Title:

Optimal level of silicon for maize (Zea mays L. c.v. AMADEO) growth in nutrient solution under controlled conditions.

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Abstract:

Silicon (Si) is the second most abundant element in the earth's crust and plants vary in their response to Si. In order to investigate the effect of Si as Na2SiO3 fertilization on maize hybrid AMADEO growth in hydroponics, two experiments were conducted. In the first experiment, plants were supplied with two levels of Si; control (0 mM Si) and +Si (3 mM Si). In the second experiment, plants were supplied with a wide range of Si concentrations in nutrient solution in seven treatments (0, 0.4, 0.8, 1.2, 1.6, 2.0 and 3.0 mM Si). In the first experiment, no significant differences were observed in shoot and root biomass but reduced leaf area was observed after Si application. In the second experiment, plants supplied with 0.8 and 1.2 mM Si produced a significantly higher amount of fresh and dry biomass and also increased plant height and leaf area of youngest and fully developed young leaf. It is concluded that 1 mM Si represents an optimum concentration for maize nutrition in hydroponics.

Introduction:

Silicon (Si) is the second most abundant element in the earth's crust and all plants rooting in soil contain significant amounts of Si. Almost 150 years ago, Julius Sachs raised questions about the role of Si as to "whether silicic acid is an indispensable substance for those plants that contain silica, whether it takes part in the nutritional processes, and what is the relationship that exists between the uptake of silicic acid and the life of the plant?" (Lewin and Reimann, 1969). These questions are still valid and require an intensive investigation about the role of Si in plant physiology and biochemistry. In nature, Si is not an inert element and its bioactive role in plants under various biotic and abiotic stresses is more evident (Epstein, 1999). But there is contradiction about the direct role of Si in plants as a nutrient. There is some evidence that Si can have an impact on plant growth by changing photosynthetic activity (Adatia and Besford, 1986) and by changing cell wall extensibility in young growing regions of root and shoot (Hossain et al., 2002, 2007). Fauteux et al. (2006) showed, using a microarray expression, that only two genes were affected when Si was supplied under no-stress conditions. In contrast, plants inoculated with a fungus and treated with Si altered the expression of nearly 4,000 genes. So a study was planned to investigate whether there is a direct effect of Si on growth of maize under normal growing conditions.

Material and methods:

Two experiments were carried out to investigate the direct role of Si under controlled conditions. The following management practices were carried out during the experiment from start until harvest. At the start, seeds were soaked in 1 mM $CaSO_4$ and on the 2^{nd} day seeds were sandwiched in foam lined with filter paper. On the 5^{th} day seedlings were exposed to light. On the 6^{th} day seedlings were transferred to half-strength nutrient solution and on the 9^{th} day plants were transferred to a full-strength nutrient solution and also supplied with Si as Na_2SiO_3 neutralized with HCl to pH 7.0 $\pm$0.05.

In both experiments, plants were grown in aerated nutrient solution with the following environmental conditions: temperature 18 ^oC night and 26 ^oC day, humidity 50 % and light intensity 500 µE m^{-2} s^{-1}. The composition of full-strength nutrient solution was as described by Zörb et al. (2004). The concentration of salts in nutrient solution was, in mM, 2.5 $Ca(NO_3)_2$, 0.2 KH_2PO_4, 1.0 K_2SO_4, 0.6 $MgSO_4$, 5.0 $CaCl_2$; in µM, 1.0 H_3BO_3, 2.0 $MnSO_4$, 0.5 $ZnSO_4$, 0.3 $CuSO_4$, 0.005 $(NH_4)_6Mo_7O_{24}$, 200 Fe-EDTA. In the first experiment, only two levels of Si were used (0 mM Control and 3 mM Si) and nutrient solution was renewed after every 3^{rd} day.

Based on the results of the first experiment, a wide range of Si in nutrient solution was tested in seven treatments as follows (0, 0.4, 0.8, 1.2, 1.6, 2.0, and 3.0 mM Si) and also nutrient solution was renewed after every 2nd day. The plants were harvested 21 days after seed soaking and the following parameters were measured in order to see the effect of Si on maize growth: plant height, leaf area, shoot and root fresh weight, shoot and root dry weight.

Stastical Analysis:

Values are means $\pm$ standard error of four replicates. Significant differences were calculated using student's t test. SPSS was performed for multiple comparisons.

Results:

The results of the first experiment in which plants were grown at two different levels of Si showed that application of Si at 3 mM in nutrient solution did not have any significant effect on plant fresh and dry biomass while reduced plant height and leaf area of different leaves was observed (Table 1).

Table 1: Effect of Si application on various plant growth attributes (first experiment). Values are means of four replicates + standard error.

Plant Parts	Fresh weight (g pot^{-1})		Dry weight (g pot^{-1})		Leaf area (cm^2)					
					Leaf No. 5		Leaf No. 6		Leaf No. 7	
	0 mM Si	3 mM Si	0 mM Si	3 mM Si	0 mM Si	3 mM Si	0 mM Si	3 mM Si	0 mM Si	3 mM Si
Young shoot	26.74 +0.58	23.78 +1.26	2.83 +0.68	2.38 +0.18	117.88 +1.57	96.93 +1.11	124.59 +2.28	86.56 +9.41	53.33 +4.60	27.66 +3.59
Old shoot	38.17 +1.68	36.86 +2.34	2.57 +0.122	2.57 +0.16						
Root	23.55 +1.21	22.01 +1.74	1.48 +0.105	1.38 +0.15						

Based on these results, a second experiment was planned in which plants were supplied with a wide range of Si concentrations and more frequent renewal of nutrient solution. The results from this experiment indicate that to some extent Si application increased the growth, while after that, additional Si decreased the growth of maize plants. Application of Si at 0.8 mM and 1.2 mM produced maximum shoot and root biomass with respect to control treatment while further increases in concentration of Si did not follow the increasing trend in shoot and root biomass, as shown in Figure 1. Also, a similar trend was observed in plant height and leaf area of the fully young developed leaves (leaf no. 6 and 7 Figure 2).

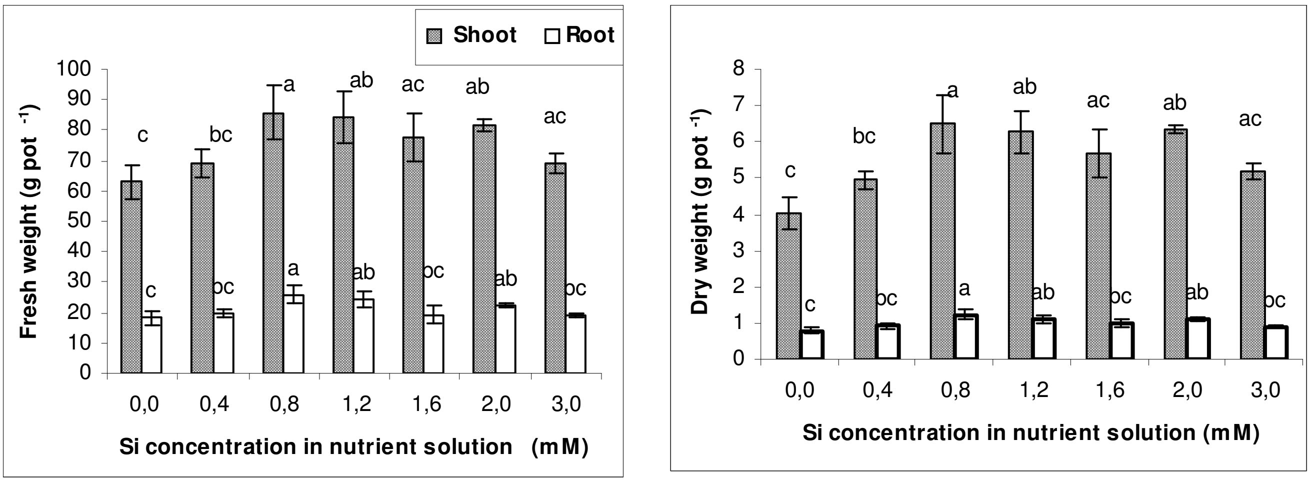

Fig. 1. Plant root and shoot fresh and dry mass with various concentrations of Si in nutrient solution. Values are the means of four replicates + standard error. Columns with different letters indicate significant difference at 5% level of significance.

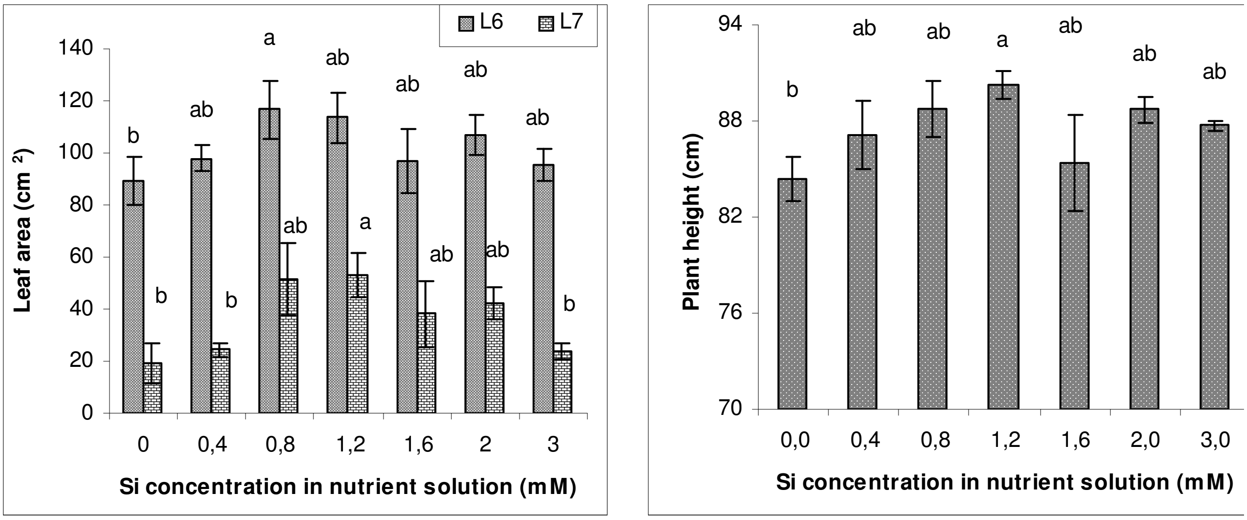

Fig. 2. Leaf area of leaf no. 6 and 7 (denoted by L6 and L7, respectively) and plant height with various concentrations of Si in nutrient solution. Values are the means of four replicates $\pm$ standard error. Columns with different letters indicate significant difference at 5% level of significance.

Conclusion:

In nature plants differ with respect to their response to Si concentration in the growth medium, so it is necessary to optimize the level of Si before detailed investigations. Secondly, Si is a bioactive element and it not only plays a role in plant physiology under stress but also under normal conditions.

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