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# Response of Wheat Plants Grown in Heavy Clay Soil to Salinity Stress and Additions of Silicon

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## ABSTRACT

A pot experiment was conducted on a heavy clay soil to evaluate growth performance of wheat plant to silicon additions under saline conditions. Plants were grown in pots filled with normal soil (EC=0.71 $dSm^{-1}$) and irrigated with saline water (EC=4.8 $dSm^{-1}$). The experiment was set up in a completely randomized block design with four treatments and three replicates. The treatments included two soil additions ($S_1$ biochar and $S_2$ - Silica-solubilizing bacteria) while, $S_3$ and $S_4$ treatments were applied as foliar applications ($S_3$ was marine algae and $S_4$ was potassium silicate), in addition to the control treatment (without any additions). The obtained results showed that silicon treatments by either soil additions or foliar applications could alleviate the hazard salinity stress. There were also, best noticeable exchanges in reducing both soil EC and pH and increasing both soil organic matter and storage of some available nutrients. The increments influences reflected on increasing the fresh weight and accordingly increasing the dry matter production of straw and grain yield of wheat plants. Furthermore, the percent increase in sodium concentration due to salinity was significantly reduced in plants receiving Si applications. Straw Si concentration significantly correlated positively with Straw K concentration (r=0.96) and negatively with shoot Na concentration (r=0.43). Based on these results, increased the potassium concentration and reduced uptake or translocation of sodium may be one of the possible mechanisms of increased salinity tolerance by Si application in wheat plant.

**Keywords:** Silicon additions - Wheat plant – saline water - heavy clay soil - Agricultural drainage water

## INTRODUCTION

In regions with water scarcity, especially in arid and semi-arid areas *viz.,* Egypt, reusing of low quality water resources such as agricultural drainage water for irrigation purposes becomes very essential for substituting fresh water resources in spite of its adverse impacts on different soil characteristics (Hammad *et al*., 2018). However, agricultural drainage water adversely affected plants growth and yield in a number of species including wheat, where it loses 65% yield due to salinity. There is an urgent need to find ways to improve wheat salinity tolerance to ensure sustainable economy and food security. Various biological, chemical, and physical strategies are adapted for production of economic crops under such conditions (Raza *et al*., 2006). Moreover, it is referred to as "Degraded Waters" because of their deterioration in biological, physical and chemical properties but, it is often considered as viable option for using as irrigation purposes (Corwin and Bradford, 2008 and O'Connor *et al*., 2008).

Some non-essential nutrient may also counteract harmful influences of salt stress. For instance, silicon is a non-essential nutrient for plant growth, however, various investigations have showed that Si addition remarkably improved plants growth under both normal and stress conditions including biotic and a biotic stresses as salt stress (Ma, 2004 and Balakhnina and Borkowska, 2013). Several researchers reported that silicon may increase salinity tolerance in plants, improving water status, increased photosynthetic activity and ultra-structure of leaf organelles, stimulation of antioxidant system and alleviation of specific ion effect by reducing Na uptake or by H-ATPase dependent enhancement in K in shoots (Liang *et al*., 2003 and Romero *et al*., 2006). Furthermore, improving root hydraulic conductivity due to Si application has been demonstrated in sorghum liu *et al*., (2014), tomato Shi *et al*., (2016) and Cucumber Wang *et al*., (2015), Si application promote osmotic driving force leads to a strong water potential gradient through accumulation of soluble sugars and amino acids in plant.

Tuna *et al.,* (2008) examined the two levels of NaCl (0 or 100 mM) and three levels of Si (0, 0.25, and 0.5 mM) on salt stressed wheat plants. The 0.5 mM Si and 100 mM NaCl in combination had greater dry mass of both the root and the shoot fractions, increased potassium concentrations when compared to the 0 mM Si and 100 mM NaCl combination, while reducing the concentration of Na in both the roots and the shoots. Also, Tahir *et al.,* (2012) measured the effect of Si on shoot and root growth as well as on the K/Na ratio in wheat plants grown under salinity stress using the same NaCl concentrations and were treated with 0 or 2 mM Si then harvested after 40 days of growth. Dry mass was increased in both roots and shoots in the stressed plants when Si was added, but the unstressed plants did not show a significant increase in either measure. In additions, the sodium concentration in shoot decreased by Si application particularly in the salt stressed plants; however, potassium concentration increased in both stressed and unstressed plants when Si was added, which increased the K/Na ratio in all Si treatments.

This is mean that silicon application led to increase of water economy and plants dry matter yield and enhance leaf water potential of wheat plants under environmental stress (Gong *et al*., 2003). The purpose of this study is evaluating the influence of silicon additions on wheat plant grown in heavy clay soil irrigated by agricultural drainage water.

## MATERIALS AND METHODS

To achieve the goal of this study, a pot experiment was conducted on a heavy clay soil to investigate the influence of silicon sources on some soil properties and nutritional status of wheat plant irrigated with agricultural drainage water. The different analysis of the experimental soil before planting as a routine work and water samples were done by the standard methods describe by Piper (1950); U.S.S.L.S (1954); Black *et al.,* (1965); Hesse (1971) and Hillel (1980). Some physical and chemical properties of soil and irrigated water are presented in Tables 1 and 2.

**Table 1. Some physical and chemical properties of the investigated soil.**

| Soil chemical properties | | Value | Soil physical properties | | Value |
|---|---|---|---|---|---|
| pH (in soil paste) | | 8.55 | Particles size distribution | Sand% | 15.80 |
| EC dS $m^{-1}$ (in extracte1:2.5) | | 0.71 | | | |
| $CaCO_3$ | | 3.23 | | Silt% | 24.20 |
| OM% | | 1.05 | | | |
| Soluble Cations (meq /100g)* | $Ca^{++}$ | 0.25 | | Clay% | 60.00 |
| | $Mg^{++}$ | 0.59 | | | |
| | $K^{+}$ | 0.13 | | Texture Class | Clay |
| | $Na^{+}$ | 0.92 | | | |
| Soluble Anions (meq /100g)* | $CO_3^{--}$ | 0.00 | Saturation percentage (SP)% | | 65.00 |
| | $HCO_3^{-}$ | 0.77 | Field capacity (FC)% | | 32.50 |
| | $Cl^{-}$ | 0.66 | Wilting point (WP)% | | 16.25 |
| | $SO_4^{--}$ | 0.45 | Available water (AW)% | | 16.25 |
| Available Macro-Nutrients (ppm) | Nitrogen (N) | 63.57 | Bulk Density (Mg $m^{-3}$) | | 1.11 |
| | Phosphorus (P) | 9.28 | Total Porosity% | | 58.49 |
| | Potassium (K) | 227.89 | Drainage rate (cm $h^{-1}$) | | 0.21 |
| Soluble Silicon (mg$Kg^{-1}$)* | | 56.98 | | | |

*** determined in soil extract 1:2.5**

**Table 2. Chemical analysis of irrigated water.**

| pH | EC ($dSm^{-1}$) | $SAR_{Adj.}$ | RSC | Soluble Cations (meq $L^{-1}$) | | | | Soluble Anions (meq $L^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Ca^{++}$ | $Mg^{++}$ | $K^{+}$ | $Na^{+}$ | $CO_3^{--}$ | $HCO_3^{-}$ | $Cl^{-}$ | $SO_4^{--}$ |
| 7.71 | 4.86 | 40.01 | 0.00 | 4.93 | 6.88 | 0.01 | 37.41 | 0.00 | 7.89 | 38.07 | 2.63 |

The experiment was carried out at the experimental station of Fac., Agric., Mansoura Univ., during winter season of 2016/2017 on wheat plant (*Triticum aestivum L.*CV. Sakha-94) grown in plastic pot (30×35 cm) filled with 9 Kg of heavy clay soil. The silicon sources were $S_0$-control (without any additions), two soil additions as $S_1$ - Biochar (rice straw was burn at a temperature of 450° for two hours and applied to soil before sowing at a rate of 10g/pot), $S_2$ - Silica-solubilizing bacteria was applied to soil before sowing, and two foliar applications as $S_3$ - marine algae applied at a rate of 0.6g $L^{-1}$ $S_4$ - potassium silicate applied at a rate of 7.5 g $L^{-1}$ both of $S_3$and $S_4$ were applied after 30, 45 and 60 day after sowing. The composition of silicon additions are illustrated at Table 3.

**Table 3. Composition of silicon sources.**

| Treat. | Silicon Sources | Composition |
|---|---|---|
| $S_1$ | Rice Straw Biochar | 22.26% Si, 1.23% N and 47.93%C |
| $S_2$ | Silica-Solubilizing Bacteria | Bio-fertilizer solubilizing Si, P and K |
| $S_3$ | Marine Algae | 50% marine algae, 15% $K_2O$, 25.28% Si and contains plant hormones, cytokinin, oxin, amino acids, vitamins. |
| $S_4$ | Potassium Silicate | (FraSil 32, 32% $K_2O$, 52% $SiO_2$) |

Plants were irrigated with agricultural drainage water. The experimental design was with a complete randomized block design plot with three replicates. The mineral fertilizers were added at the recommended doses according to the bulletin of the Egyptian ministry of agriculture as 75 Kg N, 15 Kg $P_2O_5$ and 50 Kg $K_2O$ $fed^{-1}$. Two stages of plants were taken for analysis after 50 days and after harvest. The percentage of total N, P, K and Na in wheat straw were determined according to (Jackson, 1967, Schouwenburg and Walinge, 1967 and Hesse, 1971). Total Si content in wheat straw was dissolved with the advanced microwave digestion system (Ethos Easy) sample preparation technique. 15 to 25 mg of the sample was weighed into a PTFE reactor vessel, and 8 mL concentrated hydrofluoric acid was added. The closed vessel was heated in a microwave oven up to 250°C and under a pressure of up to 8 bars. The cooled vessels were filled with distilled water to a volume of 100 mL. The analytical solution of plant acid extract or soil soluble silicon were directly injected into the hot argon ICAP 7000 Series ICP-OES Spectrometer ISDS. The spectral line at 251.611 nm which is characteristic for silicon was used for the determination of the silicon concentration. A standard solution (1000 mg $L^{-1}$ Si as $SiO_2$ in NaOH [2%], merck KGaA, Germany) was used for calibration. The ICAP data were recorded by an OPTIMA 3000 XL (Perkin Elmer) spectrometer. (Neumann *et al.,* 2011). Data were statistically analyzed according to Gomez and Gomez (1984) using CoStat (Version 6.303, CoHort, USA, 1998–2004).

## RESULTS AND DISCUSSION

It is obvious from the recorded data that there are either significant or a highly significant effect for both the studied silicon treatments of both the soil additions and the foliar applications, when these treatments added to the wheat plant irrigated with the agricultural drainage water.

The Table 4 show that there were reduction effects in soil EC values, while $S_1$ (rice straw biochar) gave the least pH result. Also, $S_1$ gave the highest result as expected for the soil organic matter. Regarding the soil available nutrients, $S_2$ treatments recorded the highest results of soil available P, K and soluble Si. The highest (a highly significant) soil-N available was in $S_1$ treatment.

**Table 4. Effect of silicon sources on some soil properties irrigated with agricultural drainage water.**

| Treat. | EC ($dSm^{-1}$) | pH | OM% | Available (mg$Kg^{-1}$) | | | Soluble (mg$Kg^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | | N | P | K | Si |
| $S_0$ | 1456.00 | 8.50 | 0.81 | 22.17 | 11.63 | 221.87 | 48.80 |
| $S_1$ | 1448.50 | 8.30 | 1.55 | 31.41 | 12.06 | 286.46 | 76.00 |
| $S_2$ | 1326.00 | 8.50 | 1.01 | 25.64 | 15.13 | 304.45 | 81.48 |
| $S_3$ | 1246.50 | 8.40 | 1.06 | 25.87 | 10.88 | 222.10 | 53.40 |
| $S_4$ | 1201.00 | 8.40 | 1.05 | 26.02 | 10.57 | 255.58 | 51.00 |
| LSD at 0.05 | 22.77 | 0.14 | 0.22 | 2.64 | 2.68 | 28.53 | 13.42 |
| | * | * | ** | ** | * | ** | ** |

These results of $S_1$ treatment may be attributed to the acid effect of OM in reducing soil pH and increasing available N. The highest mean values of soluble Si and available K appeared at $S_2$ the $S_1$ treatments (Si applied as a soil application) more than $S_3$ and $S_4$ (Si applied as a foliar application).

On the other hand, Table 5 and Figs. 1 and 2 indicate that the straw wheat plants K, Na, N, P and Si content was a highly significant affected by the studied treatments. $S_4$ treatment had the highest mean values of K, P and Si. While, $S_3$ treatment had the highest mean values of Na and N.

**Table 5. Effect of silicon sources on nutritional straw content of wheat plant irrigated with agricultural drainage water.**

| Treat. | K (%) | Na (%) | N (%) | P (%) | Si (%) |
|---|---|---|---|---|---|
| $S_0$ | 2.17 | 0.41 | 0.80 | 0.05 | 5.10 |
| $S_1$ | 2.43 | 0.30 | 0.84 | 0.05 | 5.65 |
| $S_2$ | 2.78 | 0.35 | 0.78 | 0.06 | 6.25 |
| $S_3$ | 2.44 | 0.25 | 0.86 | 0.05 | 5.80 |
| $S_4$ | 2.88 | 0.30 | 0.81 | 0.08 | 6.62 |
| LSD at 0.05 | 0.11 | 0.03 | 0.03 | 0.01 | 0.14 |
| | ** | ** | ** | ** | ** |

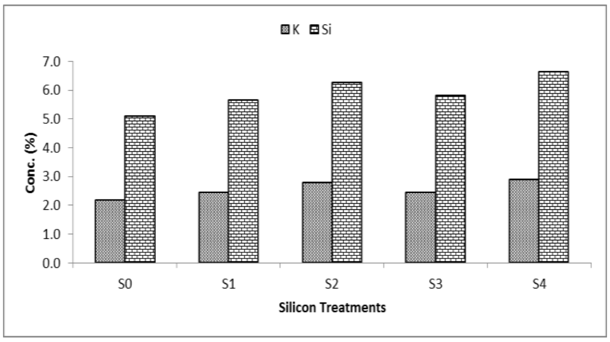


**Fig. 1. Effect of silicon sources on Si and K concentration (%) of wheat plants irrigated with agricultural drainage water.**

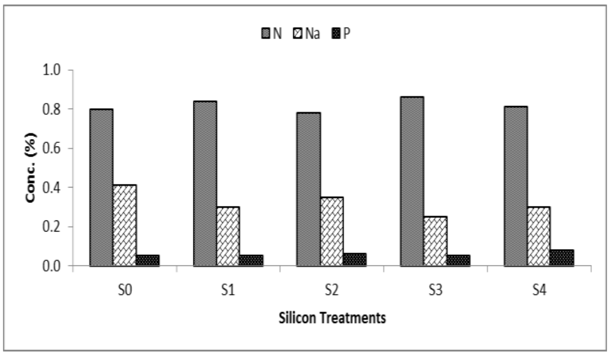


**Fig. 2. Effect of silicon sources on N, P and Na concentration (%) of wheat plants irrigated with agricultural drainage water.**

In additions, percent increase in Na concentration due to salinity was significantly reduced in plants receiving Si application. Straw Si concentration significantly correlated positively with straw K concentration (r=0.96) and negatively with shoot Na concentration (r=0.43).

These results might be confirmed that silicon role in reducing $Na^+$ concentration and another nutrients especially $K^+$ content to the Si regulating the homeostasis in plants under salt stress conditions. Besides, that the polyamines induced by silicon treatment were found to block plasma membrane $K^+$ and reduction of $Na^+$ influx,(Wang *et al.*, 2015 and Zepeda-Jazo *et al.*, 2011). Also, many workers showed that silicon is involved in regulating water balance in medium silicon- accumulator plants as well as abundant silicon-accumulator plants. Therefore, Si enhances root hydraulic conductance and effects polyamines metabolism in plants.

It is of interest to point out the high harvest with either the first or harvest stages occurred with the $S_4$ treatment followed by $S_2$ than $S_3$ and $S_1$ was the least wheat yield components as compared with the control treatment (Table 6 and Fig 3).

**Table 6. Effect of silicon sources on wheat plant growth irrigated with agricultural drainage water.**

| Treat. | First Stage ($g\ pot^{-1}$) | | Harvest Stage ($g\ pot^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | All plant | | Straw | | Grain | |
| | F.W | D.W | F.W | D.W | F.W | D.W | F.W | D.W |
| $S_0$ | 7.57 | 1.97 | 30.56 | 27.47 | 23.71 | 21.62 | 6.51 | 6.07 |
| $S_1$ | 10.07 | 3.25 | 43.43 | 39.23 | 32.32 | 23.42 | 7.78 | 7.13 |
| $S_2$ | 11.51 | 4.57 | 52.46 | 47.90 | 39.21 | 31.29 | 13.29 | 12.23 |
| $S_3$ | 10.99 | 3.92 | 50.21 | 45.87 | 36.49 | 30.74 | 11.77 | 10.88 |
| $S_4$ | 12.79 | 4.98 | 54.49 | 47.83 | 45.59 | 31.93 | 13.61 | 12.52 |
| LSD at 0.05 | 12.00 | 1.90 | 12.27 | 12.10 | 5.44 | 7.92 | 4.05 | 3.74 |
| | ** | * | ** | * | ** | * | ** | ** |

**F.W: fresh weight ($g\ pot^{-1}$), D.W: dry weight ($g\ pot^{-1}$).**

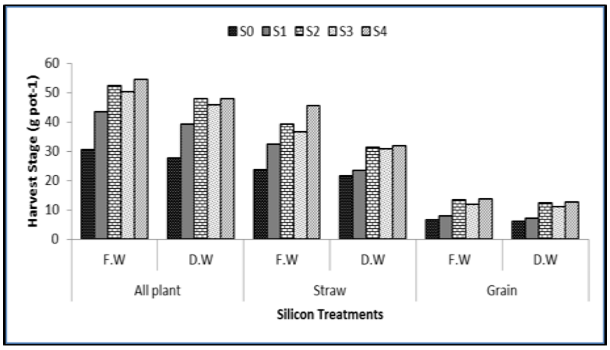


**Fig. 3. Effect of silicon sources on harvest stage of wheat plant irrigated with agricultural drainage water.**

These results mean that the different sources of studied silicate compounds are able to diminish and alleviate the salt stress of agricultural drainage water. In other words, silicon compounds can help to stimulate synthesis and accumulation of some compounds in the different plant organs such as amino acids and the polyamines and these could be helping mediate salt plant tolerance against salting stress. These results confirmed that Si compounds has beneficial role in controlling the hazard salinity effects on stressed plants. These important effects of Si might be that it have signaling factor. The work of Coskun *et al.*, (2016) confirmed these results. This means that the increment reflection effect of Si compounds on the diminished effect of the salt stress hazard and accordingly increased the plants yields. Azeem *et al.*, (2015) and Ahmed *et al.*, (2016) they found that soaking wheat seeds with Si for 6-8 h showed significant increments in germination rate, vegetative growth, and crop yield under salinity and osmotic stresses as compared to the non-soaked.

## CONCLUSION

The application of silicon compounds in agricultural can alleviated the hazard stress of salts, reducing sodium uptake and helping to use the salinity water in crops irrigation and accordingly increment both the quality and quantity of crops production.

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## استجابة نبات القمح النامي في ارض طينية ثقيلة للإجهاد الملحي وإضافات السليكون


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أجريت تجربة أصص في ارض طينية ثقيلة لتقييم أداء نمو نبات القمح لتأثير إضافات السليكون تحت الظروف الملحية. تم زراعة النبات في أصص تحتوي علي تربة عير ملحية (ذات ملوحة 0,71 ديسيمينزم$^{-1}$) ومروية بمياه مالحة (ذات ملوحة 4,80 ديسيمينزم$^{-1}$). تم إعداد التجربة بتصميم قطاعات كاملة العشوائية بخمس معاملات وثلاث مكررات. تضم المعاملات إضافتان أرضي هما البيوشار والبكتريا المذيبة للسيليكون وإضافتان رش ورقي هما الطحالب البحرية وسيليكات البوتاسيوم بالإضافة لمعاملة الكنترول (بدون إي إضافات).أفادت النتائج المتحصل عليها أن تأثيرات إضافات السيليكون سواء الأرضية أو الورقية يمكن أن تقييد من خطر الري بمياه الصرف الزراعي.ومن أفضل التغيرات الملحوظة خفض كلا من ملوحة وقلوية التربة وزيادة كل من المادة العضوية ومخزون التربة من بعض العناصر الغذائية. تنعكس هذه الزيادات على زيادة الوزن الطازج وبالتالي زيادة إنتاج المادة الجافة بمحصول القمح من القش والحبوب. علاوة علي ذلك تم تخفيض الزيادة في تركيز الصوديوم نتيجة الملوحة انخفاضًا كبيرًا في النباتات المضاف لها السليكون. يرتبط تركيز السيليكون في القش بشكل كبير ارتباطا إيجابيًا بتركيز البوتاسيوم به (r = 0.96) وسلبيًا مع تركيز الصوديوم (r = 0.43). وبناءًا علي هذه النتائج, قد يكون زيادة تركيز البوتاسيوم وتقليل امتصاص الصوديوم أو نقله إحدى الآليات الممكنة لزيادة مقاومة نبات القمح للملوحة بفعل إضافة السيليكون.