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# Macro and Micro-Nutrients Concentrations and Uptake by Maize Seedlings Irrigated with Fresh or Saline Water as Affected by K-Silicate Foliar Fertilization

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## ABSTRACT

Silicon was reported to play a role in increasing plant resistance to biotic and abiotic stress. Pot experiment was conducted in the greenhouse of the "Micronutrient Project", Fertilization Technology Department, National Research Centre, Dokki, Cairo, Egypt with (*Zea maize* L. var. Pioneer) grown on silty loam soil to study effect of K-silicate foliar fertilization on concentrations and uptake of nutrients by plant seedlings. The plants were sown on mid May, 2012 in Mitscherlich pots contained 7.0 kg sandy soil. The experiment followed the Randomized Complete Block Design (RCBD) with nine treatments, in three replicates. The K-silicate was foliar sprayed two times in the concentrations of 300, 600 and 900 mg $L^{-1}$. The first spray was 21 days after sowing and the second was 10 days after the first one. One third of the experimental pots was irrigated with tap water, the second third was irrigated with water contains 4134 mg $L^{-1}$ saline ions and the last third of pots was irrigated with water contains 5594 mg $L^{-1}$ saline ions. Data revealed that despite the increase of sodium concentrations in the seedling tissues due to irrigation with saline water, other nutrient concentrations were slightly affected ($p = 0.05$). The K-silicate foliar fertilization found also to significantly affect concentrations and uptake of the determined micronutrients iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu). Iron concentration was increased as K-silicate was added in the tissues of both plants irrigated with fresh or saline water. The best dose was 600-900 mg $L^{-1}$. The same trend was almost found with Zn and Mn while Cu showed no trend, however, its concentrations were higher than that determined for control plants. The best dry weight accumulation (4.1 g per plant) was achieved by the treatment 600 mg $L^{-1}$ K-silicate on the plants irrigated with fresh water. The best dose gave the highest dry matter accumulation with the plants irrigated with saline water was also 600 mg $L^{-1}$ K-silicate with low level salinity (2.8 g per plant) and 300 mg $L^{-1}$ K-silicate with the higher level salinity in irrigation water (2.13 g per plant). Despite K-silicate could keep the concentrations of nutrients in the normal ranges, however, salinity of irrigation water found to interfere with dry matter synthesis and negatively affect dry matter accumulation. Thus, silicon treatment can be only partially alleviating salinity stress on maize plants.

**Key words:** Foliar fertilization, K-silicate, nutrient uptake, maize, salinity stress

## INTRODUCTION

Silicate minerals are the major components of soil crust while silicon is not considered as an essential element for higher plants, studies proved its role in increasing plant resistance to biotic and abiotic stresses including soil salinity and nutrient unbalance (Ashraf, 2008; Liang *et al.*, 2007; Ma *et al.*, 2006).

Maize (*Zea mays* L.) is one of the most essential crops in Egypt used as human food and animals feed (Moussa, 2001). Soil salinity is well known to inhibit plant growth and yield through accumulation of harmful elements such as sodium and chlorine and slows down translocation and assimilation of essential nutrients (Lauchli and Epstein, 1990). Overcoming salt stress effects is a main task to sustainability of food production. Thus, attempts to improve tolerance to salinity through physiological and biochemical processes have increased (Noble and Rogers, 1992). Addition of silicate fertilizers found as one of the most beneficial processes ameliorated salinity stress effects and improved yields (Moussa, 2006). The present study aimed at studying effects of potassium-silicate foliar fertilization on nutrient uptake and concentrations in maize seedlings irrigated with fresh or saline water.

## MATERIALS AND METHODS

Pot experiment was conducted in the greenhouse of the "Micronutrient Project", Fertilization Technology Department, National Research Centre, Dokki, Cairo, Egypt with (*Zea maize* L. var. Pioneer) grown on silty loam soil to study effect of K-silicate foliar fertilization on concentrations and uptake of nutrients by plant seedlings. Physical and chemical characteristics of the used soil are shown in Table 1.

The experiment followed the Randomized Complete Block Design (RCBD) with nine treatments in three replicates. The plants were sown on mid May, 2012 in Mitscherlich pots contained 7.0 kg sandy soil. Before sowing, each of maize pots received 2.1 g ammonium nitrate (33.5% N), 1.4 g super mono-phosphate (15.5% $P_2O_5$) and 0.7 g potassium sulphate (48-50% $K_2O$). At the seedling age, the plants were thinned to leave 6 plants per pot.

**Treatments:** The K-silicate was foliar sprayed two times in the concentrations of 300, 600 and 900 mg $L^{-1}$. The first spray was 21 days after sowing and the second was 10 days after the first one. Every pot received 15 mL as a spray solution volume and tap water was used for preparing spray solutions and for spraying control plants. One third of the experimental pots was irrigated with tap water, the second third was irrigated with water contains 4134 mg $L^{-1}$ saline ions and the last third of pots was irrigated with water contains 5594 mg $L^{-1}$ saline ions. Used saline irrigation water was diluted sea water with fresh water.

Table 1: Chemical and physical characteristics of the used soil

| Physical characteristics | Nutrient concentrations |
|---|---|
| pH 9.0 | Exchangeable macronutrients (mg 100 $g^{-1}$ soil) |
| EC (dS $m^{-1}$) 0.31 | P 0.26 |
| $CaCO_3$ (%) 2.80 | K 21.20 |
| OM (%) 0.68 | Ca 142.60 |
| | Mg 13.06 |
| Sand (%) 4.00 | Na 31.20 |
| Silt (%) 88.80 | Available micronutrients |
| Clay (%) 7.20 | (mg $kg^{-1}$ soil) |
| Texture silty loam | Fe 3.10 |
| | Mn 2.90 |
| | Zn 0.80 |
| | Cu 0.60 |

**Harvest:** Ten days after the second spray, maize plants were harvested to determine dry weights. The plant tissues, then analyzed for nutrient concentrations and nutrient uptake was calculated.

**Determinations and measurements**

**Soil:** A representative soil sample before fertilization was air-dried and passed through 2 mm sieve pores. Soil fractions were determined using the hydrometer method (Bouyoucos, 1951). Electric Conductivity (EC) and pH were determined in a soil/water extract (1:2.5) according to Jackson (1973). The $CaCO_3$ content was determined using the calcimeter method according to Black (1965). Organic matter was determined using the potassium dichromate method according to Walkely and Black (1934). Soil P was extracted using sodium bicarbonate ($NaHCO_3$) (Olsen *et al*., 1954). Magnesium, sodium and potassium were extracted using ammonium acetate ($C_3H_3O_2NH_4$) (Chapman and Pratt, 1978). Iron, Mn, Zn and Cu were extracted using DTPA-solution (Lindsay and Norvell, 1978).

**Vegetative tissue:** Harvested maize plants were washed with tap water, 0.01 N HCl and bi-distilled water, respectively, dried at 70°C for 24 h, weighed and ground. A part of the dry parts was wet-digested according to the method of Chapman and Pratt (1978).

**Nutrient measurements:** Nitrogen was determined using Micro-Kjeldahl method digestion and titration method (Ma and Zuazaga, 1942). Phosphorus was photometrical determined using the molybdate-vanadate method. Potassium and sodium were measured using Lang-M8D Flame-photometer. Magnesium, Fe, Mn and Zn were determined using the Atomic Absorption Spectrophotometer (Perkin-Elmer 100 B).

**Statistical analysis:** Data were subjected to statistical analysis as specified by Snedecor and Cochran (1990). Treatment means were calculated and subjected to the one-way Anova analysis and Student-Newman Keuls (SNK) and LSD ($p = 0.05$) tests-multiple comparison of means using Costate 2 Program (Cohort software) for different treatments.

## RESULTS AND DISCUSSION

**Effect of K-silicate on macronutrients:** Macronutrient concentrations of maize seedlings as affected by irrigation with saline water and K-silicate foliar fertilization are shown in Table 2. Despite the increase of sodium (Na) concentrations in the seedling tissues due to irrigation with saline water (4143 and 5594 mg $L^{-1}$), other nutrient concentrations were slightly affected ($p = 0.05$). This means that K-silicate foliar fertilization with all used concentrations (300, 600 and 900 mg $L^{-1}$) enable the plants to overcome saline ions effects on nutrient translocations to different plant tissues to reach levels over control (irrigated with fresh water). Tahir *et al.* (2011) found that addition of Si to wheat genotypes irrigated with saline water significantly improved K uptake and reduced $Na^+$ uptake. This can be also explained by the higher uptake of almost all determined macronutrients with all treatments compared to control plants (Table 3). Recent studies showed that salinity exerts oxidative stress through production of some Active Oxygen Species (AOS) like the superoxide ($O^{-2}$), hydroxyl radicals (OH) and hydrogen peroxide ($H_2O_2$) (McCord, 2000). In order to scavenge these toxic radicals, a wide variety of plants synthesize antioxidants such as superoxide dismutase (SOD) and catalase enzyme (CAT). Previous studies stated that silicon addition to salt treated barley significantly increased superoxide dismutase and catalase activity while decreased

Table 2: Macronutrient concentrations of maize seedlings as affected by saline water irrigation and K-silicate foliar fertilization

| | Macronutrient concentrations on dry weight basis (%) | | | | | |
|---|---|---|---|---|---|---|
| Treatments | N | P | K | Ca | Mg | Na |
| Control | 1.14 | 0.21 | 4.36 | 0.53 | 0.95 | 1.27 |
| 300 mg $L^{-1}$ K-Silicate | 1.21 | 0.20 | 4.47 | 0.48 | 1.02 | 1.62 |
| 600 mg $L^{-1}$ K-Silicate | 1.21 | 0.22 | 5.12 | 0.42 | 1.97 | 1.35 |
| 900 mg $L^{-1}$ K-Silicate | 2.03 | 0.20 | 4.83 | 0.34 | 0.84 | 1.19 |
| 300 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 2.06 | 0.16 | 4.81 | 0.44 | 1.13 | 3.72 |
| 600 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 2.01 | 0.30 | 4.63 | 0.39 | 1.08 | 3.95 |
| 900 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 1.97 | 0.30 | 4.38 | 0.71 | 1.24 | 3.93 |
| 300 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 2.10 | 0.29 | 4.75 | 0.52 | 1.04 | 1.95 |
| 600 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 2.34 | 0.24 | 4.12 | 0.84 | 1.32 | 4.32 |
| 900 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 2.45 | 0.21 | 4.25 | 0.87 | 1.52 | 9.75 |
| LSD 5% | 0.34 | 0.03 | 0.50 | 0.10 | 0.97 | 0.36 |

Saline: Saline irrigation water resulted from diluting sea water with fresh water 1: 6: 3134 gm $L^{-1}$ and 1: 3: 5594 gm $L^{-1}$

Table 3: Macronutrient uptake by maize seedlings as affected by saline water irrigation and K-silicate foliar fertilization

| | Macronutrient uptake on dry weight basis (mg $kg^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| Treatments | N | P | K | Ca | Mg | Na |
| Control | 40.0 | 7.53 | 152.7 | 18.5 | 33.4 | 44.3 |
| 300 mg $L^{-1}$ K-Silicate | 42.7 | 7.00 | 153.7 | 17.5 | 36.2 | 57.3 |
| 600 mg $L^{-1}$ K-Silicate | 49.3 | 8.87 | 210.0 | 17.4 | 39.6 | 55.3 |
| 900 mg $L^{-1}$ K-Silicate | 75.0 | 7.47 | 178.3 | 12.8 | 35.0 | 43.7 |
| 300 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 53.0 | 4.04 | 124.7 | 11.4 | 29.2 | 96.0 |
| 600 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 56.0 | 8.23 | 130.3 | 10.9 | 30.3 | 111.7 |
| 900 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 51.7 | 7.70 | 114.3 | 18.5 | 32.3 | 102.7 |
| 300 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 45.0 | 6.10 | 101.0 | 11.1 | 22.3 | 41.3 |
| 600 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 46.0 | 4.73 | 80.3 | 16.3 | 25.9 | 43.7 |
| 900 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 42.7 | 3.70 | 73.7 | 15.1 | 26.4 | 117.0 |
| LSD 5% | 10.5 | 1.11 | 13.1 | 3.0 | 3.2 | 13.2 |

malondialdehyde (MDA) concentration in plant leaves (Liang, 1999). Studies also showed that physiological function of silica is based on relations between silica deposition at certain points and increased tolerance to various stresses. It was found that depositions of silica in cuticle and epidermis are correlated to reduced transpiration and interference with fungal attack (Dallagnol *et al.*, 2009; Kim *et al.*, 2002). However, endodermis deposition of silica is correlated with increased tolerance to drought (Lux *et al.*, 2002) and high concentrations of sodium ions (Gong *et al.*, 2006). Thus foliar fertilization of silicon compounds may be more beneficial for silica deposition in the required key points which keep healthy root hairs enabling better water and nutrient absorption.

**Effect of K-silicate on micronutrients:** The K-silicate foliar fertilization found also to significantly affect concentrations (Table 4) and uptake (Table 5) of the determined micronutrients iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu). Iron concentration was increased as K-silicate was added in the tissues of both plants irrigated with fresh or saline water. The best dose was 600-900 mg $L^{-1}$. The same trend was almost found with Zn and Mn while Cu

Table 4: Micronutrient concentrations of maize seedlings as affected by saline water irrigation and K-silicate foliar fertilization

| | Micronutrient concentrations on dry weight basis (mg $kg^{-1}$) | | | |
|---|---|---|---|---|
| Treatments | Fe | Zn | Mn | Cu |
| Control | 177 | 38 | 68 | 15 |
| 300 mg $L^{-1}$ K-Silicate | 119 | 38 | 63 | 19 |
| 600 mg $L^{-1}$ K-Silicate | 168 | 65 | 66 | 20 |
| 900 mg $L^{-1}$ K-Silicate | 153 | 43 | 64 | 18 |
| 300 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 139 | 52 | 57 | 20 |
| 600 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 149 | 53 | 51 | 20 |
| 900 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 183 | 45 | 51 | 17 |
| 300 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 208 | 39 | 43 | 16 |
| 600 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 223 | 47 | 36 | 20 |
| 900 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 213 | 54 | 41 | 19 |
| LSD 5% | 17 | 5 | 6 | 3 |

Table 5: Micronutrient uptake by maize seedlings as affected by saline water irrigation and K-silicate foliar fertilization

| | Micronutrient uptake on dry weight basis (μg $kg^{-1}$) | | | |
|---|---|---|---|---|
| Treatments | Fe | Zn | Mn | Cu |
| Control | 619 | 133 | 238 | 51 |
| 300 mg $L^{-1}$ K-Silicate | 415 | 135 | 222 | 67 |
| 600 mg $L^{-1}$ K-Silicate | 687 | 267 | 270 | 80 |
| 900 mg $L^{-1}$ K-Silicate | 565 | 160 | 235 | 67 |
| 300 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 360 | 133 | 146 | 51 |
| 600 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 419 | 147 | 144 | 56 |
| 900 mg $L^{-1}$ K-Silicate+4134 mg $L^{-1}$ saline | 478 | 115 | 133 | 44 |
| 300 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 444 | 82 | 92 | 35 |
| 600 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 435 | 91 | 70 | 40 |
| 900 mg $L^{-1}$ K-Silicate+5594 mg $L^{-1}$ saline | 368 | 93 | 72 | 33 |
| LSD 5% | 69 | 19 | 18 | 6 |

showed no trend, however, its concentrations were higher than that determined for control plants. Micronutrients uptake was generally reduced in the plant tissues as affected by saline water irrigation. Addition of K-silicate as foliar fertilizer could, to some extent, improve micronutrient uptake to reach the levels of the uptake by plants irrigated with fresh water and sprayed with 300 mg $L^{-1}$ K-silicate. Higher K-silicate doses (600 and 900 mg $L^{-1}$) found to increase uptake of micronutrients above these levels. Moussa (2006) found that Si addition significantly reduced $H_2O_2$, free proline level and MDA concentration in stressed maize leaves and in the same time enhanced activities of SOD and CAT. This may protect the plant roots from salt stress damage enabling them to normally absorb water and dissolved nutrients.

**Effect of K-silicate on dry matter accumulation:** Salinity stress resulted from saline irrigation water significantly reduced dry matter accumulation by maize seedlings (Fig. 1). The best dry weight accumulation was achieved by the treatment 600 mg $L^{-1}$ K-silicate on the plants irrigated with fresh water (4.1 g per plant). The best dose gave the highest dry matter accumulation with the plants irrigated with saline water was also 600 mg $L^{-1}$ K-silicate with low level salinity (2.8 g per plant) and 300 mg $L^{-1}$ K-silicate with the higher level salinity in irrigation water

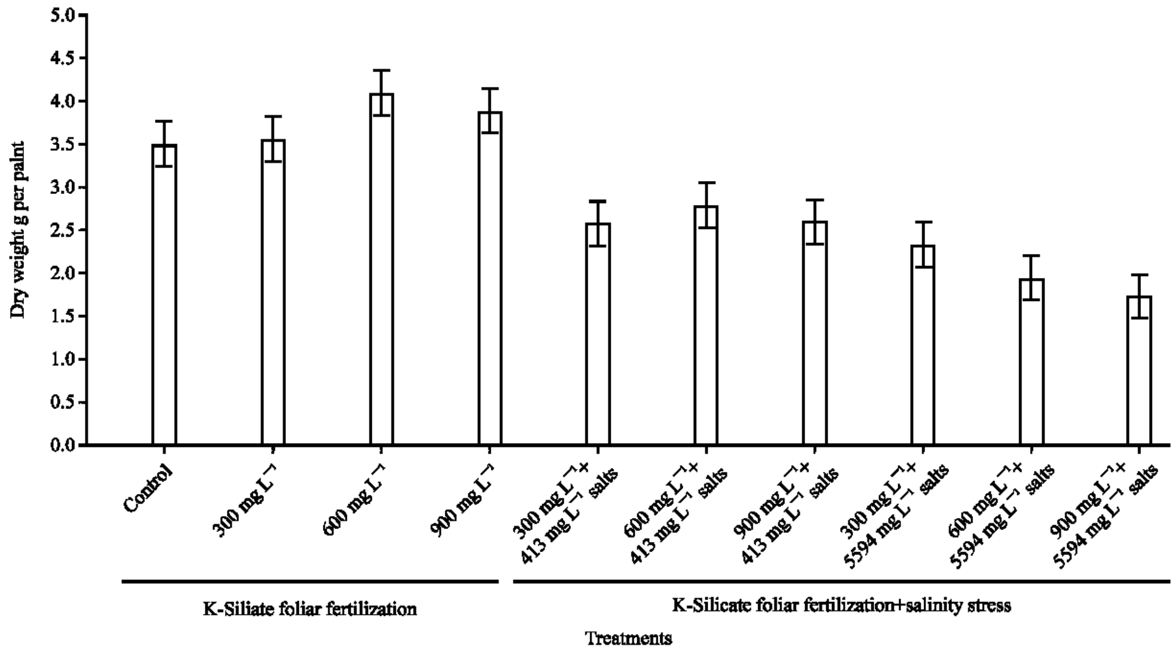


Fig. 1: Dry weight of maize seedlings as affected by saline water irrigation and K-silicate foliar fertilization, $LSD_{0.05}$ = 0.25

(2.13 g per plant). These results are in contrary with the results obtained by Moussa (2006) who stated that added silicon to maize plants did not affect dry matter accumulation when there is no salt stress and the presence of silicon in the nutrient solution just alleviated the growth inhibition induced by the added NaCl. However, previous studies showed that silicon feeding increases chlorophyll content, photosynthesis and other activities related to the primary plant metabolism (Belanger, 2008) which definitely positively affect dry matter accumulation. Despite K-silicate could keep the concentrations of nutrients in the normal ranges, however, salinity of irrigation water found to interfere with dry matter synthesis and negatively affected dry matter accumulation. According to these findings, silicon treatment can be only partially alleviate salinity stress on maize plants. More study is needed to determine the highest extent of salinity stress could be completely overcome by silicon treatments.

## CONCLUSION

From the present study, it can be concluded that treatment of maize seedlings with K-silicate could overcome salt stress effects on nutrient uptake and keep nutrient concentrations in the plant tissues in the normal ranges. However, presence of silicon could not prevent salinity ions to negatively interfere with dry matter synthesis and hence dry matter accumulation.

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