Beneficial Effects of Silicon on Water Stress Tolerance in Maize (*Zea mays L.*) Grown in Calcareous Soil

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ABSTRACT: The growth of maize (*Zea mays L. cv* hybrid 2031) plants were evaluated under water stress induced by decreasing soil moisture from 80% of field capacity as optimal value (control)to 40%, 50%, 60% and 70% of FC treatments, being considered as water stress for maize as affected by Si application at five rates (0. 50. 100, 150 and 200mg Si kg^{-1} soil). This evaluation was carried out in a pot experiment using calcareous soil in a split plot design. The soil moisture levels were applied to the main plots and the silicon levels were assigned to the sub-plots. The results obtained showed that water stress depressed the growth of shoot, relative water content and chlorophyll index values. Addition of Si up to 200 mg kg^{-1} soil partially improve the growth of shoot and increase the relative water content, chlorophyll index and proline content. The proline content in the leaves was markedly increased under water stress or with silicon application especially under high water stress conditions. The negative relationship between proline content and shoot dry weight, supporting the view that proline accumulation is a symptom of stress damage. Addition of Si increased Si accumulation in the shoot. Analyses of N, P, K, Cu and Zn showed no accumulation of these elements in the shoot under water stress, and added Si even increased their concentrations under water stress. These results suggest that under water stress conditions, silicon nutrition can improves maize plant growth.

Key words: Drought, *Zea mays*, silicon, water relation, proline, chlorophyll index

INTRODUCTION

Drought is a serious agricultural problem and also one of the most important factors contributing to crop yield loss. According to the prediction of current climate change models, the frequency and severity of drought will increase in several regions around the world (Shen *et al.*, 2010). Water deficit leads invariably to a decrease in photosynthetic rate, leaf area, transpiration and growth rate (Kron *et al.,* 2008), as well as modification of activity of enzymes in carbon and nitrogen metabolism and changes in the antioxidants levels (Gunes *et al.,* 2008). In all, drought is not beneficial for plant growth and development, and the increase in plant resistance to drought is an important way to overcome drought problems. One viable strategy of overcoming the drought-induced injurious effect on plant growth is the exogenous application of inorganic nutrients (Ashraf and Foolad, 2007). By adopting this strategy, addition of Si has been considered beneficial for improving crop tolerance to a biotic stresses including water deficit (Epstein, 2009; Kojic *et al.*, 2012). The ameliorative role of Si to adverse effects of drought has been examined in different crops e.g., rice (Hakim *et al.*, 2012), sugarcane (Bokhtiar *et al.*, 2012), wheat (Tahir*et al.*, 2006), tomato (Romero-Aranda *et al.*, 2006), sorghum (Ahmed *et al.*, 2011) and soybean (Shen *et al.*, 2010). Different mechanisms are reported to induce drought tolerance in plants through silicon treatment (Liang *et al.,*2006) including increased water status of plants (Romero-Aranda and Haddad 2006), improved photosynthetic efficiency (Zuccarini, 2008), osmotic adjustment (Sonobe *et al.*, 2010; Ahmad and Haddad, 2011), maintenance of photosynthetic apparatus and pigments (Chutipaijit *et al*., 2012), changes in ultra-structure of leaf organelles (Shu and Liu, 2001), up-regulation of plant defense system (Milne *et al*., 2012), lowered transpiration rate (Zou *et al*., 2005) and enhanced K^+ uptake (Kaya *et al*., 2006).

Maize (Zea *mays* L.) is one of the important crops in Egypt due to its significance as a feed crop, being used in a number of foods and in oil, starch and pharmaceutical industries, as well as newly emerging as a biofuel crop (Ali *et al.*, 2015). Unluckily, in many regions, especially in the tropics and sub-tropics, the productivity of maize is markedly reduced due to water stress. Maize has been known as a Si accumulator (Liang *et al.,* 2007) and thus it is a popular crop for studies on the useful impacts of Si under environmental pressures (Malčovská, *et al.*, 2014). Thus, this study was carried out to investigate the effects of Si the growth, the contents of chlorophyll, relative water, proline, some nutrient elements and silicon contents of maize plant grown under different levels of soil water stress conditions.

MATERIALS AND METHODS

Soil

Composite surface soil sample (0-30 cm) was collected from Banger Elsokkar region which is located 55 km south west Alexandria city. The soil was air dried and greatly crushed with a wooden pestle, sieved through < 2 mm sieves and then subjected to laboratory analysis. The soil pH, electrical conductivity (EC), calcium carbonate ($CaCO_3$), organic matter (OM), water soluble ions, available P and particle size distribution (sand, silt, clay.,) were carried out according to the methods described in Page *et al.* (1982).The field capacity was determined as gravimetric basis (Nachabe, 1998). For field capacity determination, the saturation percentage of three samples of 100 g each (oven - dried soil at 105 ^{0}C for 24 hours) was approximated by measuring and then average of the distilled water used in making saturated paste of each samples. The field capacity (FC) was calculated by using the formula: Field capacity **=** Saturation percentage/2. The soil sample was analyzed for total content of Si using the procedure of Buckley and Cranston (1971) and the filtered aliquots were analyzed for Si using the method described by Elliott and Synder (1991). Also, the soil sample was analyzed for extractable silicon using the method of Ayres (1966). The soil was extracted with 0.5 M ammonium acetate, pH 4.5-4.8 solution using1:20 soil: solution ratio for 1hr shaking and centrifugation before analysis. The filtered aliquots were analyzed for Si using colorimetric the method described by Elliott and Synder (1991). All the obtained data are presented in Table 1.

Pot experiment

A trial was conducted at the greenhouse faculty of agriculture (Saba Bash), Alexandria University, Egypt using plastic pots, (30cm deep and 13 cm in diameter). One kg of prepared soil was filled in each of the used plastic pots. The recommended fertilizer dose of N (140 mg kg^{-1}) as urea, P (90 mg kg^{-1}) as single super phosphate15%P_2O_5) and K (120 $mgkg^{-1}$) as potassium sulphate 48% K_2O_2. All P and K doses and 1/3 of N fertilizer dose were added before seed sowing while remaining the N was applied in two splits i.e., five and ten days after germination. Silicon was applied as basal dose at 0, 50, 100,150 and 200 mg kg^{-1} using potassium silicates. Five seeds of corn (*Zea mays L. cv.* hybrid 2031) were sown and thinned to three plants per pot after emergence.

Table (1). the main initial physical and chemical characteristics of the used soil

Properties	Value
Sand %	73
Clay %	19
Silt %	8
Soil texture class	Sandy Loam
Organic matter, %	1.83
Field capacity, %	21.45
E.C$_e$., dS/m(saturation extract)	3.38
pH (saturation extract)	8.30
$CaCO_3$, %	30.30
Soluble cations, meq/l	
Na^+	17.30
K^+	0.50
Ca^{2+}	10.2
Mg^{2+}	5.40
Soluble anions, meq/l	
SO_4^{--}	13.20
HCO_3^-	5.40
CO_3^{--}	0.00
Cl^-	16.00
SAR	6.30
Available P, mg kg^{-1} soil	8.00
Available Si, mg kg^{-1}soil	150
Total Si, mgkg^{-1}soil	189

Soil moisture regime was achieved by watering to 80% of FC as optimal value (control) and then to 40%, 50%, 60% and 70% of FC, these treatments option, are being considered as water stress levels for maize. The moisture content at 80, 70, 60, 50, 40% of FC, were17.16 %, 15.02%, 12.87%, 10.73% and 8.58%,respectively. The moisture content of the soil in each pot was adjusted gravimetrically to the desired level. The pots were arranged in a split-plot design with three replicates. The soil moisture levels were applied to the main plots and the silicon levels were assigned to the sub- plots. At occurrences of leaf wilting, all above ground biomass was harvested and analyzed for dry mass, elements concentration, chlorophyll, proline, and relative water contents as follows:

Dry weight determination:

At the end of the experiment, two randomly chosen shoots were cut just above soil surface for the determinations of dry weight and elemental contents. The shoots were washed by the distilled water to remove dust from plant surfaces and then dried at 70°C for 48 hrs. to constant weight.

Elemental analysis:

The dried shoots were ground in a Wiley mill built-in with stainless steel chamber into fine powder. The determinations of some nutrient elements and silicon contents were carried out as follows:

-Determination of N, P,K, Zn and Cu.

Half gram fine powder of plant material was wet-digested with H_2SO_4-H_2O_2 (Lowther, 1980) and potassium, phosphorus, copper and zinc determination was carried out in the digested solution according to the methods described by Jackson (1973). Also total nitrogen was determined by Micro kjeldehl according to Bermner and Mulvaney (1982).

- Determination of Si:

Half gram powdery plant material was digested in 2 mL 50% hydrogen peroxide (H_2O_2) and 4.5 g 50 % NaOH in open vessels (Teflon beakers) on a hot plate at 150 ºC for 4 hours. Si concentration was measured using colorimetric aminom molybdate blue color method (Elliot and Synder, 1991). To 1 mL of supernatant filtrate liquid, 10 mL of ammonium molybdate solution ($54gL^{-1}$) and 25 mL of 20 % acetic acid was added in 50 mL of polypropylene volumetric flask. After five minutes, 5 mL of 20 % tartaric acid and 1 mL of reducing solution was added in the flask and the volume was made to some with 20 % citric acid. After 30 minutes, the absorbance was measured at 650 nm wave lengths with a UV visible spectrophotometer(Shimdzu, Spectronic 100, Japan). The reducing agent was prepared by dissolving0.5g1amino-2-naphthol-4-sulfonic acid, 1 g Na_2SO_3 and 30 g $NaHSO_3$in 200mLwater.

Measuring of chlorophyll:

Leaf chlorophyll meter readings were taken from maize plants at the five to six-leaf stages with a CCM-200 Chlorophyll Meter. The chlorophyll meter can be used to measure chlorophyll concentration index that is proportional to the amount of chlorophyll in the sample. The CCM-200 is a self-contained, handheld device powered by a 9V alkaline battery.

Determination of proline:

Proline content of leaves was determined according to the method described by Bates *et al.* (1973).Samples of leaves (0.2 g) were homogenized in a glass mortar and pestle with 3 mL sulpho salicylic acid (3%, w: v), and then centrifuged for 15 min, 2 mL of the supernatant was then added to a test tube, to which 2 mL glacial acetic acid and 2 mL freshly prepared acid ninhydrin solution (1.25 g ninhydrin dissolved in 30 mL glacial acetic acid and 20 mL 6 mole L^{-1}orthophosphoric acid) were added. The test tubes were incubated in a water bath for 1 hr. at 100°C and then allowed to cool to room temperature.

Four mL of toluene was then added to the tube and mixed on a vortex mixer for 20 s. The test tube was allowed to stand for at least 10 min, to allow separation of the toluene and aqueous phases. The toluene phase was carefully pipetted out into a glass test tube and its absorbance was measured at 520 nm using spectrophotometer. The content of proline was calculated from a calibrated standard curve.

Relative water content:

Plant sample consisting of flag leaves was taken from each pot. Fresh weight of each sample was measured. Leaves were soaked in distilled water for 14-16 hours. After soaking period, the leaves were wiped with tissue paper and the soaked weight was measured. After wards, sample was oven dried at 80 ºC to determine its dry weight. For each pot, relative water content was calculated by using the formula given below as proposed by Turner (1986).

RWC (%) = (FW-DW) x 100/ (TW-DW)

Where; RWC = relative leaf water content (%), FW = fresh weight of leaf (g), DW = dry weight of leaf (g), TW = turgid weight of leaf (g).

Statistical analysis:

The obtained data were statistically analyzed for variance and means comparison to fulfill the signification according to Steel and Torrie (1982). Single and multiple linear regressions were applied to fit the data using the method of Draper and Smith (1967).

RESULTS AND DISCUSSION

Soils

The soil samples showed different physical and chemical properties (Table 1). In general, the soil is typic calciorthid. It has high $CaCO_3$ percentage. The total silicon content was about 189 g kg^{-1}soil. The normal range of silicon was in soils is in range from 1000 to 450000 mg kg^{-1} soil (Sommer *et al.,* 2006) or in the range from 200 to 300 g Si kg^{-1}in clay soils and 450 to 480 g Si kg^{-1}in sandy soils (Matichenkov and Calvert, 2002) who suggested low Si contents in calcareous soils than the alluvial. The comparatively lower value of Si in the studied soil (calcareous soil) can be justified due to; (i) severe and frequent soil erosion and sediment transportation in the study areas, (ii) usually plants absorb Si more than other elements (Savant *et al.,* 1997), (iii) the nature of parent materials in the study areas could be the cause for the low Si level in this soil. . Since, the amount extractable silicon in the studied soil, using the extraction by ammonium acetate (Ayres, 1966) was 150 mg kg^{-1} soil and according to the suggested critical value of =<50 mg/kg, the used soil is non-deficit in available silicon.

To interpret soil tests and to determine fertilization guidelines for a nutrient requires knowledge of the real critical level in the soil must be well established. To date, the published critical silicon levels varied with soil type, crops, and soil testing procedure (Lima et al., 2003). The critical silicon level which obtained using the Ayres (1966) extraction procedure would not predict the levels of silicon deficiency in the tested soil for maize crop. The critical silicon levels currently reported are very specific not only to the crop species but also to the location and the soil used, which underscores the necessity to establish site-specific plant and soil silicon content interpretations. As a result, different researches about this subject are needed for the different crops and soils in Egypt.

Plant growth

Tables (2 and 3) reveal that the shoot dry weight of maize significantly affected by water stress and silicon rates. The results reveal that decreasing water stress (increasing soil moisture) from 40% to 80% of field capacity significantly and progressively increased dry weight of shoot. The decreases of shoot dry weight of 73.0%, 63.48%, 40.48% and 36.5% at 40, 50, 60, and 70% of FC. respectively as compared with the control (80% of the field capacity). Regarding the effect of silicon application rate, data in the same tables also showed that the shoot dry weight of maize plants increased significantly with increasing the silicon. The interaction between water stress levels and silicon rate had no significant effect on shoot dry weight. However, it is clear from Table (2) that the values of dry weight of maize plants were increased at each water stress level with increasing the silicon rate. In general, maize shoot dry weight increased with the addition of silicon, independent of water stress.

In plants subjected or not subjected to water stress, increasing silicon supply to 200 mg kg^{-1} increased shoot dry mass.. The relationship between the dry weight (Y_1), water stress level (X_1) and silicon rate (X_2) for maize were calculated. The regression equation for this relationship was:

$$Y_1=-0.78+0.021x_1+0.002x_2$$

$$R^2= 0.9387 \qquad P<0.0$$

The comparison of slopes of each variable in the equation (0.021:0.002) gives quantitative estimate for the effect of one variable in relation to the other. Thus, the effects of water stress and silicon rates would be equal to (10.5:1). The beneficial roles of Si in combating various biotic and a biotic stresses have been widely reported by Van Backhaven *et al.* (2013).

Maize is also one of the cereal crops that actively take up and accumulate Si into its organs (Mitani *et al.* 2009). It seems to suggest that the beneficial effects of Si on plant growth and yield are particularly distinct under drought stress conditions.

Silicon known to increase drought tolerance in plants by maintaining plant water balance, photosynthetic efficiency, erectness of leaves and structure of xylem vessels under high transpiration rates due to higher temperature and moisture stress (Hattori *et al* , 2005). Similarly, Gong *et al.,* (2003 and 2005) observed improved water economy and dry matter yield of wheat by silicon application.

Table (2). Effect of water stress and silicon application rates on dry weight,(DM) relative water content (RWC), chlorophyll index and proline contents of maize plants

Moisture (% of field capacity) (M)	Silicon rate (kg^{-1} soil mgSi)	DM (g $plant^{1}$)	RWC (%)	Chlorophyll index	Proline mmol kg^{-1}DM
40	**0**	0.15	49.01	16.64	0.50
	50	0.21	66.02	21.75	0.59
	100	0.24	69.02	24.80	0.64
	150	0.27	72.02	27.05	0.82
	200	0.31	83.02	30.16	0.93
50	**0**	0.33	64.01	16.80	0.44
	50	0.40	71.02	21.98	0.48
	100	0.44	75.02	25.11	0.52
	150	0.47	79.02	27.44	0.57
	200	0.57	85.03	30.63	0.65
60	**0**	0.42	69.02	17.88	0.29
	50	0.57	75.69	23.39	0.34
	100	0.63	78.03	26.72	0.39
	150	0.75	82.03	29.20	0.41
	200	0.83	88.04	32.60	0.55
70	**0**	0.52	73.03	19.41	0.21
	50	0.67	77.03	25.39	0.26
	100	0.73	78.03	29.01	0.29
	150	0.80	85.04	31.69	0.35
	200	0.91	91.04	35.38	0.40
80	**0**	0.90	79.03	21.35	0.20
	50	1.06	80.04	27.93	0.23
	100	1.16	83.04	31.91	0.26
	150	1.26	90.05	34.88	0.28
	200	1.37	94.06	38.94	0.32
$LSD_{0.05}$					
M		0.13	**1.00**	0.05	0.02
Si		0.11	**0.96**	0.06	0.01
M * Si		NS	**2.09**	0. 20	0.01

Table (2).Mean effects of water stress and silicon rates on shoot dry weight (DM), relative water, chlorophyll and proline contents of maize plants

Treatments	DM, (g plant^{-1})	Relative Water content (%)	Chlorophyll Index	Proline (mmole kg^{-1})
Moisture, % of FC				
40%	0.24	68.82	24.07	0.69
50%	0.44	75.00	24.39	0.53
60%	0.64	79.01	25.95	0.39
70%	0.73	80.80	28.17	0.30
80%	1.15	85.24	31.00	0.26
$LSD_{0.05}$	0.13	1.00	0.05	0.02
Silicon rate, mg/kg soil				
0	0.46	67.02	18.42	0.33
50	0.58	74.16	24.08	0.38
100	0.64	78.03	27.51	0.42
150	0.71	82.03	30.05	0.54
200	0.80	88.04	32.00	0.57
$LSD_{0.05}$	0.11	0.96	0.06	0.01

Relative water content (RWC)

Tables (2and 3) show that the relative water content of maize plant leaves was affected significantly by water stress and silicon rates treatments. On the other hand, the interaction between the two factors was non-significant. Table (3) revealed that decreasing water stress level from 40 to 70 % of FC progressively and significantly increased the leaves relative moisture content of maize plants. Also, the leaves relative water content showed decreases of 22.09, 13.95, 9.3 and 5.81% for maize plants at 40, 50, 60, and 70 % of FC, respectively as compared with 80% of FC moisture level. Concerning the effect of silicon rates, Table (3) clearly showed that, the values of RWC were increased with increasing silicon rates. The mean effect of silicon rate on leaves relative moisture content increases were 12.12, 15.5, 24.24 and 33% with application of 50, 100, 150 and 200 mg Si/kg soil, respectively as compared with the control treatment (without silicon application). The interaction between water stress levels and silicon rate had no significant effect on RWC. However, it is clear from Table (2) that the RWC values of shoots were increased at each water stress level with increasing the silicon rates.

Relative water content in leaves is known as alternative moisture of plant water states, reflecting the metabolic activates in tissues (Flower and Ludlow, 1986). Similar results have been reported for many plants species under water stress conditions (Ramanjulu and Sudhaker (1997). Silicon deposited in tissue alleviated water stress by decreasing transpiration and improves light interception characteristics by keeping the leaf blade erect (Epstein,1999). The findings of Ma et al. (2001) supported the obtained results as they were of the opinion that silicon improves crop relative water potential. Improved plant water status (higher RWC) may result from reduced water loss by transpiration due to deposition of Si forming silica gel layer on epidermal cell walls (Kaya et al. (2006).

Chlorophyll index

Tables (2 and 3) indicated that decreasing water stress resulted in significant increase in chlorophyll index. The data showed decreases of 22.35, 21.32, 16.29 and 9.13 at moisture of 40, 50, 60 and 70% of FC, respectively as compared with moisture at 80% of FC. Regarding the effect of silicon rates on chlorophyll index as illustrated in Table (3), the results showed significant increases in chlorophyll index by 30.80, 49.43, 63.23 and 82.18% at 50, 100, 150 and 200 mg Si kg^{-1} soil rates, respectively as compared with control treatment (without silicon application). The interaction between water stress and silicon rates on chlorophyll index was significant (Table 2). The highest value of chlorophyll index was 38.94 which obtained at 80% of FC and 200 mg Si/kg soil. However, the lowest chlorophyll index (16.64) was recorded at 40% of FC and without Silicon application.

Silicon proportionately increased the levels of chlorophyll in the water-deficient plants, indicating the synthesis of new pigments and the maintenance of previously existing chlorophyll. Donegá (2009) also, concluded that silicon improved the plant architecture and increased photosynthesis. The deposition of silicon in the cell wall also increases tissue resistance and promotes better-performing plants due to leaf position and their interception of light (Lana *et al.,* 2003). Water-deficient plants that were treated with silicon showed an increase in the chlorophyll content. Correspondingly, a decrease of chlorophyll was observed in plants exposed to water deficit in the absence of silicon, likely because of the decrease in nitrogen absorption, an essential element necessary for the formation of chlorophyll. Silicon treatments were shown to cause changes in nitrogen metabolism (Watanabe *et al.,* 2002).

Proline content

Tables (2 and 3) indicate that decreasing water stress resulted in significant decrease in proline concentration in leaves of maize plants. The decreases were significant up to the highest level of water stress (40 % of FC). Concerning the effect of silicon rates on proline concentration of maize plants, the result in Table (3) showed that application of silicon from 50 to 100, 150 and 200 mg Si kg^{-1} soil significantly increased proline concentration in leaves of maize plants compared to the control (without silicon application). Similar results were observed by Gunes *et al.* (2008) and Crusciol *et al.* (2009) found that silicon increased proline who content in stressed plant tissue. However, Kaya *et al.* (2006) and Lee *et al.* (2010) found the opposite.

The interaction between water stress and Silicon rate on Proline concentration in leaves is presented in Table (2). The highest obtained values of proline concentration in leaves were 0.93 mmole g^{-1}D.M.using 40% of FC (highest water stress). However the lowest Proline concentration in leaves of maize were 0.20 mmole g^{-1}D.M.andwas recorded at 80% of FC (the lowest water stress) and without Silicon. The proline concentration in maize leaves (Y_3) was regressed with water stress (X_1)and silicon rates (X_2) and the following relationship was obtained:

$$Y_3=0.48-0.01X_1+0.001X_2$$
$$R^2= 0.9307 \quad P < 0.01$$

The comparison of slopes of each variable in the equation (0.01:0.001) gives quantitative estimate for the effect of one variable in relation to the other. Thus, the relative effect of water stress and silicon rates would be equal to (1: 0.1). In general, the addition of Si highly increased proline accumulation in the leaves under water stress condition (40% of FC) and slightly under non water stress condition (80% of FC).Proline accumulations in response to water stress have been reported widely and play a role in stress adaptation within the cell. Osmotic adjustment (OA) is part of drought avoidance mechanisms to counteract the of turgor by increasing and maintaining a higher amount of intracellular compatible solutes in the cytosol and vacuole (Cushman, 2001). Proline is one of the key osmolytes contributing to OA (Hare and Cress, 1997).

Elemental composition

Tables (4 and 5) showed that N, P, K, Cu, Zn and Si concentrations in maize shoots significantly affected by water stress and silicon rates. The results indicated that decreasing water stress resulted in significant increase of N, P,K, Cu, Zn and Si concentrations.

Regarding the effect of silicon rates, the data in Table (5) showed that increasing Si rate from zero to 200 mg kg-1 soil increased significantly the concentration of these elements in maize shoots. Also, the interaction between the water stress and silicon rates (Table 4) showed significant effect on K, P, Cu, Zn and Si concentrations of maize shoots. The highest values were found at moisture level of 80% of FC and 200 mg Si kg^{-1}soil, while the lowest values were obtained at water stress of 40% of FC and without silicon applications.

Potassium plays an important role in osmotic adjustment and its adequate level in plants may improve water stress tolerance. Under water stress conditions, the presence of Si resulted in better supply of potassium as shown in Tables (4 and 5) .This results were confirmed by Kaya *et al.* (2006).

This beneficial effect may be attributed to the stimulating action of Si on H^+-ATP-ase (Liang, 1999). Also, increasing Si rate under different water stress levels helps in maintaining an adequate supply of N and P. Li *et al* (1999) showed that the yield of maize receiving silicon fertilizer was increased over the control and silicon fertilization significantly increased concentrations of N, P, Zn and Mn in maize plants.

Environmental stresses also affect the uptake and translation of nutrient elements including P, K, Ca and Mg and micronutrient such as Fe, Mn, Cu, B and Zn in plants (Wang and Han, 2007).

Table (4). Effect of water stress and silicon rates on N, P,K, Cu, Zn and Si concentrations shoot of maize plants

Treatments		N	P	K	Cu	Zn	Si
Moisture, % of field capacity (M)	**Silicon rate, mg Kg^{-1} soil (Si)**	**(g Kg^{-1}DM)**			**(mg Kg^{-1}DM)**		
40	**0**	10.0	5.7	3.77	2.6	32	119
	50	11.3	6.9	5.13	3.0	40	280
	100	11.4	7.3	5.48	3.6	46	405
	150	11.7	7.8	6.18	3.8	48	491
	200	14.2	9.1	7.53	4.2	50	740
50	**0**	10.1	5.7	3.92	2.8	62	149
	50	11.3	6.9	5.36	3.4	84	341
	100	11.5	7.3	5.79	3.8	108	516
	150	11.7	7.9	6.57	4.6	126	611
	200	14.3	9.1	8.01	5.4	146	671
60	**0**	10.7	5.7	4.18	3.8	68	177
	50	12.0	7.0	5.71	4.6	92	347
	100	12.2	7.4	6.17	5.2	116	509
	150	12.5	7.9	7.00	5.6	134	644
	200	15.2	9.2	8.53	7.4	156	732
70	**0**	11.6	5.8	4.55	6.0	76	209
	50	13.1	7.1	6.20	6.4	102	381
	100	13.2	7.5	6.70	7.0	128	455
	150	13.5	8.0	7.60	7.6	148	647
	200	16.5	9.3	9.26	8.6	172	851
80	**0**	12.8	5.9	5.00	6.6	84	232
	50	14.4	7.2	6.83	7.8	114	512
	100	14.5	7.5	7.38	8.6	142	526
	150	14.9	8.2	8.38	11.0	166	687
	200	18.1	9.5	10.21	12.4	192	907
		$LSD_{0.05}$					
M		0.7	0.01	0.02	0.1	0.3	19
Si		0.7	0.02	0.01	0.1	0.3	18
M * Si		NS	0.3	0.03	0.1	0.6	60

Table (5).Mean effects of water stress and silicon rates on N, P, K, Cu, in Zn and Si concentrations shoot of maize plants

Treatments	N	P	K	Cu	Zn	Si
	g kg^{-1}D,M,			mg kg^{-1}D.M.		
Moisture, %of FC						
40	11.7	7.36	3.05	3.4	42	407
50	11.7	7.39	3.36	4.0	104	458
60	12.5	7.45	3.58	5.2	112	482
70	13.5	7.54	3.90	7.0	124	508
80	14.9	7.65	4.30	9.2	138	573
$LSD_{0.05}$	0.7	0.10	0.02	0.1	0.3	19
Silicon rate, mg Kg^{-1}						
0	11.0	5.7	2.6	4.2	64	177
50	12.4	7.0	3.2	5.0	86	372
100	12.5	7.4	3.6	5.6	106	480
150	13.5	8.1	4.1	6.4	124	616
200	15.5	9.2	4.5	7.4	142	780
$LSD_{0.05}$	0.7	0.02	0.01	0.1	0.3	18

Table 3 showed the increase of silicon in the shoots where silicon was applied in either well watered (80% of FC) or drought condition (40% of FC) indicating the ability of maize to uptake the silicon. Therefore a positive correlation exists between Si concentration in shoots and dry matter of plant shoots (Table 1) as shown in Figs. (1 and 2) and the effect of silicon was about 2.3 times more in well water (80% of FC) condition in comparison to the drought condition (40% of FC).

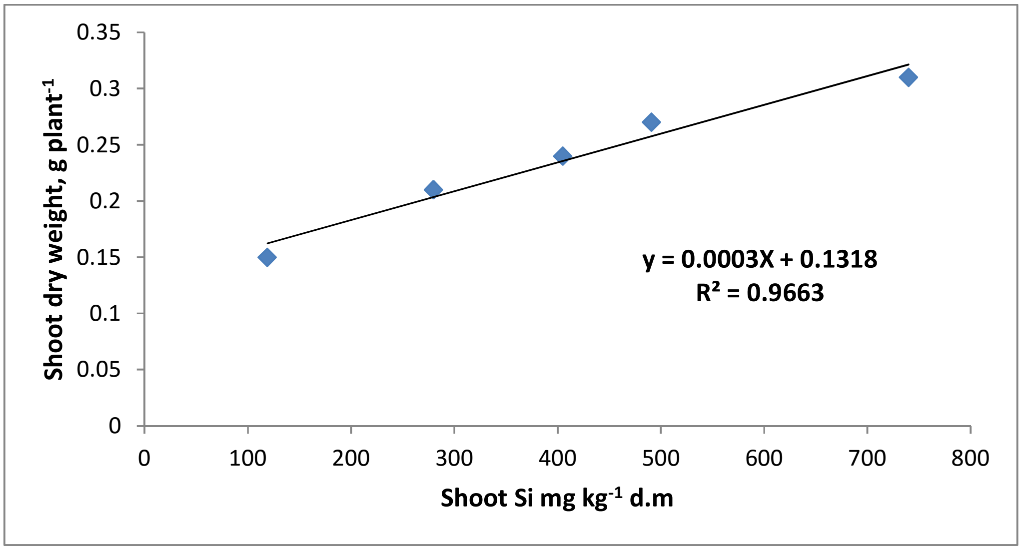

Fig.(1).The relationship between Si concentration of maize shoot and shoot dry weight under water stress (40% of FC) condition

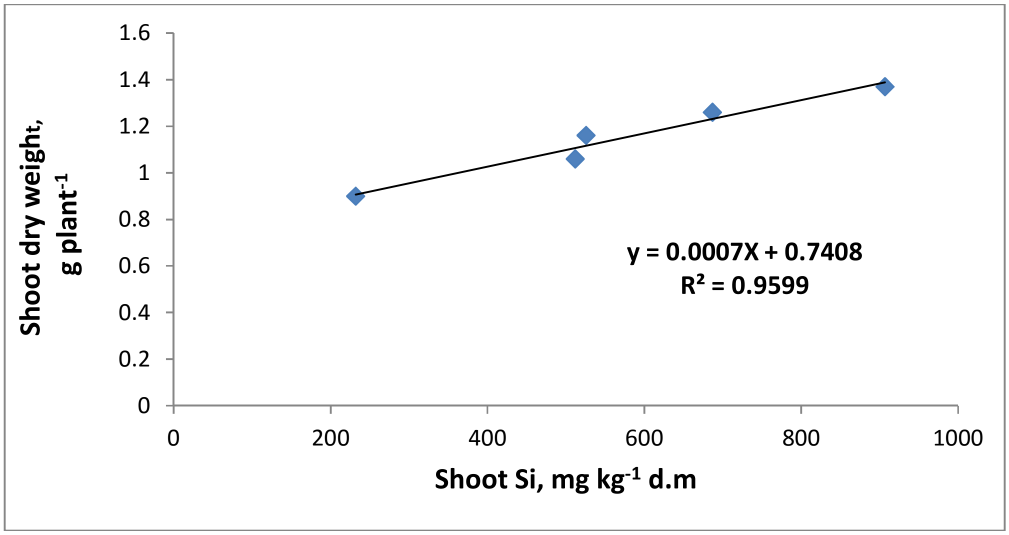

Fig.(2). The relationship between Si concentration of shoot and shoot dry weight under well watered (80% of FC) condition

The results also indicated a positive correlation between Si concentration of shoots and relative water content (Figs. 3 and 4), chlorophyll index (Figs. 5 and 6), and proline content (Figs.7 and 8) under both conditions.

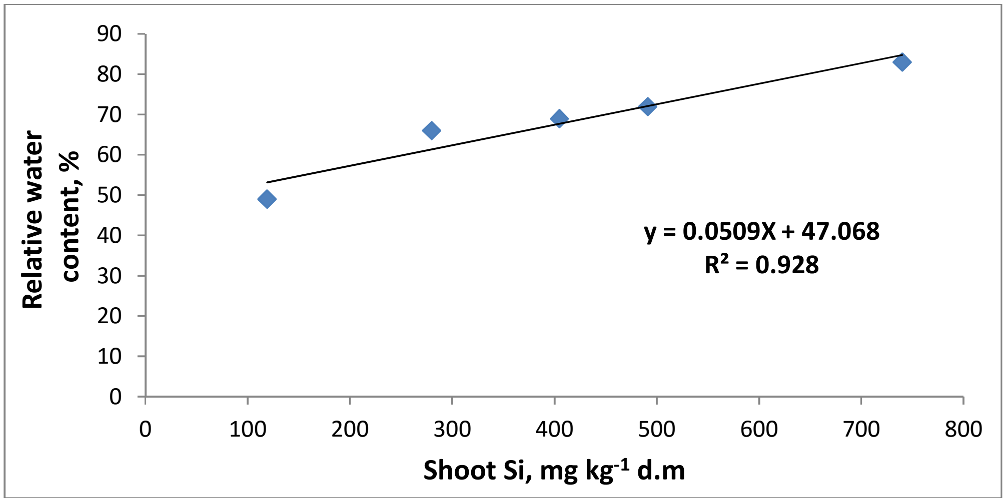

Fig.(3). The relationship between Si concentration of maize shoot and relative water content under water stress (40% of FC) condition

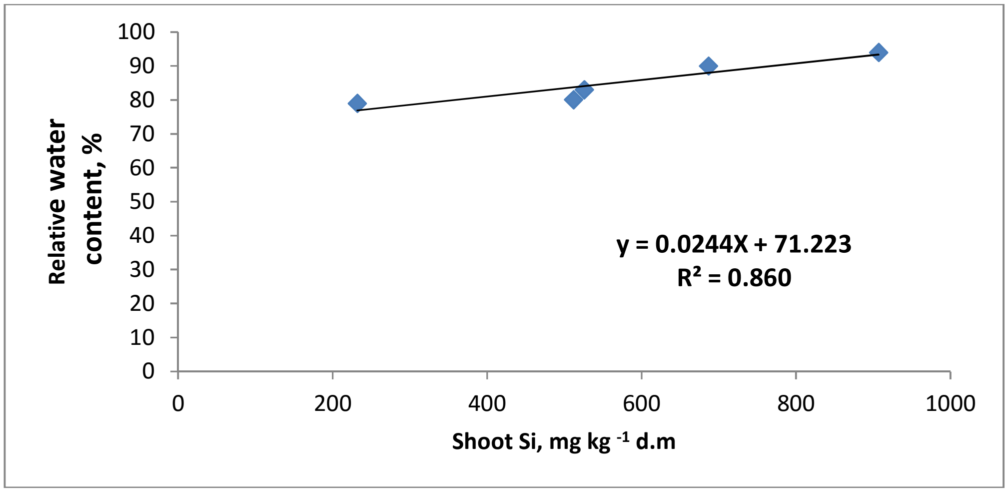

Fig.(4). The relationship between Si concentration of maize shoot and relative water content under well watered (80% of FC) condition

The effect of silicon was about 2.1 times more under drought condition (40% of FC) in comparison to the well watered soil (80% of FC) for relative water content. While the effect of silicon was about 1.2 times more in well watered soil(80% of FC) in comparison to the drought condition (40% of FC) for chlorophyll index.

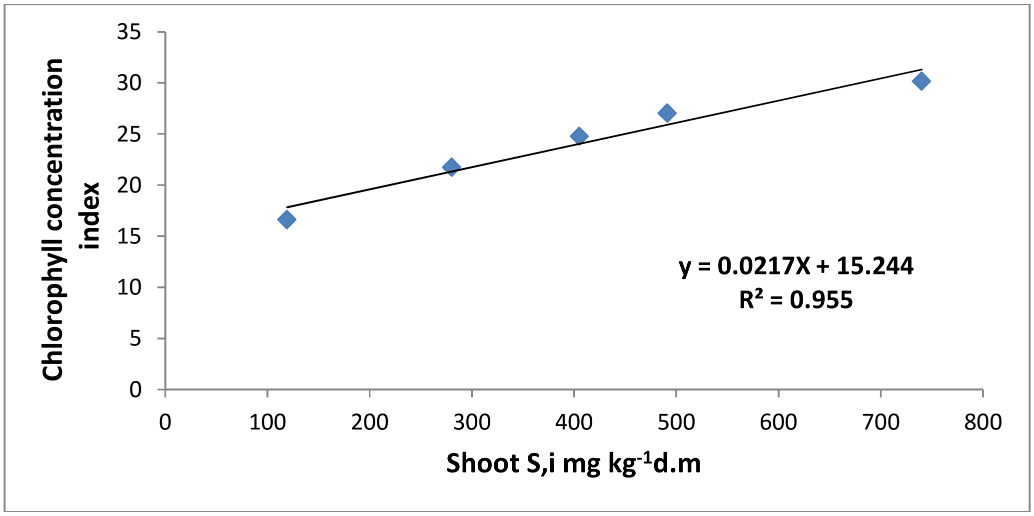

Fig.(5). The relationship between Si concentration of maize shoot and Chlorophyll index under water stress (40% of FC) condition

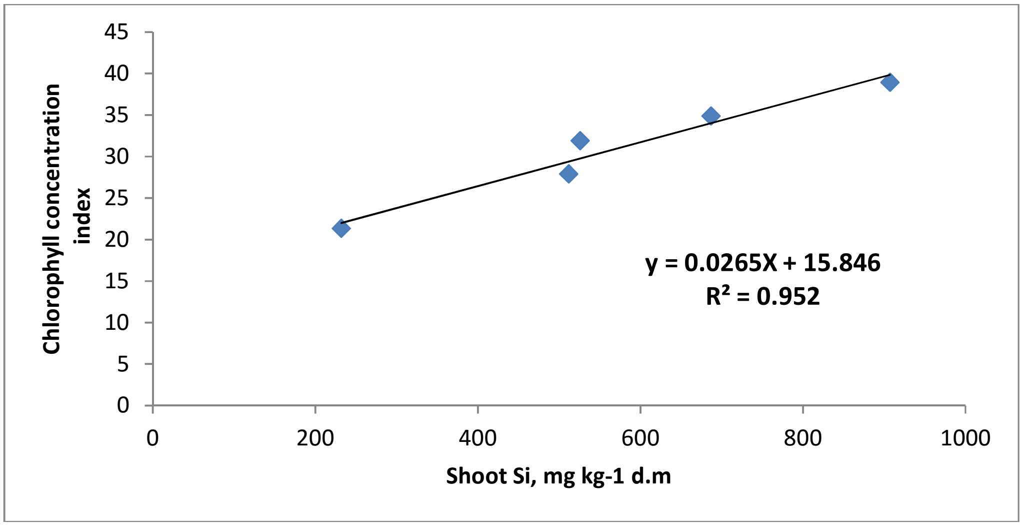

Fig.(6). The relationship between Si concentration of maize shoot and Chlorophyll index under well watered (80% of FC)) condition

On the other hand, the effect of silicon on proline content was about 3.5 times more in drought condition (40% of FC) in comparison to the well watered soil (80% of FC) condition.

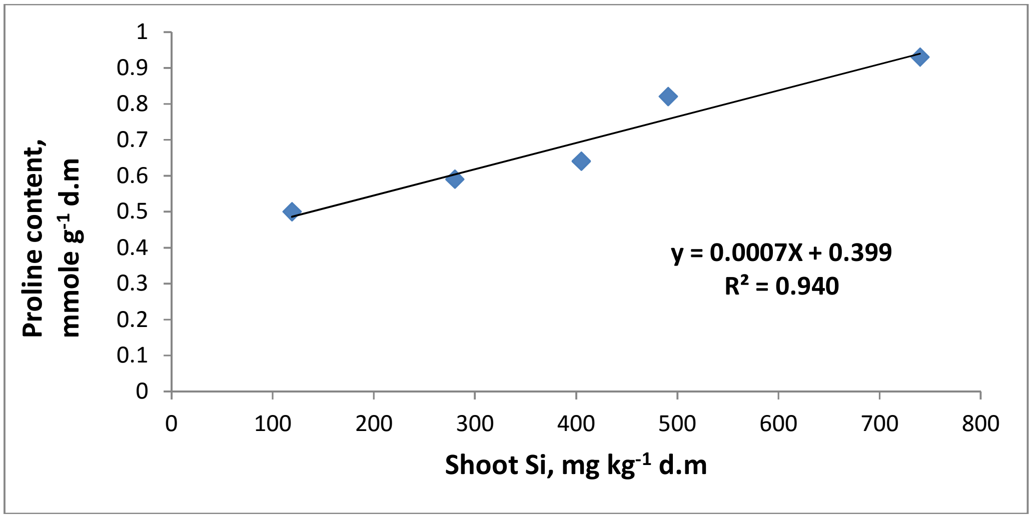

Fig.(7). The relationship between Si concentration of maize shoot and proline concentration under water stress (40% of FC) condition

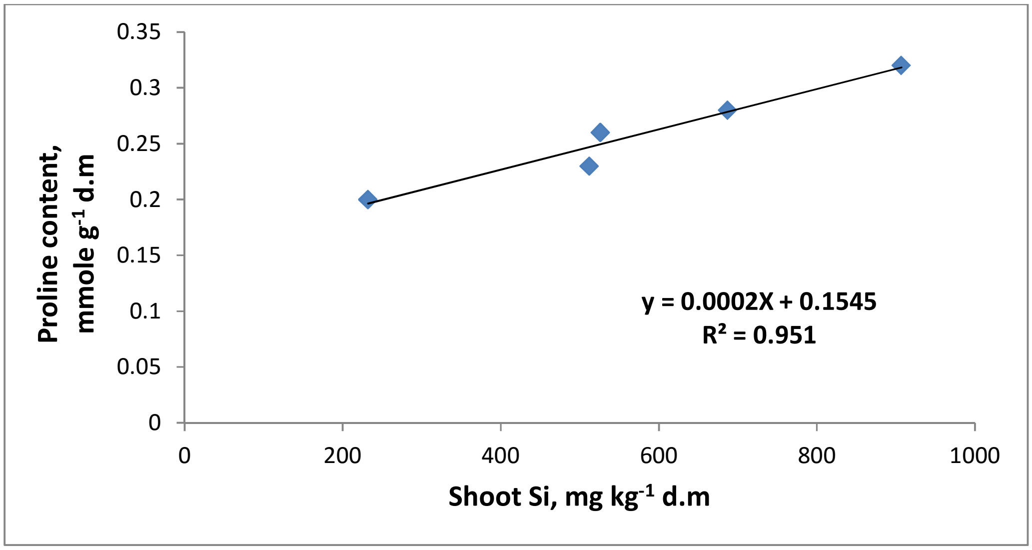

Fig.(8). The relationship between Si concentration of maize shoot and proline concentration under well watered (80% of FC) condition

CONCLUSION

The results of this study indicate that water stress is able to induce significant alteration of the physiological stress indicators associated with water relations, growth and metabolic activities. Silicon application might improve the drought tolerance of maize plants via increasing the oxidative defense abilities through different effects including improvement of the water status. The facts mentioned above make it is possible to recommend safely the treatment of plants grown under condition of high soil water potential with silicon application.

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الملخص العربي

التأثيرات المفيدة للسليكون على تحمل الاجهاد المائى فى الذره النامي فى أرض جيرية

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تم تقييم نمو الذره تحت اجهاد نقص الماء وذلك بتقليل محتوى الرطوبه فى التربه من ٨٠% من السعه الحقليه كمستوى رطوبه أمثل واعتبار المعاملات ٤٠ ،٥٠، ٦٠، و٧٠% من السعه الحقليه أنها مستويات مختلفه من الاجهاد المائى للذره مع اضافة السيليكون بمعدلات تتراوح بين صفر و٢٠٠ مجم لكل كيلوجرام تربه. ولقد تم هذا التقييم فى تجربة أصص باستخدام تربه جيريه وفى تصميم القطع المنشقة وقد أضيفت معاملات الاجهاد المائى الى القطع الرئيسيه ومعاملات السليكون الى القطع تحت الرئيسيه. ولقد أوضحت النتائج أن الاجهاد المائى أدى الى تخفيض الوزن الجاف للمجموع الخضرى ومحتوى الرطوبه النسبى وقيم دليل الكلوروفيل مع زيادة تركيز البرولين فى الأوراق. وباضافة السليكون حتى ٢٠٠ مجم/كجم تربه قد أدى الى تحسين النمو جزئيا بزيادة الوزن الجاف للمجموع الخضرى وزيادة محتوى الماء النسبى ومحتوى الكلوروفيل فى الأوراق وأيضا تركيز البرولين فى الأوراقخاصة تحت ظروف الاجهاد المائى االمرتفع. والعلاقه السلبيه بين محتوى البرولين والوزن الجاف للمجموع الخضرى يدعم وجهة النظر أن البرولين هو أحد أعراض ضرر الاجهاد المائى. واضافة السليكون قد أدى الى تجمع السليكون فى المجموع الخضرى.كما أوضحت تقديرات العناصر الصغرى والكبرى فى المجموع الخضرى أنه لم يحدث تجمع لهذه العناصر فى المجموع الخضرى تحت الاجهاد المائى وأن اضافة السليكون أدى الى زيادة تركيز هذه العناصر حتى تحت هذه ظروف. هذه النتائج تشير الى أنه تحت ظروف الاجهاد المائى فالتغذيه بالسليكون تؤدى الى تحمل الجفاف و تحسين نمو نبات الذره .