Using Silicon to Ameliorate the Deleterious Effects of Drought on Wheat (*Triticum Aestivum* L.)

Ahmed S. M. Morsy[1] and Naheif E. M. Mohamed[2]

[1]Agronomy Dept. Fac. of Agric. Minia Univ., [2]Agronomy Dept. Fac. of Agric. Sohag Univ., Egypt.

Abstract: Silicon is known to ameliorate the deleterious effects of drought on plant growth. This study was a trial for evaluating growth and nutritional status of wheat cv. Sids- 12 on different soil water deficits as influence by silicon application. Silicon in the form of potassium silicate was added to the soil at 150 and 200 mg/ kg^{-1} soil. Plants were grown under three levels of soil water contents namely 50 %, 75 % and 100 % of field capacity. Water stress conditions especially at 50 % field capacity was responsible for reducing growth aspects, spike weight, leaf water content %, plant pigments and concentrations and uptake of N, P, K, Mg, Ca and Si at all levels of water content. Drought treatments considerably enhanced H_2O_2 in the leaves. Poor growth and nutritional status of wheat seedlings grown under water deficit conditions was measurably improved with silicon application. In water deficit area where wheat cv. Sids- 12 are planted, its is essential for using silicon.

[Ahmed S. M. Morsy and Naheif E. M. Mohamed. **Using Silicon to Ameliorate the Deleterious Effects of Drought on Wheat (*Triticum Aestivum* L.)**. *Stem Cell* 2013;4(2):1-8] (ISSN 1545-4570). http://www.sciencepub.net. 1

Keywords: Silicon; Ameliorate; Deleterious Effect; Drought; Wheat (*Triticum Aestivum* L.)

1. Introduction

Drought stress usually causes a reduction in crop production. It inhibits the photosynthesis of plants, causes changes of chlorophyll contents and components and damaged of photosynthesis apparatus. It also, inhibits the photochemical activities and decreases the activities of enzymes in the calvin cycle **(Baligar *et al*., 2001)**. One of the important reasons that environmental stress inhibits the growth and photosynthetic abilities of plants is the breakdown of the balance between the production of reactive oxygen species and the antioxidant defense causing accumulation of oxygen species which induces oxidative stress to proteins, membrane lipids and other cellular components **(Alvi and Sharif, 1995)**. The antioxidant defense system in the plant cell includes both enzymatic such as perioxidase and non- enzymatic constituents such as ascorbic acid. In case of drought, high activities of antioxidant enzymes and non- enzymatic constituents are important for plants to tolerate stresses **(Iturbe-Omaetxe *et al*., 1998).**

Silicon (Si), the second most abundant element in the earth's crust, has not yet received the title of essential nutrient for higher plants, as its role in plant biology is poorly understood **(Epstein, 1999).** However, various studies have demonstrated that Si application increased plant growth significantly **(Alvarez and Datnoff, 2001).** Beneficial effects of Si are more prominent when plants were subjected to multiple stresses including biotic and abiotic stresses **(Aziz *et al*., 2002; Rodrigues *et al*., 2003; Ma, 2004; Tahir *et al*., 2006).** Silicon is also known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic activity, erectness of leaves and structure of xylem vessels under high transpiration rates **(Melo *et al*., 2003; Hattori *et al*., 2005). Gong *et al*., (2003a)** observed a great promotion on water economy and dry matter yield of water by Si application. Silicon application is reported to enhance leaf water potential under water stress conditions **(Matoh *et al*., 1991).** They suggested that a silica-cuticle double layer formed on leaf epidermal tissue is responsible for this higher water potential. **Lux *et al*. (2002)** reported that endodermal tissue accumulates large amounts of Si in drought tolerant cereal cvs. **Jones and Handreck (1999); Hattori *et al*. (2003); and Lux *et al*. (2003)** suggested that Si plays an important role in water transport and root growth under drought conditions in sorghum.

Previous studies show that application of silicon is useful for drought stress tolerance improvement of crops in relative to non- silicon treatment under drought **(Alvi and Sharif, 1995; Rafi *et al*., 1997; Akram *et al*., 2004; Gong *et al*., 2005; Gunes *et al*., 2006; Mitani and Ma, 2005 and Rahmatullah *et al*., 2007). Samarah *et al*., (2004)** confirmed the beneficial effect of using silicon in alleviating the adverse effects of drought on growth of Soybean.

To ensure food security and sustainable economy, it is extremely important to find ways to improve drought tolerance of wheat. Keeping in view the importance of wheat, it is essential for testing the beneficial effects of silicon on wheat cv. Sids- 12 grown under different soil water contents.

2. Material and Methods

This pot investigation was conducted in greenhouse located at Sohag district, Sohag

Governorate during 2012 and 2013 seasons started on (2nd week of Nov. during both seasons) wheat cv. Sids- 12 was selected for initiating this experiment. After sterilization of the seeds surface with 1 % sodium hypochlorite for 10 min and germinated for 24 h. the seeds were put in plastic pots (45 cm × 32 cm × 13 cm dimensions). Each pot was filled with 17.0 kg clay soil (pH 8.2, OM 2.92 %, total N 0.1 %; Available P 6.1 ppm; Available K 406 ppm and Available Si, 180 ppm). Analysis was done according to the different procedures that outlined in **A.O.A.C., (1995).** Nitrogen, phosphorus and potassium fertilizers at 80, 60 and 50 mg/ kg^{-1} soil, respectively were mixed with the soil before filling the plastic pots.

This experiment included the following nine treatments:-

1. Irrigation at 50 % F.C. without silicon.
2. Irrigation at 75 % F.C. without silicon.
3. Irrigation at 100 % F.C. without silicon.
4. Irrigation at 50 % F.C. + 150 mg/ kg^{-1} soil/ Si.
5. Irrigation at 75 % F.C. + 150 mg/ kg^{-1} soil/ Si.
6. Irrigation at 100 % F.C. + 150 mg/ kg^{-1} soil/ Si.
7. Irrigation at 50 % F.C. + 200 mg/ kg^{-1} soil/ Si.
8. Irrigation at 75 % F.C. + 200 mg/ kg^{-1} soil/ Si.
9. Irrigation at 100 % F.C. + 200 mg/ kg^{-1} soil/ Si.

Each treatment was replicated three times, four pots per each. Therefore, the total pots used for achieving of this study were 108 pots. Before sowing the seeds, silicon in the form of potassium silicate (25 % Si + 10 K_2O) was added to the soil at 150 or 200 mg kg^{-1} soil. Ten seeds of wheat cv. Sids- 12 were sown per each pot and thinned to four seedlings per pot after 15 days of seedling emergence. Distilled water was used for irrigation and all of the pots were kept at field capacity till 15 days. Three moisture levels via 50 %, 75 % and 100 % of field capacity were then maintained in these pots till harvesting. After 75 days, height of plants (cm.) was measured from the surface. Average soil by using measuring tape Spike weight (g.) was recorded. The selected seedlings were separated into shoots and roots for measuring averages dry weights of shoots and roots (g/ plant) and whole plant dry weight was estimated by summation of dry shoots and roots. Leaf water content was determined by drying the leaves at 80 °C for 48 h and calculated as water content % = Fresh weight – dry weight × 100.

Fresh weight

Total proteins (mg g^{-1} d.w) in the leaves was estimated by multiplying N % by 6.25. Total carbohydrates % in the leaves was determined by phenol and sulphoric acid method **(A.O.A.C., 1995).**

Hydrogen peroxide (H_2O_2) content in the leaves was assayed according to the method of **He *et al.* (2005).** Leaves were homogenized in ice bath with 0.1 % (w/v) TCA. The extract was centrifuged at 12,000 × g for 15 min, after which to 0.5 ml of the supernatant was added 0.5 ml of 10 mM potassium phosphate buffer (pH 7.0) and 1 ml of 1 M KI, and the absorbance was read at 390 nm. The content of H_20_2 was given on a standard curve.

Plant pigments namely chlorophylls a & b and total carotenoids (mg/ g^{-1} F.W.) were determined from fully expanded leaves according to **Arnon (1948)**. Total chlorophylls as mg/ g^{-1} F.W. was calculated by summation of chlorophyll a plus chlorophyll b **(Wettstein, 1957)**. Also, percentages of N, P, K, Mg and Ca were determined in the mixture of dried shoots and roots (according to **Piper, 1950 and A.O.A.C., 1995**). Silicon as mg g^{-1} was determined according to **Elliot and Snyder (1991).** Uptake of these nutrients/ plant was recorded by multiplying percentage of each clement by dry weight of whole plant (mg in the whole per plant).

Statistical analysis was done (according to **Mead *et al*., 1993)** using revised L.S.D at 5 % for made all comparisons among different treatment means.

3. Results and Discussion

1-Growth aspects:

There were significant interactive effects of water content and silicon (Si) application on the four growth characters of wheat. Seedlings namely shoot and dry weights and plant height (Table 1). Reducing the filled capacity from 100 to 50 % caused a significant and a gradual decrease in all growth parameters. Values of growth characters of the plants grown with 200 mg/ kg^{-1} Si was slightly higher than those grown with 150 mg/ kg^{-1} Si in soil. It is worth to mention that the inferior effects of water deficit on growth characters significantly can be alleviated by using Si at 150 to 200 mg/ kg^{-1} soil. The maximum values were recorded on the plants that irrigated with water at 100 % field capacity and fertilized with Si at 200 mg/ kg^{-1} soil. The minimum values were recorded on the plants grown under drought conditions (50 % F.C) without using silicon. Similar trend was noticed during both seasons.

These results are in agreement with those obtained by **Mitani and Ma (2005); Tahir *et al*., (2006) and Rahmatullah *et al*. (2007).**

2-Spike weight:

It is clear from the data in Table (1) that varying water contents in the soil with or without Si application significantly resulted in great variation on spike weight. There was a gradual reduction on spike weight with reducing water content from 100 to 50 % field capacity. Under water deficit (75 or 50 % field capacity), using silicon at 150 to 200 mg/ kg^{-1} soil significantly was accompanied with amelioration of the adverse effects of drought on spike weight. There was a slight and insignificant promotion on spike weight with increasing the levels of Si from 150 to 200 mg/kg^{-1} soil. This means that it is enough from economical of view for using Si at 150 mg/ kg^{-1} soil in the deficit in water area grown with wheat. The maximum values of spike weight from economical point of view reached 0.94 and 0.98, in the plants irrigated with water at 100 % field capacity + silicon application. Using silicon in wheat plant under drought was significantly preferable than the neglections of using Si under arid conditions. The lowest values were recorded on the plants grown under drought conditions and did not fertilize with Si. These results were true during both seasons.

These results are in agreement with those obtained by **Mitani and Ma (2005); Tahir *et al*. (2006) and Rahmatullah *et al*. (2007).**

3-Leaf water content, proteins and total carbohydrates:

It is clear from the data in Table (2) that there was significant main and interactive effects of soil water content and silicon levels on leaf water content, proteins and total carbohydrates. These parameters were significantly more in plants grown under higher field capacity (100 %) than those grown under lower values (75 and 50 % field capacity). Values were slightly more when silicon was applied at 200 mg/ kg^{-1} soil than those supplied with 150 mg/ kg^{-1}. Silicon application significantly improved these three parameters under drought conditions. Similar trend was observed during both seasons. These results are in agreement with those obtained by **Mitani and Ma (2005); Tahir *et al*. (2006) and Rahmatullah *et al*. (2007).**

4-H_2O_2 content of leaves under drought:

Detection of H_2O_2 in plant tissues under stress conditions is important because it can be a precursor of highly reactive oxygen species. As shown in Table (2) the H_2O_2 content in the leaves was significantly increased with reducing filed capacity of soil from 100 to 50 %. Values were significantly higher under drought conditions (50 and 75 % field capacity) in relative to that in well watered plants. Values of H_2O_2 was significantly promoted in the absence of applying silicon. Soil addition of silicon at 150 to 200 mg/ kg^{-1} soil under drought conditions significantly was accompanied with depressing H_2O_2 in relative to non- application under the same conditions. Planting wheat under drought conditions (50 %field capacity) with the neglection of Si application gave the maximum values. Irrigation the plants with water at 100 % field capacity plus exposing the soil to silicon gave the lowest values. Similar results were noticed during both seasons. These results are in agreement with those obtained by **Gong *et al*. (2005) and Rahmatullah *et al*. (2007).**

5-Plant pigments as well as content and uptake of N, P, K, Mg, Ca and Si by plant:

It can be seen from the data in (Tables 2 - 5) that there was significant main and interactive effects of water contents and silicon on the three plant pigments namely chlorophyll a & b and total carotenoids, total chlorophylls as well as concentrations and uptake of N, P, K, Mg, Ca and Si. These were a gradual and significant reduction on these parameters with decreasing filed capacity used for irrigations from 100 to 50 %. Using silicon at 150 to 200 mg/ kg^{-1} soil to water deficit plants significantly was very effective in enhancing plant pigments as well as concentrations and uptake of nutrients rather than leaving the plants under drought alone. Results further reveal that silicon application to soil under drought conditions succeeded in ameliorating the inferior effects of drought on plant pigments and nutritional status of the seedling. Irrigation of wheat seedlings with water at 100 % field capacity plus soil addition of silicon at 150 mg/ kg^{-1} soil gave the maximum values (since no significant differences were observed among 150 and 200 mg Si/kg^{-1} soil). Irrigation at 50 % field capacity without using silicon gave the lowest values. These results were true during both seasons. These results are in concordance with those obtained by **Melo *et al*. (2003); Mitani and Ma (2005); Tahir *et al*. (2006) and Rhamatullah *et al*. (2007).**

Table (1): Dry matter of shoots, roots and plants, plant height and spike weight of wheat cv. Sids- 12 grown with two silicon doses at three levels of soil water contents during 2012 and 2013 seasons.

Silicon and soil water content treatments	Shoot dry matter (g/ plant)		Root dry matter (g/ plant)		Plant dry matter (g/ plant)		Plant height (cm.)		Spike weight (g.)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Irrigation at 50 % F.C without silicon (Si)	3.00	3.31	1.10	1.14	4.10	4.45	40.0	41.2	0.41	0.48
Irrigation at 75 % F.C without (Si)	3.40	3.71	1.14	1.17	4.54	4.88	44.5	45.7	0.55	0.61
Irrigation at 100 % F.C without (Si)	4.10	4.41	1.24	1.27	5.34	5.68	48.0	49.1	0.69	0.76
Irrigation at 50 % F.C + 150 mg/kg^{-1} soil Si	5.20	5.51	1.41	1.44	6.61	6.95	44.7	46.0	0.71	0.80
Irrigation at 75 % F.C + 150 mg/kg^{-1} soil Si	5.90	6.20	1.52	1.56	7.42	7.76	51.2	63.5	0.82	0.91
Irrigation at 100 % F.C + 150 mg/kg^{-1} soil Si	6.30	6.60	1.62	1.66	7.92	8.26	53.7	55.0	0.94	0.98
Irrigation at 50 % F.C + 200 mg/kg^{-1} soil Si	5.30	5.50	1.52	1.45	6.72	6.99	45.0	46.3	0.73	0.81
Irrigation at 75 % F.C + 200 mg/kg^{-1} soil Si	6.00	6.30	1.53	1.57	7.53	7.87	52.0	54.0	0.83	0.92
Irrigation at 100 % F.C + 200 mg/kg^{-1} soil Si	6.40	6.70	1.63	1.67	8.03	8.37	54.0	55.4	0.95	0.99
Revised L.S.D at 5 %	**0.30**	**0.20**	**0.02**	**0.03**	**0.31**	**0.33**	**1.8**	**2.1**	**0.06**	**0.07**

F.C = Field capacity

Table (2): Leaf water content %, proteins, total carbohydrates, H_2O_2 content and chlorophyll a of wheat cv. Sids- 12 grown with two silicon doses at three levels of soil water contents during 2012 and 2013 seasons.

Silicon and soil water content treatments	Leaf water content %		Proteins (mg g^{-1} dw)		Total carbohydrates %		H_2O_2 content (µmol g^{-1} dw)		Chlorophyll a (mg/ g F.W)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Irrigation at 50 % F.C without silicon (Si)	69.9	71.0	53.9	55.0	14.2	14.4	8.11	8.10	6.90	7.31
Irrigation at 75 % F.C without (Si)	71.1	71.2	61.0	62.2	4.8	15.0	7.12	7.11	7.71	8.11
Irrigation at 100 % F.C without (Si)	73.3	74.5	71.9	73.0	15.3	15.6	6.40	6.38	8.51	8.90
Irrigation at 50 % F.C + 150 mg/kg^{-1} soil Si	74.0	75.1	89.0	90.1	15.0	15.5	5.55	5.51	8.91	9.42
Irrigation at 75 % F.C + 150 mg/kg^{-1} soil Si	76.9	78.0	101.2	102.0	15.7	16.2	5.00	4.98	9.90	10.21
Irrigation at 100 % F.C + 150 mg/kg^{-1} soil Si	78.9	80.0	106.0	106.3	16.5	17.1	4.60	4.57	11.22	11.92
Irrigation at 50 % F.C + 200 mg/kg^{-1} soil Si	74.3	75.2	91.0	90.5	15.1	15.6	5.50	5.48	9.01	9.51
Irrigation at 75 % F.C + 200 mg/kg^{-1} soil Si	77.0	78.3	103.3	103.0	15.8	16.3	5.94	5.91	10.01	10.33
Irrigation at 100 % F.C + 200 mg/kg^{-1} soil Si	79.0	80.2	107.0	107.9	16.6	17.2	4.41	4.41	11.30	12.03
Revised L.S.D at 5 %	**0.9**	**0.7**	**4.1**	**4.3**	**0.4**	**0.5**	**0.08**	**0.09**	**0.61**	**0.52**

F.C = Field capacity

Table (3): Some plant pigments and percentages of N and P in the leaves of wheat cv. Sids- 12 grown with two silicon doses at three levels of soil water contents during 2012 and 2013 seasons.

Silicon and soil water content treatments	Chlorophyll b (mg/ g F.W)		Total chlorophylls (mg/ g F.W)		Total carotenoids (mg/ g F.W)		Leaf N %		Leaf P %	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Irrigation at 50 % F.C without silicon (Si)	2.65	2.70	9.55	10.01	1.33	1.40	1.66	1.67	0.14	0.15
Irrigation at 75 % F.C without (Si)	2.91	3.02	10.62	11.13	1.41	1.48	1.75	1.78	0.18	0.20
Irrigation at 100 % F.C without (Si)	3.22	3.37	11.73	12.27	1.51	1.60	1.82	1.85	0.23	0.24
Irrigation at 50 % F.C + 150 mg/kg^{-1} soil Si	3.00	3.15	11.91	12.57	1.61	1.71	1.90	1.92	0.23	0.28
Irrigation at 75 % F.C + 150 mg/kg^{-1} soil Si	3.50	3.66	13.4	13.87	1.70	1.85	1.95	1.97	0.27	0.31
Irrigation at 100 % F.C + 150 mg/kg^{-1} soil Si	4.01	4.16	15.23	16.08	1.89	1.95	2.05	2.07	0.31	0.33
Irrigation at 50 % F.C + 200 mg/kg^{-1} soil Si	3.11	3.16	12.12	21.63	1.62	1.72	1.91	1.93	0.24	0.29
Irrigation at 75 % F.C + 200 mg/kg^{-1} soil Si	3.60	3.68	13.61	14.01	1.72	1.86	1.96	1.98	0.28	0.32
Irrigation at 100 % F.C + 200 mg/kg^{-1} soil Si	4.11	4.18	15.41	16.21	1.90	1.97	2.06	2.09	0.32	0.34
Revised L.S.D at 5 %	**0.21**	**0.31**	**0.64**	**0.60**	**0.03**	**0.04**	**0.06**	**0.05**	**0.02**	**0.03**

F.C = Field capacity

Table (4): Percentages of K, Mg, Ca and Si^{++} in the leaves and N uptake/ plant of wheat cv. Sids- 12 grown with two silicon doses at three levels of soil water contents during 2012 and 2013 seasons.

Silicon and soil water content treatments	Leaf K %		Leaf Mg %		Leaf Ca %		Leaf Si % (mg/ g^{-1})		N uptake/ plant (mg.)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Irrigation at 50 % F.C without silicon (Si)	1.11	1.20	0.49	0.51	2.55	2.58	5.11	4.98	68.1	74.3
Irrigation at 75 % F.C without (Si)	1.21	1.32	0.54	0.56	2.69	2.71	5.22	5.11	79.5	86.6
Irrigation at 100 % F.C without (Si)	1.33	1.44	0.60	0.62	2.81	2.80	5.31	5.41	97.2	105.1
Irrigation at 50 % F.C + 150 mg/kg^{-1} soil Si	1.25	1.36	0.60	0.62	2.83	2.79	9.99	10.11	125.6	133.4
Irrigation at 75 % F.C + 150 mg/kg^{-1} soil Si	1.36	1.47	0.66	0.67	2.92	2.95	10.19	10.21	144.7	152.9
Irrigation at 100 % F.C + 150 mg/kg^{-1} soil Si	1.51	1.52	0.72	0.71	3.11	3.10	12.11	12.22	162.4	171.0
Irrigation at 50 % F.C + 200 mg/kg^{-1} soil Si	1.26	1.37	0.61	0.63	2.85	2.80	12.11	12.69	128.4	134.9
Irrigation at 75 % F.C + 200 mg/kg^{-1} soil Si	1.37	1.48	0.67	0.68	2.93	2.96	13.11	13.11	147.6	155.8
Irrigation at 100 % F.C + 200 mg/kg^{-1} soil Si	1.52	1.53	0.73	0.72	3.11	3.11	14.09	14.22	165.9	174.9
Revised L.S.D at 5 %	**0.06**	**0.07**	**0.04**	**0.04**	**0.07**	**0.08**	**0.04**	**0.06**	**5.1**	**5.9**

F.C = Field capacity

Table (5): Uptake of P, K, Mg, Ca and Si/ plant of wheat cv. Sids- 12 grown with two silicon doses at three levels of soil water contents during 2012 and 2013 seasons.

Silicon and soil water content treatments	P uptake/ plant (mg.)		K uptake/ plant (mg.)		Mg uptake/ plant (mg.)		Ca uptake/ plant (mg.)		Si uptake/ plant (mg.)	
	2012	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**	**2012**	**2013**
Irrigation at 50 % F.C without silicon (Si)	5.74	6.68	45.51	53.4	20.09	22.70	104.55	114.81	20.95	22.16
Irrigation at 75 % F.C without (Si)	8.17	9.76	54.94	64.42	24.52	27.33	122.13	132.25	23.70	24.94
Irrigation at 100 % F.C without (Si)	12.28	13.63	71.02	81.79	32.04	35.22	150.05	159.04	28.36	30.73
Irrigation at 50 % F.C + 150 mg/kg^{-1} soil Si	15.20	19.46	82.63	94.52	39.66	43.09	187.06	193.91	66.03	70.26
Irrigation at 75 % F.C + 150 mg/kg^{-1} soil Si	20.03	24.06	100.91	114.07	48.97	51.99	216.66	228.92	75.61	72.23
Irrigation at 100 % F.C + 150 mg/kg^{-1} soil Si	24.55	27.26	119.59	125.55	57.02	58.65	246.31	256.06	95.91	100.23
Irrigation at 50 % F.C + 200 mg/kg^{-1} soil Si	16.66	20.27	84.67	95.76	40.99	44.04	191.52	195.72	81.83	88.70
Irrigation at 75 % F.C + 200 mg/kg^{-1} soil Si	21.08	25.18	103.16	116.48	50.45	53.52	220.63	232.95	98.92	103.18
Irrigation at 100 % F.C + 200 mg/kg^{-1} soil Si	25.70	28.46	122.06	128.06	58.62	60.26	249.73	260.03	113.14	119.02
Revised L.S.D at 5 %	**2.1**	**1.9**	**4.0**	**3.8**	**2.1**	**1.8**	**4.9**	**5.2**	**2.1**	**1.9**

F.C = Field capacity

4. Discussion

It was suggested that silicon could increase drough tolerance of plants **(Epstein, 1999 and Ma, 2004)**. Plantation in drough conditions resulted in inhibiting plant photosynthesis through reducing internal CO_2 concentrations and stomatal conductance **(Matoh *et al*., 1991 and Gong *et al*., 2005).** Drought conditions increase the formation of reactive oxygen species such as superoxide, H_2O_2 and OH (**Sudhakar *et al*., 2001**). Plants posses efficient antioxidant defense systems for scavenging reactive oxygen species. The major antioxidant enzymes were superoxide dismutase, catalase, peroxidase and acid phosphlipase. Glycolate oxidase plays an important role in maintaining a high glutathione reducase/ reduced glutathione ratio in plants **(Liang *et al*., 2003 and Zhu *et al*., 2004).** Drought conditions increase the formation of reactive oxygen species that oxidizes photosynthetic pigments, membrane lipids, proteins and nucleic acids **(Smirnoff, 1993; Alscher *et al*., 1997; Yordanov *et al*., 2000 and Egert and Tevini, 2002).** Plants with high levels of constitutive or induced antioxidants have been reported to have greater resistance to this oxidative damage **(Sudhakar *et al*., 2001).** In the present study, drough stress inhibited the activates of antioxidant enzymes and included the accumulation of H_2O_2 which caused protein decomposition and oxidization, lipids peroxidation and decrease in photosynthetic pigment contents **(Gong *et al*., 2005).** Previous studies showed that Si increases the activities of antioxidant enzymes in the leaves that protect plant tissues from oxidative damage under drough conditions **(Gong *et al*., 2003b).**

Silicon is also known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic activity, erectness of xylem vessels structure. A silicon- cuticle double layer formed on the leaf epidermal tissue is responsible for the action of Si in enhancing water potential. Also, Si is responsible for stimulating water transport and root growth **(Hattori *et al*., 2005).**

Conclusion

It is essential for using silicon at 150 to 200 mg/ kg^{-1} soil via soil for wheat cv. Sids- 12 plants growing under drough conditions for producing vigourous plants.

References

1. **Akram, H. M.; lqbal, M. S.; Saeed, M.; Yar, A.; Ali, A.; Sahi, K. A. and M. Nadeem, A. (2004):** Drought tolerance studies of wheat genotypes. Pak. J. Biol. Sci. 7 (1): 90 – 92.
2. **Alscher, R.G.; Donahue, J.L.and Cramer, C.L. (1997):** Reactive oxygen species and antioxidants: relationships in green cells. Physiol. Plant. 100 (1997) 224 – 233.
3. **Alvarez, J. and Datnoff, L. E. (2001):** The economic potential of silicon for integrated management and sustainable rice production. Crop Prot. 20: 43 – 48.
4. **Alvi, A. S. and Sharif, M. (1995):** Arid zone agriculture research in Pakistan. Prog. Farming. 15: 5 – 12.

A. **O. A. C. (1995):** Official Methods of Analysis 16th Ed, A.O.A.C Benjamin Franklin Station, Washington, D.C, U.S.A. pp 490 – 510.

5. **Arnon, D. I. (1949):** Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. Plant Physiology. 24: 1 – 10.
6. **Aziz, T.; Gill, M. A. and Rahmatullah, R. (-2002):** Silicon nutrition and crop production: A review. Pak. J. Agric. Sci. 39 (3): 181 – 187.
7. **Baligar, V. C.; Fageria, N. K. and He, Z. I. (2001):** Nutrient use efficiency in plants. Commun. Soil Sci. Plant Anal. 32: 921 – 950.
8. **Egert, M. and Tevini, M. (2002):** Influence of drought on some physiological parameters symptomatic for oxidative stress in leaves of chives (*Allium schoelloprasum*), Environ. Exp. Bot. 48 (2002) 43 – 49.
9. **Elliot, C. L. and Snyder, G. H. (1991):** Autoclave-induced digestion for the colorimetric determination of silicon in rice straw. J. Agric. Food Chem. 39: 1118 – 1119.
10. **Epstein, E. (1999):** Silicon. Annl. Rev. Plant Physiol. Plant Mol. Biol. 50: 641 – 664.
11. **Gong, H. J.; Chen, K. M.; Chen, G. C.; Wang, S. M. and Zhang, C. L. (2003a):** Effect of silicon on growth of wheat under drought. J. Plant Nutr. 26 (3): 1055 – 1063.
12. **Gong, H.; Chen, K. M.; Chen, G. C.; Wang, S. M. and Zhang, C. L. (2003b):** Effects of silicon on the growth of wheat and its antioxidative enzymatic system, Chin. J. Soil Sci. 34 (2003) 55 – 57.
13. **Gong, H.; Zhu, X.; Chen, K.; Wang, S. and Zhang, C. (2005):** Silicon alleviates oxidative damage of wheat plants in pots under drought. Plant Sci. 169: 313 – 321.
14. **Gunes, A.; Cicek, N.; Inal, A.; Alpaslan, M.; Eraslan, F.; Guneri E. and Guzelordu, T. (2006):** Genotypic response of chickpea (*Cicer arietinum* L.) cultivars to drought stress implemented at pre-and post-anthesis stages and its relations with nutrient uptake and efficiency. Plant Soil Environ. 52 (8): 368 – 376.
15. **Hattori, T.; Inanaga, S.; Tanimoto, E.; Lux, A.; Luxova, M. and Sugimoto, Y. (2003):** Silicon induced changes in viscoelastic properties of sorghum root cell walls. Plant Cell Physiol. 44: 743 – 749.
16. **Hattori, T.; Inanaga, S.; Araki, H.; An, P.; Mortia, S.; Luxova, M. and Lux, A. (2005):** Application of silicon enhanced drought tolerance in sorghum bicolor. Physiolgia Plantarum. 123: 459 – 466.
17. **He, Y.; Liu, Y.; Cao, W.; Huai, M.; Xu, B. and Huang B. (2005)** Effects of salicylic acid on heat tolerance associated with antioxidant metabolism in *Kentucky bluegrass*. Crop Sci. 45: 988 – 995.
18. **Iturbe- Ormaetxe, P. R.; Escuredo, C.; Arrese- Igor, C. and Becans, M. (1998):** Oxidative damage in pea plants exposed to water deferent or paraquat. Plant Physiol. 116: 173 – 181.
19. **Jones, L. H .P. and Handreck, K. A. (1999):** Silica in soils, plants and animals. Adv. Agron. 19: 107 – 149.
20. **Liang, Y.; Chen, Q.; Liu, Q.; Zhang, W. and Ding, R. (2003):** Exogenous silicon (Si) increases antioxidant enzyme activity and reduces lipid peroxidation in roots of salt-stressed barley (*Hordeum vulgare* L.), J. Plant Physiol. 160 (2003) 1157-1164.
21. **Lux, A.; Luxova, M.; Abe, J.; Tanimoto, E.; Hattori, T. and lnanaga, S. (2003):** The dynamics of silicon deposition in the sorghum root endodermis. New Phytol. 158: 437 – 441.
22. **Lux, A.; Luxova, M.; Hattori, T.; lnanaga, S. and Sugimoto, Y. (2002):** Silification in sorghum (*Sorghum bicolor*) cultivars with different drought tolerance. Physiologia Plantarum. 115: 87 – 92.
23. **Ma, J. F. (2004):** Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. Soil Sci. Plant Nutr. 50: 11–18.
24. **Matoh, T.; Murata, S. and Takahashi, E. (1991):** Effect of silicate application on photosyntheis of rice plants (in Japanese). Jpn. J. Soil Sci. Plant Nutr. 62: 248 – 251.
25. **Mead, R.; Currow, R. N. and Harted, A. M. (1993):** Statistical Methods in Agriculture and Experimental Biology. Second Ed. Chapman & Hall London. pp 10 - 44.
26. **Melo, S. P.; Korndorfer, G. H.; Korndorfer, C. M.; Lana, R. M. Q. and Santan, D. G. (2003):** Silicon accumulation and water deficit

tolerance in grasses. Scientia Agricola. 60: 755-759.

27. **Mitani, N. and Ma, J. F. (2005):** Uptake system of silicon in different plant species. J. Exp. Bot. 56: 1255 – 1261.
28. **Piper, C. D. (1950):** Soil and Plant Analysis. Inter. Sci., New York pp 48 – 110.
29. **Rafi, M. M.; Epstein, E. and Falk, R. H. (1997):** Silicon deprivation causes physical abnormalities in wheat (*Triticum aestivum* L.). J. Plant Physiol. 151: 497 – 501.
30. **Rahmatullah, F. A.; Tariq Azia, M; Maqsood, A. M.; Tahir, M. A. and Kanwal, S. (2005):** Effect of silicon application on wheat (*Triticum aestivum* L.) growth under water deficiency stress. Emir. J. Food Agric. 19: 1 – 7.
31. **Rodrigues, F. A.; Vale, F. X. R.; Korndorfer, G. H.; Prabhu, A. S.; Datnoff, L. E.; Oliveira, A. M. A. and Zambolim, L. (2003):** Influence of silicon on sheath blight of rice in Brazil. Crop Prot. 22: 23 – 29.
32. **Samarah, N.; Mullen, R. and Cianzio, S. (2004):** Size distribution and mineral nutrients of soybean seeds in response to drought stress. J. Plant Nutr. 27: 815 – 835.
33. **Smirnoff, N. (1993):** The role of active oxygen in the response of plants to water deficit and desiccation. New Phytol. 125 (1993) 27 – 58.
34. **Sudhakar, C.; Lakshmi, A. and Giridarakumar, S. (2001):** Changes in the antioxidant enzyme efficacy in two high yielding genotypes of mulberry (*Morus alba* L.) under NaCl salinity, Plant Sci. 161 (2001) 613 – 619.
35. **Tahir, M.; Rahmatullah, A.; Aziz, T.; Ashraf, M.; Kanwal, S. and Maqsood, M. A. (2006):** Beneficial effects of silicon in wheat (*Triticum aestivum* L.) under salinity stress. Pak. J. Bot. 38 (5): 1715–1722.
36. **Wettstein, D. V. C. (1957):** Clatale und der Sumbmikro Skopisne Formwechsel de Plastids. Experimental Cell Research, 12: 427.
37. **Yordanov, I.; Yelikova, V. and Tsonev, T. (2000):** Plant responses to drought, acclimation, and stress tolerance, Photosynthetica 38 (2000) 171 – 186.
38. **Zhu, Z.; Wei, G.; Li, J.; Qian, Q. and Vu, J. (2004):** Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucwnis sativus* L.). Plant Sci. 167 (2004) 527-533.

3/2/2013