCORDING TO LSD AT $P \leq 0.05$

Effect of interaction between irrigation and Si levels on plant height of Sorghum crop:

Table (4) indicated that under each irrigation level increase in Si level from 0 to 2 kg/ha resulted in increase in plant height. The maximum plant height was recorded during 1st cut as 122.67cm, during 2nd cut 110.47cm and during 3rd cut as 127.67cm.

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TABLE 4: EFFECT OF INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON MEANS OF NUMBER OF PLANT HEIGHT (CM) OF SORGHUM CROP DURING 2017 CROP SEASON.

	Irrigation levels (% of ETc)	**Silicon levels (kg/ha)**		
		0	1	2
1st Cut	100	105.00	116.67	122.67
	80	97.67	101.67	110.00
	60	88.33	96.00	104.33
	LSD (0.05)	3.24		
	Irrigation levels (% of ETc)	Silicon levels (kg/h a)		
		0	1	2
2nd Cut	100	94.53 88.33	104.43	110.47
	80	80.10	91.60	99.60
	60		86.10	94.17
	LSD (0.05)	NS		
	Irrigation levels (% of ETc)	Silicon levels (kg/h a)		
		0	1	2
3rd Cut	100	111.00	122.00	127.67
	80	103.33	107.00	116.67
	60	94.00	101.00	110.00
	LSD (0.05)	NS		

* MEANS FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT ACCORDING TO LSD AT P≤0.05

Effect of irrigation and Si levels on fresh forage yield of Sorghum crop:

Means comparisons of fresh forage yield of Sorghum crop:

The production of forage yield was decreased from 45.80 t/ha to 37.43 t/ha (18.27%) due to reduction in irrigation water supply from 100% to 60% of ETc, simultaneously fresh forage yield of Sorghum crop increased by application of Si from 0 to 2 kg/ha to reach averages from 35.93 t/ha to 47.19 t/ha (23.86%) during 1st cut. The same trend was followed during 2nd cut and 3rd cut with water stress resulting in reduction in forage yield from 41.27 t/h to 33.75 t/ha (18.22%) and from 44.99 t/ha to 36.79 t/ha (18.22%) reduction during the two cuttings respectively, and application of Si compensated this reduction by increase in forage yield from 32.40 t/ha to 42.47 t/ha (23.71%), and from 35.31 t/ha to 46.29 t/ha (23.72%) (Table 4.6) during 2rd cut and 3rd cut respectively (Table 5).

TABLE (5): MEANS OF FRESH FORAGE YIELD (T/HA) OF SORGHUM CROP UNDER THE EFFECT OF VARYING LEVELS OF IRRIGATION AND SILICON DURING 2017 CROP SEASON.

Treatments levels	**Number of cuts of Sorghum crop**		
	1st cut	**2nd cut**	**3rd cut**
Irrigation levels (% ETc)			
100	45.80 a	41.27 a	44.99 a
80	40.04 b	36.04 b	39.28 b
60	37.43 c	33.75 c	36.79 c
LSD (0.05)	1.3	1.19	1.3
Silicon levels (kg/ha)			
0	35.93 c	32.40 c	35.31 c
1	40.15 b	36.19 b	39.45 b
2	47.19 a	42.47 a	46.29 a
LSD (0.05)	1.02	0.99	1.08

Effect of interaction between irrigation and Si levels on fresh forage yield of Sorghum crop:

The interaction of irrigation and Si (Irr.*Si) levels on fresh forage yield was also significant (P≤ 0.05) during 1st cut while it was non-significant (P≤ 0.05) during 2nd and 3rd cut. Interaction between irrigation and Si treatments means (Table 6) showed within same irrigation levels, the increase in Si dose increased the fresh forage yield (t/ha) and the decrease in irrigation levels (increase drought stress) decreased the fresh forage yield according to LSD, compared with control during all cuts. For the 1st cut the maximum fresh forage yield was 52.33 (t/ha) while it was 47.10 (t/ha) for the 2nd cut and 51.33 (t/ha) for the 3rd one. In the 1st cut, compared with controls, the plants treated with Si treatment two (2kg Si ha-1) and irrigation treatment one (80%ETc) gave a higher yield 44.87 (t/ha), while it was 40.38 t/ha for the 2nd cut and 44.03 t/ha for the 3rd one.

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TABLE (6): EFFECT OF INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON MEANS OF FRESH FORAGE YIELD (T/HA) OF SORGHUM CROP DURING 2017 CROP SEASON.

	Irrigation levels (% of ETc)	Silicon levels (kg/ha)		
		0	**1**	**2**
1st Cut	100	40.33 36.10 31.37	44.73 39.17 36.57	52.33 44.87 44.40
	80			
	60			
	LSD (0.05)	1.77		
2nd Cut	Irrigation levels (% of ETc)	S ilicon levels (kg/h a)		
		0	1	2
	100	36.47 32.49 28.25	40.26 35.25 33.08	47.10 40.38 39.94
	80			
	60			
	LSD (0.05)	NS		
3rd Cut	**Irrigation levels (% of ETc)**	S ilicon levels (kg/h a)		
		0	1	2
	100	39.77 35.40 30.80	43.87 38.43 36.03	51.33 44.03 43.53
	80			
	60			
	LSD (0.05)	NS		

Effect of irrigation and Si levels on root volume of sorghum crop:

Means comparisons of root volume of Sorghum crop:

Results of table (7) shows that decrease in irrigation level from 100% to 60% of ETc increased the root volume, and also increase in Si dose from 0 to 2 kg/ha also increased the root volume (Table 7).

Interaction effect of Irrigation and Si levels on the root volume of Sorghum crop.

The interaction of irrigation and Si (Irri*Si) levels and its effect on root volume of sorghum forage plant is significant ($P \leq 0.05$). According to the values of the interaction between irrigation and Si treatments means (Table 8), it is clear that within each irrigation level, the increase in Si dose resulted in an increased in the root volume, and also the decrease in irrigation level (increase drought stress) within each Si treatment level increased the root volume according to LSD compared with control. The maximum root volume (0.030 m3) was observed in the highest deficit irrigation (60% ETc) and 2 kg ha-1 Si dose.

With passage of time, more Si was accumulated in the plants causing lateral growth in the roots. The root depth was almost same in all plots which increased gradually. The increase in root volume increased the water uptake and consequently the studied crop parameters were improved. The increase in root volume also reduced moisture level in the soil near harvesting due to more water uptake efficiency.

TABLE (7): MEANS OF ROOT VOLUME OF SORGHUM CROP UNDER THE EFFECT OF VARYING LEVELS OF IRRIGATION AND SILICON DURING 2017 CROP SEASON (FINAL HARVESTING).

Treatments levels	**Root volume (m3) of sorghum crop**
Irrigation levels (% of ETc)	
100	0.020 c
80	0.022 b
60	0.025 a
LSD (0.05)	0.0009
Silicon levels (kg/ha)	
0	0.019 c
1	0.021 b
2	0.027 a
LSD (0.05)	0.001

TABLE (8): EFFECT OF INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON MEANS OF ROOT VOLUME (M3) OF SORGHUM CROP DURING 2017 CROP SEASON (FINAL HARVESTING).

Root volume (m3) of Sorghum at final harvesting				
Root volume at harvesting	**Irrigation levels (% of ETc)**	**Silicon levels (kg/ha)**		
		0	1	2
	100	0.016 0.019 0.020 0.020 0.024	0.021	0.024 0.026 0.030
	80			
	60			
	LSD (0.05)	0.0017		

V. DISCUSSION

Si helps plants to acclimatize under drought condition by modifying a variety of physiological processes, including stomatal conductance, transpiration rate, water relations and synthesis of photosynthetic pigments, and improving nutrient uptake and decreasing Na+ content in leaf tissue, thereby improving growth and yield of plants. Many previous studies have been conducted on Si to investigate its mechanisms of environmental stresses alleviation in crop plants (Kim et al., 2014a; Martínez et al., 2015). Drought stress represented in the different water regimes (80% , 60% Ec) significantly affected sorghum growth parameters (number of tillers/m2, plant height, fresh forage yield, and root volume). The results indicated that drought conditions particularly during 2nd cut decreased plant height (15.50%) and fresh yield (22%) of sorghum. This result obtained agree with what has been obtained by (Anjum et al., 2003a; Bhatt & Srinivasa Rao, 2005; Kusaka et al., 2005; Shao et al., 2008). The foliar application of silicon increased number of tillers per square meter (almost 1.5%), plant height (14%), fresh yield (25%) and root volume as compared to control. During 2nd cut number of tillers per square meter increased as compared with 1st cut and the trend started decreasing during 3rd cut. The reason of more branching in Si treated plots is probably due to more water uptake efficiency of Si, nature of ratoon crops and increase root depth of sorghum. These results agree with previous studies on tillering effects by application of Si on crops (Tabassam et al., 2014; Cossani and Reynolds, 2012). Also the results of mitigating effect of Si application on drought effects on crop plants growth was approved by number of researchers (Specht et al., 2001 on soybean , Wu et al., 2008 on citrus, Heuer and Nadler, 1995 on potato, Sankar et al., 2007-08 on Abelmoschus esculentus; Manivannan et al., 2007a on Vigna unguiculata; Zhang et al. 2004 on soybean). The plant height, dry matter, chlorophyll content, relative water content, stomatal conductance was increased in wheat when treated with Si under drought stress (Gong et al., 2003; Hattori et al., 2005; Eneji et al., 2005), and in Sorghum (Ahmad et al., 2011b). May be Si is accumulated more in the root than in the shoot, which might be the probable reason of the increase in root volume enabling the movement of roots in search of more water to compensate with drought condition. These finding are similar to some previous researchers (Mohammad and Rahimi 2011) working on Portulaca oleracea L. and (Gau et al., 2006) working on alfalfa.

VI. CONCLUSION

Growth of sorghum under irrigation water stress i.e. under reduction of irrigation water from 100% to 60% ETc resulted in significant reduction in growth components of sorghum. Plant height, number of tillers and total fresh forage yield decreased with decrease in irrigation water from 100% to 8% and 60% ETc. The foliar application of silicon on sorghum leaves increased number of tillers per square meter (almost 1.5%), plant height (14%), fresh yield (25%) and root volume as compared to control in all cuttings. Foliar application of silicon mitigated and alleviated the harsh conditions created by drought stress on sorghum plant growth. Silicon when applied at concentration of 2 kg/ha with the water stress level 2 (80%ETc) gave the maximum plant height (109.0 cm) and the maximum fresh forage yield (44.00 t/ha) compared with control treatment (100% ETc). Root volume was maximum (0.031 m3) under 60% ETc and 2 kg ha-1 Si treatments compared with control (100% ETc). For production of sorghum fodder under the arid land environmental conditions of Saudi Arabia deficit irrigation with (80% and 60% ETc) with application of 2 kg ha-1 silicon (Si) as foliar spray seems a reasonable option than irrigating the crop with 100% ETc due to scarcity of irrigation water in this country. It gives higher yields than 100% irrigation and optimum moister level in the root zoon.

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