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ASSESSING THE EFFECT OF SILICON FERTILIZATION ON THE PRODUCTIVITY OF MAIZE (*Zea mays* L.) GROWN IN A CLAY SODIC SOIL

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ABSTRACT

Silicon (Si.) has an important role as a nutrient element to many plants belongs to the poaceae family such as maize. To assess the effect of silicon fertilizer on maize production, a field experiment was carried out in the Faculty of Technology and Development Farm, Ghazala El-Khis Village Zagazig, Sharkia Governorate, Egypt during two summer seasons of 2013 and 2014. Plants were sprayed with Si solution of 0, 140, 280, 420, and 560 mg Si l^{-1} applied as potassium silicate. The foliar spray on maize leaves was done 30 days after planting and repeated 10 days after the first dose for 4 times. Increasing the level of Si increased the biomass yield, grain yield, 100-grain weight and grain protein content. Contents of N, P and K in leaves increased by increasing the application level of silicon, whereas, Na content decreased. The study demonstrates that addition of silicon may ameliorate the hazard effects of sodium ion in clayey sodic soils.

Key words: Maize, chemical composition, grain yield, biomass yield, potassium silicate, silicon, foliar spraying.

INTRODUCTION

Silicon (Si) is ubiquitous in the earth's crust and considered the second most abundant element after oxygen (Wollast and Mckenzie, 1983). Available Si in soils may occur as silicic acid, H_4SiO_4, which is a prevalent component of most soil solutions (Dove, 1995). Soluble Si in soils: (1) May migrate to ground water. (2) May react with other elements in soil solution and form new clay minerals. (3) May be taken up by plants and returned to the soil as crystalline phytoliths in litter (Blecker *et al*., 2006; Sommer *et al*., 2006). SiO_2 contents in plant tissues range from 0.1 to 10% according to Epstein, (1994), while Marschner (2006) reported that wetland vegetations (*e.g.*, cattails, sedges, and reeds) generally contain 10 to 15% SiO_2. Silicon has been recently acknowledged as a plant nutrient element (Epstein, 2001). It has an important role as a nutrient element to many plants which belongs to the poaceae family such as rice, maize, wheat, and sugarcane (Alvarez and Datnoff, 2001). Plants can absorb Si in a hydrated form ($SiO_2.nH_2O$), which is deposited in their tissues. Silica bodies of different shapes and size may occur depending on the plant species. The silica bodies accumulate mainly in the family poaceae (*e.g.*, maize), in organs such as leaves, seeds, fruits, roots and stems, where they may be deposited inside the cells or in their walls (Runge, 1999; Alvarez *et al.*, 2005). Silica bodies are microscopic and are precipitated in the tissues of plants during their life cycle. In grasses, they create support structures (Piperno and Pearsall, 1998; Medeanic *et al.*, 2008).

Seebold *et al*. (2001) Stated that Si can alleviate disease severity through blocking of fungus ingress, therefore a continuous source of silicate is very important. When adding silicates to a foliage spray program, they will help in decreasing the rate of disease attack and help protect the plants new leaves from spider mites, aphids, and many other sucking type insects.

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Silicon helps plant growth by depositing in the epidermal cell walls, enhancing the plant's ability to keep the leaves pointed towards the light source. Silicate plays an active role in combating fungal growth by the production of polyphenolic compounds; this is a main part of the plants natural defense against fungal and insect attacks. Silicate also increases the stem strength, making it easier to hold up more weight. Silicate increases the mechanical strength of the plant to help it in extreme heat and cold, salt-build up in soils and water. It also controls the rate of transpiration of plants. As the plant increases the silicon levels, it increases nutrient uptake and distribution, and increased concentration of chlorophyll and Ribulose biophosphate (RUBP) carboxylase in leaves. Leaf system in plant will rapidly bind potassium silicate in the tissue and cell walls (within 24 hours of uptake) Datnoff (1992) and Miyake and Takahashi (1983).

The present study aimed at assessing the effect of silicon as foliar spraying fertilizer on yield and the content of N, P, K and Na of maize leaves under heavy clayey sodic soil conditions.

MATERIALS AND METHODS

Experimental Field Sites and Soil Characteristics

A field experiment was carried out in the experimental farm, Faculty of Technology and Development, Ghazala El-Khis village (30°34'01.6"N 31°34'22.6"E) Zagazig, Sharkia Governorate, Egypt. Composite soil samples representing the plowing layer (0.0 – 0.3 m) were collected randomly at a depth of 0.30 m from experimental site. The soil samples were air dried and sieved (< 2 mm.). Properties of the soil are presented in Table 1. The physical and chemical characteristics of the soil were carried out according to the recommended procedures of the USDA (2004, 2011). Soluble silicon was extracted by 0.01 M $CaCl_2.2H_2O$ and determined colorimetrically using ammonium sulfomolybdate then adds tartaric acid and L-ascorbic acid methods and measure silicon on spectrophotometer at 660 nm wave length (ICARDA, 2013).

Experimental Design

The experiment was laid out in a randomized complete block design with three replicates, the plot area was $10.4 m^2$. Treatments included five silicon concentration levels, 0, 140, 280, 420 and 560 mg Si L^{-1} were applied as a foliar spray on maize leaves 30 days after planting and were repeated each 10 days *i.e.,* 40, 50 and 60 days after the first dose. Spray rate was 1923 l ha^{-1} each spraying time.

Agronomic Practices

Maize (*Zea mays* L.) cv. High Fine was planted on 19th of May 2013 and 1st June 2014 for first and second seasons, respectively in hills 30-cm apart with a seeding rate of 28.6 kg ha^{-1}. Maize seedlings were thinned to a single plant per hill. The recommended N P K rates for maize were band applied. Nitrogen fertilizer was added to all plots at a rate of 238 kg N ha^{-1} in the form of urea 465 g N kg^{-1} in three equal splits 15, 30 and 45 days after planting. Phosphorus was added to all plots before sowing at a rate of 238 kg P ha^{-1} as super phosphate 68 g P kg^{-1}. Potassium fertilizer was added at a rate of 119 kg K ha^{-1} as potassium sulfate 400 g K kg^{-1} after 15 days of planting. In addition, after 30 days from planting, plants were sprayed with silicon in the form of potassium silicate 58.45 g Si l^{-1} at the concentrations of 0, 140, 280, 420, and 560 mg Si l^{-1} and then repeat spraying after that four times every 10 days and foliar spray rate 1923 l ha^{-1}. The other common agricultural practices of growing maize were done. Maize was harvested on the last week of September in both seasons.

Sampling Technique

At harvest, grain yield was determined from the central three ridges and adjusted to 15.5% moisture. A random sample of 15 ears from each plot was taken and 100-grain weight was recorded. Grain samples of the two seasons from each treatment were mixed together for chemical analyses.

Chemical Analyses of Leaves and Protein in Grains

Main ear leaves and grain/samples were oven-dried at 70˚C to a constant weight. The oven-dried samples were ground in a stainless steel blade blender. A set of leaves powder and grain ground material was wet-digested in mixture

Table 1. Physical and chemical properties of the investigated soil

Soil property	Season (2013)	Season (2014)
Sand (%)	20.13	20.01
Silt (%)	25.01	25.02
Clay (%)	54.86	54.97
Texture class	clay	clay
$CaCO_3$, g kg^{-1}	21.03	23.00
Organic C, g kg^{-1}	10.3	10.52
pH (1 : 2.5, soil : water)	8.37	8.40
EC (soil paste ext.) dSm^{-1}	3.03	3.01
Soluble ions , mmol$_c$ l^{-1}		
CEC, cmol$_c$ kg^{-1}	51.9	52.04
ESP (%)	18.12	17.96
Available nutrients, mg kg^{-1}		
(NH_4^+ + NO_3^-) - N	21.93	22.04
P	22.01	21.90
K	221.02	323.02
Si	31.03	31.04
Na	2150.01	2250.03

* Extracts are: KCl for N; $NaHCO_3$ for P; NH_4OAc for K and Na as well as $CaCl_2$ for Si

(H_2SO_4-H_2O_2) according to Parkinson and Allen (1975) for chemical analysis. Total N content was determined using the modified micro-Khjeldahl apparatus as described by Jackson (1973) and the obtained values were multiplied by 6.25 to calculate crude protein percentage. Phosphorus content was determined colourimetrically using the ascorbic acid methods (Watanabe and Olsen, 1965). Potassium and sodium contents were determined by a flame photometer according to Jackson (1973).

Statistical Analysis

Data collected during the study were statistically analyzed by Fisher's ANOVA technique. All data were statistical analyzed according to the technique of analysis of Variance for the randomized completely block design using MSTATC software package according to Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Chemical Composition of Leaves

Data presented in Table 2 show NPK and Na contents in maize leaves as affected by silicon application in 2013 and 2014 seasons. Nitrogen content increased significantly by Si application in both seasons. The increase was progressive with increasing of silicate rate up to 420 mg Si l^{-1}. Phosphorus content also increased in both seasons, it was highly significant at 560 mg Si l^{-1} and significant with 420 mg Si l^{-1}, 140 mg Si l^{-1} and 280 mg Si l^{-1} during the first season. In the second season, however, it was highly significant with 280 mg Si l^{-1}, 420 mg Si l^{-1} and 560 mg Si l^{-1}. Potassium content increased with high silicon level in the spraying solution and the increase was highly significant with 280 mg Si l^{-1}, 140 mg Si l^{-1}, and 420 mg Si l^{-1} and significant with 560 mg Si l^{-1}. In the second season, it was significant with 280 mg Si l^{-1} and 420 mg Si l^{-1}, respectively. These results are similar to the results obtained by Edvaldo *et al.* (2013) and Abou Basha *et al.* (2013). Hattori *et al*. (2007) concluded that silicon application improved water uptake by sorghum and consequently enhanced crop tolerance to deficit irrigation. These results suggest that silicon application was mainly beneficial to the growth of root and its effect become more prominent in presence of irrigation which stimulated development of root system, allocating more matter to root system. As the silicon level, increases nutrient uptake and distribution increased, and contains high concentration of chlorophyll and RUBP carboxylase in leaves. This result may be due to the favorable effects of silicon on maize plants by deposition of Si in form amorphous silica SiO_2H_2O (Inanaga and Okasaka 1995; Epstein, 1999) Si increased the thickness and roughness of leaves, thus improving light reception, which results in enhanced yield (Savant *et al*., 1999).

Table 2. Effect of silicon fertilizer on chemical analyses of maize leaves in 2013 and 2014 seasons

Silicon rates mg Si l^{-1}	N in leaves g kg^{-1}		P in leaves g kg^{-1}	
	2013	2014	2013	2014
	Value	Value	Value	Value
Control	10.15	10.15	0.29	0.33
140	13.31	10.38	0.67	0.54
280	12.41	13.76	0.58	0.70
420	13.09	13.31	0.71	0.66
560	11.28	12.18	1.23	0.64
LSD 0.05	1.27	0.78	0.32	0.2
LSD 0.01	1.81	1.11	0.46	0.28
Silicon rates mg Si l^{-1}	**K in leaves g kg^{-1}**		**Na in leaves g kg^{-1}**	
	2013	2014	2013	2014
	Value	Value	Value	Value
Control	17.68	19.45	1.24	0.52
140	19.57	20.95	0.74	0.30
280	20.14	22.45	0.52	0.30
420	19.57	21.89	0.52	0.23
560	19.00	20.95	0.37	0.37
LSD 0.05	0.96	2.92	0.2	0.37
LSD 0.01	1.36	4.16	0.28	0.52

Yield and Yield Attributes

Data in Table 3 represented grain yield and some related characters as affected by Si spray. Results show a highly significant increase in the biomass yield with 280 mg Si l^{-1}, while the application of 420 mg Si l^{-1} and 140 mg Si l^{-1} caused significant increase during first season. In the second season, biomass increased highly significantly with 280 mg Si l^{-1}, 560 mg Si l^{-1} and 420 mg Si l^{-1}, respectively. Grain yield increased significantly with 420 mg Si l^{-1} in the first season, while in second season there was a highly significant increase with 280 mg Si l^{-1}, 420 mg Si l^{-1}, 560 mg Si l^{-1} compared to the application of 140 mg Si l^{-1}. These results are consistent with results obtained by Edvaldo *et al.*(2013) and Gurmani *et al.* (2013). The 100-Grain weight showed a highly significant increase with 420 mg Si l^{-1} and 280 mg Si l^{-1} application in first season. In the second season, 100- grain weight was highly significant increased with 280 mg Si l^{-1} and 420 mg Si l^{-1}, respectively. Data presented in Table 3 for the two seasons, also indicate a significant increase in the protein content in grain with both the 280 mg Si l^{-1}, 420 mg Si l^{-1} levels during the first season. There was a significant increase with each treatment; except for 280 mg Si l^{-1} which showed a highly significant increase.

Table 3. Effect of silicon fertilizer on grain yield and protein content for maize in 2013 and 2014 seasons

Silicon rate mg Si l^{-1}	Grain yield Mg ha^{-1}		100- Grain weight g	
	2013	2014	2013	2014
	Value	Value	Value	Value
Control	7.04	4.07	40.56	29.46
140	7.45	6.87	42.28	29.09
280	7.83	12.76	43.36	36.16
420	8.74	9.77	44.36	35.05
560	3.41	9.75	40.99	32.70
LSD 0.05	1.67	2.75	*0.43*	3.38
LSD 0.01	2.38	3.91	0.58	4.80
Silicon rate mg Si l^{-1}	**Protein g kg^{-1} (Dry weight basis)**		**Biomass Mg ha^{-1}**	
	2013	2014	2013	2014
	Value	Value	Value	Value
Control	91.0	8.25	22.25	18.77
140	93.4	9.59	29.25	24.08
280	99.5	10.07	31.26	41.12
420	99.5	9.71	30.58	30.97
560	98.3	9.59	20.08	33.41
LSD 0.05	0.73	1.24	6.27	7.39
LSD 0.01	1.03	1.77	8.92	10.51

When applied to plant foliage as a preventive action, the silicon is taken into the plant cuticle and forms a silicon matrix that acts as a physical barrier; to help build the plants and resistance insects and fungus according to Datnoff (1992) and Miyake and Takahashi (1983). The mechanism of enhanced resistance to disease *via* Si application can be associated with accumulation of silicon in leaf epidermal cells which acts as a mechanical barrier against fungal infestation (Bowen *et al*., 1992 and Cai *et al*., 2008). The plants leaf system will rapidly bind potassium silicate in the tissue and cell walls (within 24 hours of uptake). When a plant has silicate uptake, it will start with the older growth and work its way into the newer growth to help build up the mechanical strength of the plant according to Remus-Borel *et al*. (2005), Rodrigues *et al*. (2003). Si increases the metabolic rate of plants, and improves resistance to wilt, and water stress, and can help fight heat stress up too 41^{o}C. It also increases reproductive rate in plants (bud growth). The correct Si levels in the plant tissue increase tolerance of Zn deficiency and protect from excessive or toxic levels of P, Mn, Na, and Al. Si-induced plant resistance can also be related to increased activity of defense related enzymes such as POD and PPO as well as higher accumulation of antifungal compounds such as phytoalexins.

Na/Si and Na/K Ratio in Maize

Silicon and potassium ratio increased in maize leaves but sodium decreased by increasing silicon application (Table 2). Figs. 1 and 2 show relationship between Na /Si, Na/K ratios and biomass yield. The ratios decreased with increasing biomass yield, in the two seasons mean with increasing application silicon rate. Silicon reduces the risks and effect of sodium in maize crop. Gong *et al*. (2006) suggest that silicon deposition in exodermis and endodermis reduces sodium uptake through a reduction in apoplastic transport across the root.

Conclusion

Results of the current study clearly indicate a considerable response of maize to Si foliar spray. Grain yield, biomass and 100-grain weight were significantly increased with increasing silicate application rate up to 420 mg Si l$^{-1.}$ Also N, P and K contents were increased for two seasons. But Na content was decreased in maize leaves with increasing silicate fertilizer while silicon ameliorates the hazards effects of sodium on maize crop.

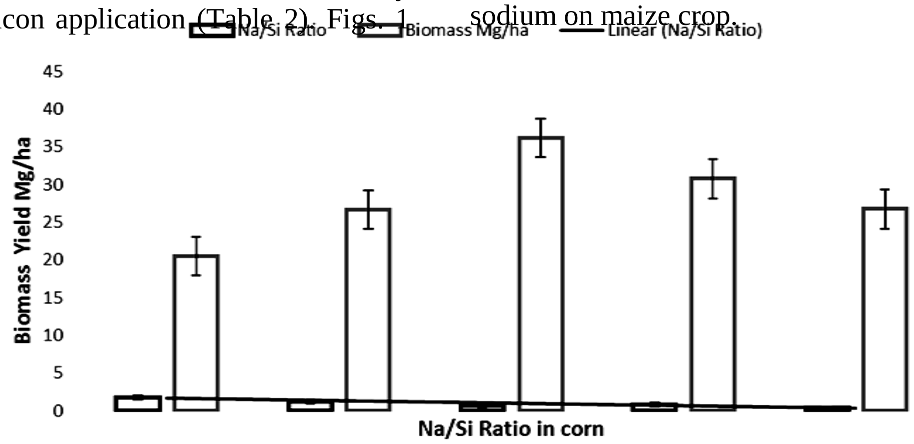

Fig. 1. Relationship between Na/Si ratio and biomass yield for the two seasons mean

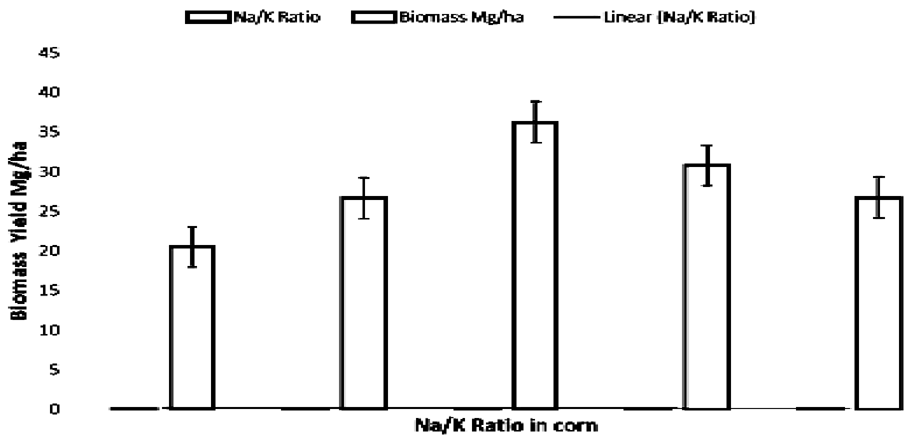

Fig. 2. Relationship between Na/K ratio and biomass yield for the two seasons mean

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تقييم تأثير التسميد بالسيليكون على إنتاجية الذرة النامية في الأراضي الطينية الصودية

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أصبح عنصر السيليكون من العناصر الضرورية لتغذية العديد من النباتات وخاصة التابعة للعائلة النجيلية مثل الذرة ولتقييم تأثير التسميد بالسيليكون على إنتاجية الذرة النامي في الأراضي الطينية الثقيلة الصودية، أجريت تجربة حقلية بمزرعة كلية التكنولوجيا والتنمية في قرية غزالة الخيس - مدينة الزقازيق - محافظة الشرقية- مصر خلال موسمي صيف ٢٠١٣، صيف ٢٠١٤ حيث تضمنت المعاملات خمسة تركيزات من السيليكون هى الكنترول، ١٤٠، ٢٨٠، ٤٢٠، ٥٦٠ ملليجرام Si/لتر أضيفت رشا بعد ٣٠ يوم من الزراعة كل ١٠ أيام من الجرعة الأولى وتكررت أربع مرات عند عمر ٤٠، ٥٠ و٦٠ يوماً من الرشة الأولى، ووزعت المعاملات علي القطع التجريبية في قطاعات كاملة العشوائية وتكررت كل معاملة ثلاث مرات، تشير النتائج إلى أن التسميد بعنصر بالسيلكون أدى إلى تحسين وزيادة إنتاجية محصول الذرة من الحبوب ومحتوي الحبوب من البروتين زيادة معنوية، كما أدي زيادة إضافة السيليكون إلى زيادة معنوية في تركيز عناصر النيتروجين والفوسفور والبوتاسيوم فى الأوراق بينما انخفض تركيز الصوديوم فى الأوراق، ويمكن من هذه النتائج استخلاص أن التسميد بعنصر السيليكون يحسن إنتاجية محصول الذرة ويخفف من التأثيرات الضارة لايون الصوديوم السائد في الأراضى الطينية الثقيلة الصودية المنتشرة على نطاق واسع في محافظة الشرقية.

المحكمون :

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