

Forage Production and Water use Efficiency (WUE) of Sorghum (*Sorghum Bicolor L.*) Under Drought Stress as Affected by Silicon (SI) Treatments

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Abstract: This study investigated the role of silicone (Si) in mitigating effects of drought on sorghum (*Sorghum bicolor L.*) dry forage production and water use efficiency (WUE). Reduction of irrigation water from 100% to 60% ETc resulted in significant reduction in dry forage production of sorghum up to (22.75%). Reduction in irrigation water from (100% to 60% ETc) increased WUE. Under application of Si forage dry yield and WUE increased significantly. Within each irrigation water level application of Si resulted in increase in forage dry yield and WUE with increase in Si dose from 0 to 2 kg ha⁻¹. In the meanwhile, the foliar application of Si (2 kg ha⁻¹) with irrigation treatment (100% ETc) significantly increased the dry forage yield and raised it to the highest percentage 30% compared to no Si treatment. Irrigation with 80% ETc together with application of 2 kg ha⁻¹ Si gave the highest WUE compared to 100% ETc. In growing sorghum for dry yield purpose, 60% ETc and 2 kg ha⁻¹ Si is an economical option with more water saving and small reduction in yield especially in arid regions.

Key words: *Sorghum bicolor L.*, drought stress, silicon foliar spray

I. INTRODUCTION

Sorghum (*Sorghum bicolor L.*) is one of the best plant crops planted in Saudi Arabia for production of forage, because it grows well in arid land conditions and tolerates water deficient stresses. Drought stress causes 50% reduction of major crops yield in arid regions as compared to humid and semi-arid regions [4,27]. Sorghum cultivation in Saudi Arabia could be increased to cope with increasing fodder demand of dairy animals by integrated use of some eco-friendly approaches of mitigating drought stress. Silicon (Si) application and proper irrigation scheduling can mitigate drought stress in plants. Researchers have investigated the positive effect of Si on crop production under drought stress. Silicon (Si) is the second most abundant element in the earth's crust and plays a number of important roles in the mineral nutrition of plants [5]. Calcium silicate is a good source of Si which is used as fertilizer and some other sources of Si are silica and calcium silicates [7]. When applied as foliar spray, plants absorb Si by leaves and then the absorbed Si is redistributed in the leaves and other tissues and plants vary in their ability to absorb Si even in the same species [19].

Si concentration in plants varies from 0.1 to 10% of dry weight according to genotypes [11]. Si regulates the nutrients uptake in many crops particular under environmental stresses [25,18]. In this research study the aim is to examine the effects of silicon Si in mitigating the sever effects of deficit in irrigation water on the water use efficiency (WUE) and the dry forage production of sorghum under the arid land conditions 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.

Plots irrigation system

Four plastic tanks (6000 liters capacity of each) were installed, 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 coarse 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 moisture content (%) (Upper limit).

PWP: is the permanent wilting point (volumetric moisture 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. Sorghum seeds were sown manually in all plots after preparation of irrigation system and levelling. Spacing between rows kept at 30cm. 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. Foliar application of Si was at the rate of (1 kg/ha= 0.1 gram/m² and 2 kg/ha= 0.2 gram/m²).

III. RESULTS

Analysis of variance (ANOVA) for WUE and dry forage yield of sorghum during growing season 2017.

The analysis of variance (Table 1) indicated that the effects of irrigation treatments ((100%, 80% and 60%ETc) and Si foliar applications (1 and 2 kg/ha) were highly significantly different in results of the studied parameters (water use efficiency WUE and total dry forage yield of sorghum) at (P< 0.01) during all cuts. Also there are significant differences between treatments as regards interaction between irrigation and silicon (irr. X Si).

TABLE 1. THE ANALYSIS OF VARIANCE FOR WATER USE EFFICIENCY (IWUE) AND DRY FORAGE YIELD, OF SORGHUM CROP UNDER THE EFFECT OF IRRIGATION AND SILICON TREATMENTS AND THEIR INTERACTION DURING.

	Source of variance	df	Irrigation water use efficiency	Dry forage yield
			(kg/m ³ /ha)	(t/ha)
1st Cut	Replication	2	0.63 NS	2.03 NS
	Irrigation(Irri)	2	5.81 **	19.30**
	Error (a)	4	0.14	0.18
	Silicon (Si)	2	43.90**	24.10**
	Irri* Si	4	1.20**	0.69*
	Error (b)	12	0.138	0.136
2nd cut	Replication	2	0.19 NS	1.66 NS
	Irrigation(Irri)	2	0.53*	14.89**
	Error (a)	4	0.05	0.18
	Silicon (Si)	2	16.08**	18.48**
	Irri* Si	4	0.31 *	0.46**
	Error (b)	12	0.62	0.117
3rd cut	Replication	2	0.69 NS	1.98 NS
	Irrigation(Irri)	2	15.39**	17.66**
	Error (a)	4	0.21	0.21
	Silicon (Si)	2	58.89**	21.96**
	Irri* Si	4	1.86**	0.55*
	Error	12	0.223	0.138

Ns: not significant at (P≤ 0.05). *: Significant at (P≤ 0.05). **: significant at (P≤ 0.01).

Effect of irrigation and Si levels on water use efficiency (WUE) of sorghum crop

Means comparisons of irrigation water use efficiency of Sorghum crop

Analysis of variance

Table (1) illustrates that there were significant differences between both different water levels and different Si concentrations and their interactions on the WUE during all cuts.

During 1st cut the decrease in irrigation amount from 100% to 60% ETc increased water use efficiency from 15.26 kg/m³/ha to 16.63 kg/m³/ha and during the third cut from 17.37 to 19.87 kg/m³/ha, while under application of Si at levels from 0 to 2 kg/ha the WUE increased from 13.70 to 18.07 kg/m³/ha during the 1st cut and from 8.41 to 11.06 kg/m³/ha during the 2nd cut and from 15.95 to 21.01 kg/m³/ha during the 3rd cut. (Table 2).

TABLE 2. MEANS OF IRRIGATION WATER USE EFFICIENCY (KG/M3/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	15.26 b	9.87 a	17.37 b
80	15.22 b	9.39 b	17.69 b
60	16.63 a	9.64 ab	19.78 a
LSD (0.05)	0.506	0.317	0.606
Silicon levels (kg/ha)			
0	13.70 c	8.41 c	15.95 c
1	15.35 b	9.42 b	17.87 b
2	18.07 a	11.06 a	21.01 a
LSD (0.05)	0.382	0.256	0.485

Interaction effect of irrigation and Si on irrigation water use efficiency of Sorghum crop

Interaction between irrigation and Si treatments means (Table 3, Fig. 1) showed that water use efficiency increased within same irrigation levels, with increase in Si dose from 0 to 2 kg Si ha⁻¹ during all cuts. And the decrease in irrigation levels (increase drought stress) also increased the water use

efficiency compared with control. The overall trend in water use efficiency followed the pattern that it was more during 1st cut then decreased during 2nd cut and also increased during 3rd cut. WUE values under Si treatment (2 kg Si ha⁻¹) and irrigation treatment (60% ETc) were maximum during all cuts, compared with controls.

TABLE 3. EFFECT OF INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON MEANS OF IRRIGATION WATER USE EFFICIENCY (KG/M3/HA) OF SORGHUM CROP DURING 2017 CROP SEASON.

	Irrigation levels (% of ETc)	Silicon levels (kg/ha)		
		0	1	2
1st Cut	100	13.44	14.91	17.44
	80	13.94	16.25	19.72
	60			
	LSD (0.05)	0.66		
2nd Cut	100	8.72	9.63	11.27
	80	8.07	9.45	11.41
	60			
	LSD (0.05)	0.44		
3rd Cut	100	15.34	16.94	19.82
	80	16.55	19.38	23.40
	60			
	LSD (0.05)	0.84		

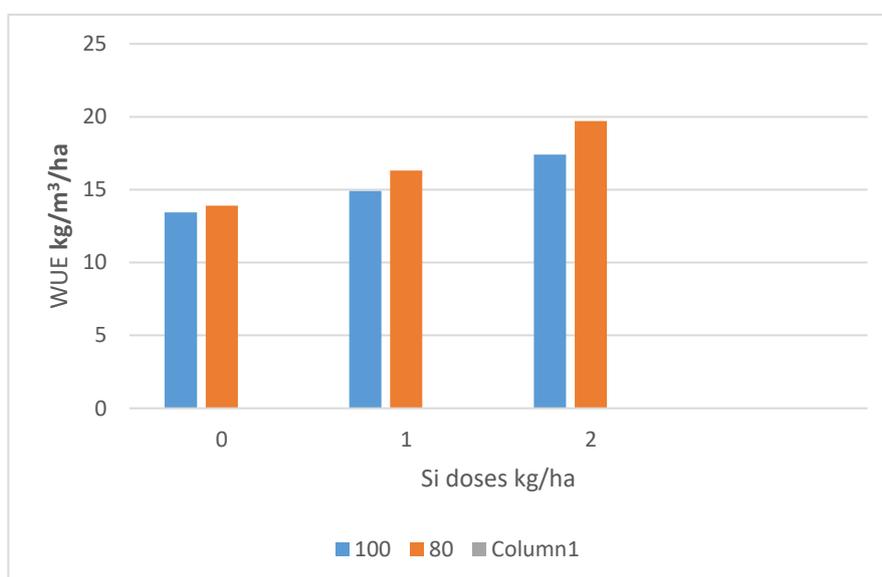


FIG.1. INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON WATER USE EFFICIENCY (KG/M3/HA) OF SORGHUM CROP DURING 1ST.

Effect of irrigation and Si levels on dry forage yield of sorghum crop:

Means comparisons of dry forage yield of Sorghum crop:

The decrease in irrigation from 100% to 60% of ETc reduced the dry forage yield of sorghum from 15.32 t/ha to 12.48 t/ha (18.53%) during 1st cut, from 13.79 t/ha to 11.30 t/ha (18.22%) during 2nd cut and from 15.03 t/ha to 12.32 t/ha (18.03%) during 3rd cut, and under application of Si from 0-2 kg/ha sorghum forage dry yield increased from 12.19 t/ha to 15.44 t/ha (21.04%), from 11.06 t/ha to 13.90 t/ha (20.43%), and from 12.06 t/ha to 15.15 t/ha (20.39%) during the 1st, 2nd and 3rd cut respectively (Table 4).

Interaction effect of irrigation and Si levels on dry forage yield of Sorghum crop:

The interaction of irrigation and Si levels was also significant ($P \leq 0.05$) during 1st and 3rd cuts while it was highly significant ($P \leq 0.01$) during 2nd cut. Means of Interaction between irrigation and Si treatments (Table 5 and Fig. 2) showed that within same irrigation level dry forage yield increased with increase in Si rate, and within each Si dose dry forage yield decreased with decrease in irrigation levels (increase drought stress) compared with. For the 1st cut, the maximum dry forage yield was 17.03 (t/ha), while it was 15.31 (t/ha) for the 2nd cut and 16.70 (t/ha) for the 3rd one. The dry forage yield was more during 1st cut then decreased during 2nd cut and also increased during 3rd cut. During 2nd cut under severe drought stress the dry yield was less affected as compared to other studied crop parameters. Under Si treatment two (2 kg Si ha⁻¹) and irrigation treatment two (60% ETc) the yield was 14.77 (t/ha) In the 1st cut, 13.28 (t/ha) for the 2nd and 14.47 (t/ha) for the 3rd cut.

TABLE 4. MEANS OF DRY FORAGE YIELD (T/HA) OF SORGHUM UNDER THE EFFECT OF VARYING LEVELS OF IRRIGATION AND SILICON DURING 2017 CROP SEASON. NUMBER OF CUTS OF SORGHUM CROP

Treatments levels	Number of cuts of Sorghum crop		
	1st cut	2nd cut	3rd cut
Irrigation levels (% ETc)			
100	15.32 a	13.79 a	15.03 a
80	13.29 b	11.97 b	13.05 b
60	12.48 c	11.30 c	12.32 c
LSD (0.05)	0.378	0.35	0.38
Silicon levels (kg/ha)			
0	12.19 c	11.6 c	12.06 c
1	13.46 b	12.11 b	13.20
2	15.44 a	13.90 a b	15.15 a
LSD (0.05)	0.378	0.35	0.38

TABLE 5: EFFECT OF INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON MEANS OF DRY FORAGE YIELD (T/HA) OF SORGHUM CROP DURING 2017 CROP SEASON.

1st Cut	Irrigation levels (% ETc)	Silicon levels (kg/ha)		
		0	1	2
	100	13.83	15.13	17.01
	80	12.24	13.06	14.56
	60	10.51	12.18	14.75
	LSD (0.05)		0.65	
2nd Cut	Irrigation levels (% ETc)	Silicon levels (kg/ha)		
		0	1	2
	100	12.45	13.62	15.31
	80	11.06	11.76	13.11
	60	9.68	13.28	13.28
	LSD (0.05)		0.61	
3rd Cut	Irrigation levels (% ETc)	Silicon levels (kg/ha)		
		0	1	2
	100	13.57	14.84	16.70
	80	12.07	12.81	14.29
	60	10.55	11.95	14.47
	LSD (0.05)		0.66	

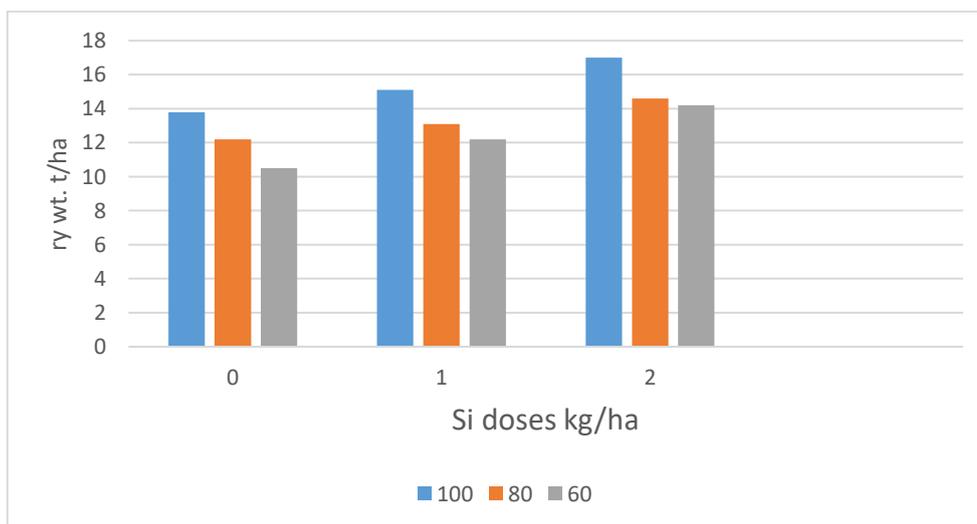


FIG. 2. INTERACTION BETWEEN IRRIGATION AND SI LEVELS ON WATER USE EFFICIENCY (KG/M3/HA) OF SORGHUM CROP DURING 1ST.

IV. DISCUSSION

In spite of the limited studies on the interaction of drought and application of silicone (Si) as mitigating factor improving irrigation water use efficiency (WUE) in soils and enhancing crop growth yields some researchers obtained good results in this field [14,21]. The results showed that drought effects under reduction of irrigation water from 100% to 60% particularly during 2nd cut decreased sorghum plant forage dry yield up to (23%), and increased WUE up to 6.6%. Drought stress is one of the most important abiotic stress factor that affects plant growth specially in arid and semi-arid regions all over the world [26,12,16]. Significant reductions have been observed in morphological, physiological and metabolic parameters of plants under drought stress [20]. Growth rate of crop plants suffered reduction under drought stress [2,3,15,23]. The increase in sorghum dry forage yield and in WUE under application of Si in this study probably might have been due to seepage of Si into the plant tissues reaching the roots, enhancing their growth enabling them to absorb more water from soil thus result in increase in dry forage yield and WUE. These results agree with previous studies on effect of Si under drought stress particularly on sorghum as was documented by [9,17]. Number of researchers applied Si under drought stresses and found improvement in crop yield and crop quality [13,22,24,6,8,10], working on wheat growth and [1] on sorghum found increases in plant height, dry matter, chlorophyll content, relative water content, stomatal conductance in wheat and sorghum plants when treated with Si under drought stress. Our data suggest that the combined use of Si under irrigation water stress is an effective approach for improving dry forage yield in Sorghum water use efficiency on marginal land.

V. CONCLUSION

The decrease in irrigation water from (100% to 60% ETc) (about 25% water saving) without Si application, resulted in a decrease in sorghum forage dry yield (22.75%) during all cuts. On the other hand reduction in irrigation water from (100% to 60% ETc) resulted in increase in WUE. Within each irrigation water level application of Si resulted in increase in forage dry yield and WUE with increase in Si dose from 0 to 2 kg ha⁻¹. In the meanwhile, the foliar application of Si (2 kg ha⁻¹) with irrigation treatment (100% ETc) significantly increased the dry forage yield by 30% compared to no Si treatment. This may be due to the improvement in the growth promoting factors initiated by application of Si represented in improved WUE and increased root volume under these drought stress conditions.

Using the yield per unit water used, the 2 kg ha⁻¹ Si treatment was the best as it reached 17-23 kg/ha.mm while it was between 13 and 17 kg/ha.mm excluding the second cut that has least effect. In growing sorghum for dry yield purpose, 60% ETc and 2 kg ha⁻¹ Si is an economical option with more water saving and small reduction in yield especially in arid regions.

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