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Alleviation Of The Adverse Effects Of Soil Salinity Stress By Foliar Application Of Silicon On Faba bean (*Vica faba* L.)

[1]F.A. Hellal, [2]M. Abdelhameid, [1]Doaa M. Abo-Basha and [1]R.M. Zewainy

[1]*Plant Nutrition Department, National Research Centre, Dokki, Egypt*
[2]*Plant Department, National Research Centre, Dokki, Egypt*

ABSTRACT

Salinity problem in Egypt is of special importance for both the old cultivated area and the newly reclaimed lands. Pot experiment were conducted at soils differed in their salinity levels (2.84, 6.03 and 8.97 dS m^{-1}) to investigate the effect of silicon application at a rate of 0, 250, 500 and 1000 ppm SiO_2 as diatomite on growth, yield and chemical composition of Faba bean (*Vica faba* L.) *var.* Nobaria 12. Soil Salinity levels significantly reduced pod and seed number and pod weight per plant; however reduction was lower at the salinity level of 2.84 dS m^{-1} than 6.03 and 8.97 dS m^{-1}. Silicon application as foliar spray significantly improved Chlorophyll and carotene, pod yield and seed number per plant grown either in normal (2.84 dS m^{-1}) and/or in saline conditions (6.03 and 8.97 dS m^{-1}), However, the highest level of silicon (1000 ppm SiO_2) had the superiority effect in decreasing the soil salinity hazard.. Potassium content was significantly increased in plants due to foliar application of Silicon under saline soil conditions. Sodium content was higher in plants grown under saline soil condition, however Si application significantly reduced Na content in shoot and seeds of Faba bean plants, resulted significant increase in K:Na ratio in shoots. Sodium content in shoots had a significant negative correlation with shoot, seed weight and pod number. Increased K content and reduced Na in shoot and seeds may be one of the possible mechanisms of increased salinity tolerance by Silicon application in Faba bean plants.

Key words: Soil salinity, silicon, K:Na ratio, chlorophyll

Introduction

Soil salinity is a major problem for agriculture throughout the world. The major constraints for plant growth and productivity are ion toxicity with excessive uptake of mainly Cl^- and Na^+ as well as nutrients imbalance caused by disturbed uptake of essential mineral nutrients (Hu and Schmidhalter, 2005). Living with salinity is the only way of sustaining agricultural production in the salt affected soil (Al-Rawahy *et al.*, 2011). So that, it is must to find the best management to alleviate salt hazard.

Silicon has not been proven to be an essential element for higher plants, but its beneficial effects on growth have been reported in a wide variety of crops, including rice, wheat, barley and cucumber. Si fertilizer is applied to crops in several countries for increased productivity and sustainable production (Ma *et al.*, 2001). Silicon was reported to reduce the hazard effects of various a biotic and biotic stresses including salt stress, metal toxicity, drought stress**,** radiation damage, various pests and diseases caused by both fungi and bacteria, nutrients imbalance, high temperature and freezing (Ma, 2004). Usually, plants grown on saline soil suffer from several nutritional disturbances and nutrient deficiencies and consequently plant growth inhibition**.** The amount of Si in soil may vary considerably from 1 % to 45 % (Sommer *et al.*, 2006). Silicon concentrations vary greatly in plant aboveground parts, ranging from 0.1 to 10.0 % of dry weight. This wide variation in Si concentration in plant tissues is attributed mainly to differences in the characteristics of Si uptake and transport (Epstein, 1999). The agricultural benefits of silicon amendments on a soil ecosystem are well established. Silicon has been shown to mitigate adverse effects of water, mineral deficiency (Ma *et al.*, 2001) and alleviate the effects of biotic stresses including salt stress, metal toxicity and nutrient imbalance (Ma, 2004). Si application has been reported to decrease the uptake of nitrogen and potassium but increases the uptake of phosphorus, calcium, magnesium and the formation of carbohydrates in transplanted rice, to enhance K:Na selectivity ratio with concomitant decline in Na adsorption by plants (Liang *et al.*, 2007) and to reduce electrolyte leakage percentage thus increasing the element content of tissues (Zhu *et al.*, 2004 ; Nwugo and Huerta, 2008).

Diatomite is a sedimentary rock primarily composed of fossilized remains of microscopic unicellular algae, namely diatoms, with cell well impregnated with silica (as SiO_2). It contains a high amount of water soluble silica (120 ppm *vs* 10 ppm of normal soil) available to plants (Kruger, 2006). Diatomite, being mostly

Corresponding Author: F.A. Hellal, Plant Nutrition Department, National Research Centre, Dokki, Egypt
E-mail: hellalaf@yahoo.com

chemically composed of SiO_2 (86-89%) and small amount of trace elements, it is considered as a complete fertilizer. Diatomites are a naturally occurring sedimentary rock primarily composed of fossilized remains of fresh water diatoms. It is chemically composed of SiO_2 (86 to 89%) in a soluble form available to plants and small amount of trace elements. It is considered as a complete, long lasting, recyclable, reusable and environmentally friendly soil fertilizer and enhancer by improving the physical structure of soil, aerating the plant's root zone, minimizing leaching and runoff thus increasing soil water retention and reducing watering. Subsequently, diatomite promotes stronger, healthier, higher-yielding plants that mature quickly and acquire self resistance against a biotic and biotic stresses (Jessen, 2007 and Abdalla, 2011). The possible beneficial effects of silicon in the performance of bean plants grown under salt stress still need to be studied. Thus, the aim of the present study was to investigate the effect of Silicon applied as foliar applications on growth and yield as well as chemical composition, to improve Faba bean yield under saline soil conditions.

Materials And Methods

Pot experiments were carried out in the Green house of the National Research Centre, Dokki, Egypt. Plastic pots (30 cm in diameter) were filled with 10 kg soil deferred in their salinity levels. Physical and chemical analyses of soils used in pot experiment were determined according to the methods reported by Rebecca (2004) and presented in Table 1. The Major chemical elements of diatomite used for foliar application of silicon were: SiO_2 89.00%, Al_2O_3 5.95%, Fe_2O_3 0.88%, CaO 0.10%, K_2O 0.63%, MgO 0.20%, Na_2O 0.32%, TiO_2 0.29%, H_2O <3%.

The pots were divided into three main groups of soil salinity at levels (2.84, 6.03 and 8.97 dS m^{-1}) considered as Low (LS), Medium (MS) and High (HS) saline soil, respectively}. This main group was sprayed with fresh water (control) as Si_0 and the others were sprayed with silicon as diatomite at a rate of 250, 500 and 1000 ppm SiO_2 which abstracted as Si_1, Si_2 and Si_3, respectively. Each pot received 2.2 g of calcium superphosphate (15.5% P_2O_5) and 1.1 g potassium sulphate (48% K_2O) before sowing and 3.0 g ammonium nitrate (33.5% N) added two weeks after sowing. In each pot, 6 grains of Faba bean (*Vica faba* L.) var. Nobaria 12 were sown at 15 November 2011.

Table 1: Initial soil properties and treatment details of the experimental

Soil texture	ECe in soil paste (dS m^{-1})	pH (1: 2.5)	Organic matter (%)	Ca CO_3 (%)
Sandy Loam	2.84 (Low salinity, LS)	7.65	0.28	2.2
Sandy Loam	6.03 (Medium salinity, MS)	7.82	0.55	2.97
Loamy Sand	8.97 (High salinity, HS)	7.91	0.34	4.18
Cation (me l^{-1})	Ca^{++}	Mg^{++}	K^+	Na^+
	2.62	1.86	1.41	5.51
	3.22	0.92	0.73	8.34
	3.76	0.82	0.66	13.71
Anion (me l^{-1})	$CO3^{--}$	$HCO3^-$	Cl^-	$SO4^{--}$
	0.00	2.12	7.33	1.72
	0.00	2.44	8.63	2.77
	0.00	3.17	12.48	3.42

The seedlings were thinned to three plants per pot two weeks after sowing. Foliar treatments of silicon were sprayed three times at 35, 60 and 85 days after sowing.

The plant samples were collected at 45 and 90 days after sowing. The chlorophyll a and b and carotene were estimated in the fresh leaves as described by Lichtenthalar and Wellburn (1983). Shoot weight, plant height and leaf area also estimated. Leaf area (LA) calculated by the model described by Erdogan (2012) using the leaflet length (L) and width (W). $LA=- 1.6923+(L*0.0161)+(W*0.0929)+(0.0062*L*W)$.

At harvest, the following measurements were recorded: shoot weight, number of pods per plant and its weight, seed number per plant and its weight (g). Shilling percentage was calculated by dividing the seeds weight into 100 by pods weight. Total nitrogen, phosphorus, potassium, calcium and sodium estimated in the plant digest according to the method described by Faithfull (2002).

Data were statistically analyzed by using factorial completely randomized design. The means were compared using the least significant difference test (LSD) at 5% level according to Gomez and Gomez (1984). Correlation studies were done and the values tested for their significance at 1 and 5 %.

Results And Discussion

Growth parameters:

Data in Table 2 indicate that salinity had adverse effects on growth parameters of Faba bean. Moderately saline (6.03 dS m^{-1}) and strongly saline (8.97 dS m^{-1}) stress caused significant reduction in shoot weight, plant height and Leaf area as compared with non-saline stress treatment (2.84 dS m^{-1}). Increasing soil salinity from LS (2.84 dS m^{-1}) to HS (8.97 dS m^{-1}) decreased dray weight of shoot (4.56 g), (8.51 g) to (3.13 g), (7.21 g) at 45 and 90 days after sowing, respectively. Also, the leaf area decreased significantly with increasing soil salinity. These confirmed previous results obtained by (Bekheta *et al.* 2009). The plant height was not significantly affected by both soil salinity and silicon application.

The foliar application of 250 up to 1000 ppm SiO_2 increased the growth parameters of Faba bean under soil salinity levels. Foliar application of silicon to the higher levels soil salinity (8.97 dS m^{-1}) increased the shoot dry weight from 2.49 g $plant^{-1}$ up to 3.72 g $plant^{-1}$ with foliar application of 250 and 1000 ppm $SiO_{2,}$ respectively at 45 days after sowing. Similar trend was observed for leaf area and plant height at 45 and 90 days after sowing. These results were in agreed with that reported by Hanafy Ahmed *et al.* (2002).

Table 2: Growth parameters and chlorophyll, carotene of Faba bean at 45 and 90 day as influenced by salinity and Si application

Soil Salinity (SL)	Applied Silicon (Si)	Shoot dry weight (g)		Leaf area (cm^2)		Plant height (cm)		Chlorophyll a (mg g^{-1} fresh weight)		Chlorophyll b		Carotene	
		45 d	90 d	45 d	90 d	45 d	90 d	45 d	90 d	45 d	90 d	45 d	90 d
LS	Si_0	3.70	6.15	9.02	17.51	33.52	79.67	1.470	1.202	0.340	0.310	2.442	1.160
	Si_1	4.70	7.23	11.28	18.11	36.17	90.33	1.620	1.207	0.450	0.367	2.470	1.197
	Si_2	4.97	9.60	10.15	17.64	37.83	94.00	1.938	1.374	0.718	0.402	2.925	1.268
	Si_3	5.29	12.16	10.96	18.65	39.73	85.00	2.147	1.969	0.817	0.512	3.213	1.589
MS	Si_0	3.12	6.56	8.55	16.36	33.65	80.26	1.240	1.077	0.443	0.327	1.711	1.092
	Si_1	3.32	6.14	8.89	16.96	34.48	82.67	1.480	1.206	0.521	0.346	2.441	1.322
	Si_2	3.29	10.41	10.79	17.43	36.70	87.67	2.009	1.356	0.617	0.376	3.085	1.332
	Si_3	3.93	8.45	11.34	17.12	40.28	83.67	2.33	1.637	0.704	0.451	3.202	1.414
HS	Si_0	2.49	6.58	8.16	14.53	31.10	73.67	0.794	0.578	0.262	0.260	1.300	1.110
	Si_1	3.18	6.87	8.24	15.06	30.13	82.00	1.345	1.204	0.407	0.381	1.512	1.131
	Si_2	3.22	8.76	8.51	15.81	31.21	83.00	1.995	1.279	0.683	0.364	2.955	1.270
	Si_3	3.72	8.20	8.60	18.09	32.54	88.67	2.339	1.551	0.812	0.323	3.202	1.389
LSD (5%)	SL	0.39	0.60	0.25	1.05	NS	NS	0.027	0.034	0.125	0.134	0.267	NS
	Si	0.45	0.69	0.29	1.22	NS	NS	0.031	0.039	0.144	0.155	0.309	0.108
	Interaction	0.78	1.19	0.50	NS	NS	NS	0.053	0.067	0.25	0.269	0.535	NS

Chlorophyll contents:

Increasing the soil salinity levels from 2.84 and 8.97 dS m^{-1} significantly decreased the chlorophyll a and b and carotene contents. However, the application of silicon as foliar spray decreased the deleterious effect of salinity on the chlorophyll content.

Application of 1000 ppm SiO_2 produced the higher chlorophyll a and b and carotene as compared to the other treatments and control under the different soil salinity levels (Table 2). The Faba bean plants grown under 8.97 dS m^{-1} of soil salinity at 90 days after sowing sprayed with 1000 ppm SiO_2 in the form of diatomite significantly increased the chlorophyll a and b carotene (1.55, 0.32 and 1.39 mg g^{-1} fresh weight) followed by application of 500 ppm SiO_2 (1.28, 0.36 and 1.27 mg g^{-1} fresh weight) followed by 250 ppm SiO_2 over control treatments. The reduction in plant growth and yield due to salinity might be attributed to the inhibiting effects of salinity on many metabolic processes including, activity of mitochondria and chloroplasts (Singh and Dubey, 1995). El-Bagoury *et al.* (1999) suggested that, biosynthesis of chlorophylls in generally might be inhibited by the depressive effect of stress conditions on the absorption of some ions involved in the chloroplast formation, such as Mg and Fe and/or an increase of growth inhibitors, such as ethylene or abscisic acid production which enhance senescence. Carotene content was significantly reduced by increasing salt concentration of the growth compared with the control plants grown under low saline soil with EC = 2.84 dS m^{-1}. These results agree with Ghassemi-Golezaniet *et al.* (2012).

Yield parameters:

Data presented in Table 3 revealed that, Soil Salinity stress significantly reduced pod and seed number and pod weight per plant; however reduction was lower at the salinity level of 2.84 than 6.03 and 8.97 dS m^{-1}. Silicon application as foliar spray significantly improved pod yield and seed number per plant grown either in low saline soil (2.84 dS m^{-1}) and/or in saline conditions 6.03 and 8.97 dS m^{-1}.

Concerning the effect of silicon, the highest rate of silicon application (1000 ppm SiO_2) resulted in pronounced increase on all of the studied yield components of Faba bean , especially at the highest level of soil salinity (8.97 dS m^{-1}) over the lower rate of applied silicon (500 and 250 ppm SiO_2) and control treatment.

Application of 1000 SiO_2 (Si_3) in the high salinity soil (SL_3) increased the pod dry weight (11.53 g $plant^{-1}$), seed dry weight (4.23 g $plant^{-1}$), shoot dry weight (20.00 g $plant^{-1}$) over application of 500 SiO_2 and 250 SiO_2 and control (6.20 g $plant^{-1}$), (2.73 g $plant^{-1}$) and (9.25 g $plant^{-1}$). Shelling percentage decreased significantly under saline conditions (39.46 % at 8.97 dS m^{-1}) as compared to normal condition (65.87 % at 2.84 dS m^{-1}).

However, shelling percentage of plants grown with salinity increased with application of Silicon. Silicon is reported to enhance growth of many of higher plants particularly under biotic and a biotic stresses (Epstein, 1999). A number of possible mechanisms are proposed by which Si can increase resistance of plants against salinity stress which is a major yield limiting factor in arid and semiarid areas. Increase in dry matter was more pronounced in saline environments indicating beneficial effects of Si application in alleviating salinity stress (Al-Aghabary *et al*., 2004).

Table 3: Seed, pod and shoot yield per plant of Faba bean at harvest as influenced by salinity and Si application

Soil Salinity (SL)	Applied Silicon (Si)	Seed number ($Plant^{-1}$)	Pod number ($Plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)	Pod dry weight (g $plant^{-1}$)	Seed dry Weight (g $plant^{-1}$)	Shelling (%)
LS	Si0	13.00	7.02	13.58	10.87	7.50	69.02
	Si1	15.33	7.33	19.13	11.23	8.43	75.07
	Si2	15.33	7.87	20.75	14.83	8.77	59.12
	Si3	19.67	8.21	25.63	15.07	9.08	60.27
MS	Si0	10.67	4.33	12.25	8.50	4.43	52.16
	Si1	13.33	5.67	14.92	10.23	5.74	56.09
	Si2	14.67	5.98	21.75	11.90	6.40	53.78
	Si3	13.05	5.91	21.17	12.90	7.11	55.12
HS	Si0	8.61	2.67	9.25	6.20	2.73	44.09
	Si1	10.04	3.35	9.86	7.17	3.12	43.53
	Si2	11.00	3.67	17.33	9.73	3.27	33.56
	Si3	12.33	4.00	20.00	11.53	4.23	36.68
LSD (5%)	SL	1.171	0.599	1.560	0.769	0.753	2.63
	Si	1.275	0.614	1.524	0.810	0.792	2.915
	Interaction	1.843	0.698	2.720	1.037	1.006	NS

Nutrient composition:

The low values of N, P and K content were recorded by plants growing under salinity when compared with control plants grown under Low saline soil (Table 4). The reduction was more pronounced at the higher salinity level. In seed also a gradual reduction in N concentrations were recorded with increasing salinity level. These results were agreed with those reported by Hanafy Ahmed *et al.* (2008) on wheat. Nitrate nitrogen was accumulated in the bean plants grown under saline conditions especially at moderately saline (EC_e = 6.03 dS m^{-1}) and strongly saline (EC_e = 8.970 dS m^{-1}) compared to control values. It might be due to an adaptation mechanism developed by the plants to overcome osmotic stress caused by salinity while further decrease in nitrate nitrogen might be related to the antagonistic relation between toxic Cl^- and NO_3^- (Meloni *et al.* 2004).

Potassium content was lower in plants shoot grown under saline soil conditions (3.61 and 3.54%) than those grown in low saline soil (3.88 % K). Liang *et al*., (2007) also reported a significant increase in K uptake and decrease in Na uptake under salt stress when Si was included because of increased activity of plasma membrane H-ATPase. Potassium: Sodium ratio was significantly lower under salinity stress when Si was not applied. Silicon application enhanced K/Na selectivity ratio in Faba bean thus enhancing pod and shoot yield. Application of 1000 SiO_2 (Si_3) in the high salinity soil (HS) increased the K: Na (1.37), (1.05 at 500 SiO_2), (0.93 at 250 SiO_2) and (0.80 at zero SiO_2). The exclusion of Na^+ ions and a higher K: Na ratio in bean plants grown under saline conditions have been confirmed as important selection criteria for salt tolerance (Abdelhamid *et. al.* 2010). Application of Si significantly increased the contents of P and K, and the K: Na ratio and decreased Na ion contents of salt-affected plants. Therefore, the results shown in Table 4 agree with experimentations with Faba bean by (Abdelhamid *et al.* 2010) which indicate that salt tolerance is associated with an enhanced K: Na discrimination trait. The ability of plant to limit Na transport into the shoot is critically importance for the maintenance of high growth rates and protection of the metabolic processes in elongation cells from the toxic effects of Na (Razmjoo *et al.*, 2008).

Sodium content was higher in plants grown under saline soil condition; however Si application significantly reduced Na content in shoot and seeds of Faba bean plants. Increased K content and reduced Na in shoot and seeds may be one of the possible mechanisms of increased salinity tolerance by Si application in Faba bean plants. Silicon is known also to reduce Na uptake (Matichenkov and Kosobrukhov, 2004). Silicon when deposited in exodermis and endodermis of roots reduces Na uptake in plants (Gong *et al*., 2003).

Correlation study:

Correlation coefficient between yield components, chlorophyll, carotene and nutrient content by Faba bean was done. Chlorophyll a and b and carotene are positively and significantly correlated with shoot weight yield (0.815**, 0.679** and 0.882**). Seed weight yield showed positive and highly significant correlation with pod number (0.614**) and seed number (0.572**) of Faba bean plants. Sodium content in shoots had a significant negative correlation with shoot (-0.666**), seed weight (-0.375*), pod number (-0.644**) and leaf area (-0.601**). Calcium contents are negatively correlated with shoot yield (0.421**) and pod number (0.557**). Leaf area negatively correlated with sodium content in shoot and seed of Faba bean plants.

Table 4: Total N, P, K, Na and Ca contents of Faba bean as influenced by soil salinity and Si application

Salinity (SL)	Silicon (Si)	N (%)		P (%)		K (%)		Na %		Ca %		K/Na	
		Shoot	Seed	Shoot	Seed	Shoot	Seed	Shoot	Seed	Shoot	Seed	Shoot	Seed
LS	Si_0	2.44	3.93	0.222	0.286	2.92	3.44	3.12	2.41	1.12	2.17	0.94	1.43
	Si_1	2.40	3.68	0.242	0.366	3.88	3.92	2.94	2.32	1.05	1.92	1.32	1.78
	Si_2	2.33	3.06	0.281	0.319	4.32	4.12	2.54	2.22	1.08	1.94	1.70	1.77
	Si_3	2.12	3.59	0.340	0.300	4.41	3.76	2.26	2.21	0.98	1.37	1.95	1.70
MS	Si_0	2.21	3.98	0.224	0.290	3.21	3.52	3.81	2.71	1.32	1.91	0.84	1.30
	Si_1	1.95	3.71	0.284	0.314	3.44	3.56	3.46	2.54	0.53	1.64	0.99	1.40
	Si_2	1.97	3.19	0.266	0.327	4.12	3.64	2.68	2.07	0.79	1.68	1.54	1.76
	Si_3	2.02	3.01	0.293	0.300	3.68	3.82	2.41	2.60	0.38	1.52	1.53	1.47
HS	Si_0	2.14	3.28	0.194	0.271	3.32	2.64	4.13	3.02	0.92	1.85	0.80	1.23
	Si_1	1.88	3.17	0.244	0.246	3.63	3.72	3.92	2.99	0.66	1.21	0.93	0.88
	Si_2	1.83	3.11	0.251	0.300	3.52	3.76	3.35	2.98	0.79	2.24	1.05	1.26
	Si_3	1.92	3.09	0.282	0.281	3.68	2.64	2.68	2.65	0.58	1.38	1.37	1.00
LSD (5%)	SL	0.161	0.153	0.080	0.025	0.256	0.231	0.249	0.137	0.076	0.070	0.136	0.086
	Si	0.193	0.177	0.027	NS	0.293	0.266	0.287	0.158	0.088	0.080	0.157	0.099
	Interaction	NS	0.307	NS	NS	0.507	0.461	NS	0.274	0.152	0.130	NS	0.172

Conclusion:

The results of this study highlight the role of silicon in improving Faba bean yield under low saline or saline soil conditions. We suggest that under low saline soil conditions, silicon should be sprayed by concentration 250 ppm at 45 and 90 days after sowing significantly increased pod yield/plant. Furthermore under saline soil condition all levels of silicon (250 and 1000 ppm SiO_2) are important to minimize the hazardous effects of sodium on growth and yield of Faba bean plants.

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