Agromorphological response of rice (Oryza sativa L.) to foliar application of potassium silicate

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Received: 23. May 2015 / Accepted: 12. October 2015 / Available online: 26 November 2015 / Printed: June 2018

Abstract. A field experiment was conducted in Mobarakeh region, Isfahan, Iran, to investigate the effect of foliar application of silicon (Si) on the yield, as also to investigate some morphoagronomical traits of rice (Oryza sativa L.). The research was designed as a randomized complete block with three replications. Forty-eight-day-old seedlings of rice were sown in plots 3 m × 3 m in size. Foliar application of silicon solution was used in treatments comprising of: Control, 50, 100, 150, 200, and 250 mg l⁻¹ of silicon. Potassium silicate (K₂SiO₃, 20% SiO₂) was used as the source of silicon. The data was recorded according to the standard evaluation system for rice, published by the International Rice Research Institute (IRRI). The data were then subjected to analysis of variance. The results showed that spraying Si on leaves had a significant effect on rice grain yield (GY), 1000-grain weight (GW), number of filled grains (FG), and grain breadth. However, the stem length, panicle length (PL), and grain length were not affected by Si. Compared with the control, the highest increase in GY was obtained at 250 mg l⁻¹ (up to almost 28.2%). The results suggested that there was a significant regression in the GY and Si concentrations. Estimation of the Pearson correlation coefficients among the studied traits revealed that GY was positively correlated with the GW and FG. Also, there were positive significant correlations between the GW and traits of PL and FG. According to the results, the recorded increase in GY, under the impact of foliar silicon, was probably because of the significant increase in FG. Foliar application of Si can be economically and environmentally efficient to increase rice yield and provide enough food for the increasing world population. The results of this research will also be important for research that deals with the enrichment of rice grains, which is of great importance to health.

Keywords: chemical fertilizers, micronutrients, Si concentration, rice growth.

Introduction

The consumption of rice is 110 g per day per person in Iran, which makes Iranians the thirteenth biggest rice consumers (Mazaheri 2009). This crop accumulates the highest rate of silicon (Si), up to 10% of the shoot dry weight. Si has some significant roles to play in crop plants including: (1) reducing water stress by decreasing transpiration, (2) improving light absorbance through affecting leaf structure, (3) increasing plant resistance to pests, diseases, and lodging, by thickening the cell wall and also increasing the vascular bundles (Shimoyama 1958), (4) adjusting nutrient imbalance and the unfavorable effects of high metal concentrations, (5) alleviating salt stress, (6) controlling the harmful effects of radiation, and (7) alleviating the stressful effects of high temperature and freezing. (Epstein 1999, Ma et al. 2001, Ma 2004, Ma & Takahashi 2002).

The silica gel is deposited in the leaf cell wall, stem, and hull epidermal cells, forming double layers of silica-cuticle and silica cellulose (Raven 2003). Si is also present in different cell types, including bulliform, dumbbell, and long and short ones, on the leaf and hull surface. Si deposition, as stated above, results in increased strengthening and rigidity of the cell walls, and hence, enhances plant resistance (Epstein 1994, Epstein 1999, Ma 2003, Ma & Takahashi 2002). Therefore, it is necessary to provide rice with high amounts of Si for its healthy growth and high yield.

From the physiological point of view, unlike the other necessary nutrients such as nitrogen (N), phosphorous (P) and potassium (K), Si is not recognized as an essential nutrient for plant growth and production. However, high amounts of Si are required for the healthy and productive growth of rice (Savant et al. 1997). Si is also the only element that is not harmful to the plant when used in high concentrations, as it is polymerized and is not dissociated at the physiological pH (Ma et al. 2002). There are some reports that the root application of Si may significantly increase rice yield (Epstein 1999, Prychid et al. 2003). However, so far few studies have been performed regarding the application of Si to foliage. Also, most of these studies are related to rice resistance to pests and diseases (Liang et al. 2005).

The current experiment has been performed to investigate the effect of Si on the rice yield. In addition, because of the importance of Si for rice production, nutritionally and economically, and the fact that the studies regarding foliar application of Si have evaluated rice resistance to diseases (Liang et al. 2005) and not rice yield, the hypothesis of this research was on foliar application of Si, which might be an efficient method to increase rice yield. The objectives were: (1) to compare the effects of different Si concentrations on rice growth and yield, and (2) to recommend the proper concentration of foliar Si for rice production.

Materials and Methods

Experimental Site and Plant Material

A field experiment was conducted in the spring and summer of 2012, in the farmers' fields, at the Mobarakeh region of Isfahan province, Iran (Latitude 32° 33′ 47″ N, Longitude 51° 55′ 70″ E, 1718.37 m a.s.l.). To prepare the required seedlings, seeds of the Tarom local variety were sown at 150 kg ha⁻¹ in the greenhouse. Also, the main farm was prepared according to the traditional method applied by the local farmers. Starting on June 12, after a 48-day period, the seedlings were transferred to the main field. After planting the seedlings, urea and ammonium phosphate were applied at 160 and 300 kg ha⁻¹, respectively. The field was irrigated, and weeds, pests, and diseases were controlled, chemically and mechanically. After performing the experimental plan and creating the plots in the field, the Si treatments were sprayed on leaves.

Experimental method

Silicon treatments, including control, 50, 100, 150, 200, and 250 mg l⁻¹...
were sprayed on the rice plants at the stem-producing stage (July 20). Potassium silicate (20% SiO₂) was used as the source of silicon. The experiments were conducted on the basis of a randomized complete block design with three replications. The plots measured 3 x 3 m with a 20 x 20 cm² space for each seedling (average of 250,000 seedlings per hectare).

**Studied traits**

At physiological maturity (September 15) the plants were harvested from a 1 m² space (including 25–28 plants from each plot). After preparing the rice seeds, they were weighed and the seed moisture was determined and accordingly the rice grain yield (GY) per hectare was calculated on the basis of 14% seed moisture. Also, using 10 plant samples from each plot, the panicle length (PL), stem length (SL), number of filled grains (FG), grain breadth (GB), grain length (GL), and the weight of 1000 grains (GW) were determined.

**Statistical analysis**

The data were analyzed using PROC ANOVA of the SAS version 9.1. Mean comparisons were performed using the Least Significant Difference (LSD) method at the 0.05 level of probability. Correlation coefficients were performed by SPSS version 15.0.

**Results**

The physicochemical characteristics of the soil are presented in Table 1, which shows some nutrient amounts in the soil at the beginning of the experiment. Table 2 shows that spraying Si on rice leaves had a significant effect on GY, GW, FG, SL, PL, and GB. However, traits SL, PL, and GL were not affected by Si. Compared with the control, the rice yield increased up to 4.5, 10.8, 13.1, 25.4, and 28.2% in response to the application of Si at concentrations 50, 100, 150, 200, and 250 mg l⁻¹, respectively. The highest amount of GY was obtained at 250 mg l⁻¹ concentration of Si (Table 2). A significant linear regression was found between GY as a dependent variable and Si as an independent variable (GY = 0.005 Si + 4.59, R² = 0.721).

Also, foliar Si had a significant effect on GW. Table 2 shows that at least 100 mg l⁻¹ of foliar Si was needed to gain a significant increase in GW. Moreover, no significant difference was observed in GW under the impact of concentrations 150, 200, and 250 mg l⁻¹ of Si. However, the highest estimated value for GW belonged to 250 mg l⁻¹ of Si, which was equal to an increase of up to 4.6% when compared with the control.

Furthermore, foliar Si had a significant effect on FG. The maximum number of filled grains was achieved at 250 mg l⁻¹ of Si. The corresponding FG values obtained at the studied concentrations of Si were 86.6, 89.87, 92.93, 94.03, 104.20, and 106.20, respectively. On the basis of the results, foliar Si at 200 and 250 mg l⁻¹ concentrations led to an increase of FG up to 20.3 and 22.6%, respectively (Table 2).

Furthermore, foliar Si had a significant negative effect on GB. Unexpectedly, foliar Si decreased the grain breadth. The maximum value of GB belonged to 250 mg l⁻¹ of Si.

Pearson correlation coefficients among the studied traits have been presented in Table 3. According to this Table, GY was positively correlated with GW (0.703, p < 0.01) and FG (0.966, p < 0.01). Also, there were positive significant correla-

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### Table 1. Properties of the soil at the beginning of the experiment.

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Soil texture components (%)</th>
<th>Soil elements (mg kg⁻¹)</th>
<th>O.C. (%)</th>
<th>pH</th>
<th>EC (dS m⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loam-sandy</td>
<td>16.3</td>
<td>32.5</td>
<td>51.2</td>
<td>0.14</td>
<td>8.45</td>
</tr>
<tr>
<td></td>
<td>(Mean±SE)</td>
<td>(Mean±SE)</td>
<td>(Mean±SE)</td>
<td></td>
<td>(Mean±SE)</td>
</tr>
</tbody>
</table>

### Table 2. Mean values of rice traits measured under the influence of different concentrations of foliar potassium silicate.

<table>
<thead>
<tr>
<th>Si (mg l⁻¹)</th>
<th>GY (t ha⁻¹) (Mean±SE)</th>
<th>GW (g) (Mean±SE)</th>
<th>FG (Mean±SE)</th>
<th>SL (cm) (Mean±SE)</th>
<th>PL (cm) (Mean±SE)</th>
<th>GB (mm) (Mean±SE)</th>
<th>GL (mm) (Mean±SE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.64±0.20 d</td>
<td>21.44±0.32 b</td>
<td>86.60±3.67 c</td>
<td>87.10±3.81</td>
<td>22.11±1.41</td>
<td>2.51±0.01 a</td>
<td>6.29±0.04</td>
</tr>
<tr>
<td>50</td>
<td>4.85±0.16 cd</td>
<td>21.59±0.23 b</td>
<td>89.87±2.52 bc</td>
<td>88.80±3.62</td>
<td>21.45±0.84</td>
<td>2.43±0.02 bc</td>
<td>6.19±0.04</td>
</tr>
<tr>
<td>100</td>
<td>5.14±0.32 bc</td>
<td>22.12±0.42 ab</td>
<td>92.93±4.78 bc</td>
<td>89.17±3.21</td>
<td>23.55±2.50</td>
<td>2.43±0.02 b</td>
<td>6.25±0.03</td>
</tr>
<tr>
<td>150</td>
<td>5.25±0.21 b</td>
<td>22.33±0.44 a</td>
<td>94.03±2.33 b</td>
<td>91.80±3.12</td>
<td>22.59±1.45</td>
<td>2.40±0.02 bc</td>
<td>6.24±0.04</td>
</tr>
<tr>
<td>200</td>
<td>5.82±0.08 a</td>
<td>22.33±0.43 a</td>
<td>104.20±0.72 a</td>
<td>90.97±2.34</td>
<td>22.54±1.13</td>
<td>2.42±0.04 bc</td>
<td>6.29±0.01</td>
</tr>
<tr>
<td>250</td>
<td>5.95±0.11 a</td>
<td>22.42±0.44 a</td>
<td>106.20±0.53 a</td>
<td>90.30±3.09</td>
<td>24.03±2.29</td>
<td>2.39±0.01 c</td>
<td>6.23±0.01</td>
</tr>
<tr>
<td>LSD(min)</td>
<td>0.311</td>
<td>0.681</td>
<td>6.846</td>
<td>N.S</td>
<td>N.S</td>
<td>0.045</td>
<td>N.S</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different at 0.05 level of probability level.


### Table 3. Pearson correlation coefficients among rice traits measured under the influence of different concentrations of foliar potassium silicate.

<table>
<thead>
<tr>
<th></th>
<th>GY</th>
<th>GW</th>
<th>SL</th>
<th>PL</th>
<th>FG</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>GW</td>
<td>0.703*</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SL</td>
<td>0.061</td>
<td>0.230</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PL</td>
<td>0.407</td>
<td>0.788*</td>
<td>0.176</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FG</td>
<td>0.966*</td>
<td>0.496*</td>
<td>-0.008</td>
<td>0.208</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>GB</td>
<td>-0.392</td>
<td>-0.256</td>
<td>-0.326</td>
<td>-0.043</td>
<td>-0.389</td>
<td>1</td>
</tr>
<tr>
<td>GL</td>
<td>-0.047</td>
<td>0.165</td>
<td>-0.221</td>
<td>0.192</td>
<td>-0.113</td>
<td>0.084</td>
</tr>
</tbody>
</table>

* and ** means that the correlation is significant at the 5% and 1% level of probability.

tions between GW and traits PL (0.788, p < 0.01) and FG (0.496, p < 0.05). According to the results, the recorded increase in rice yield was likely because of the observed significant increase in the number of filled grains.

Discussion

The demand for rice will rise at more than 60% with the increasing world population, within the next 20 years (Maclean et al. 2002). Hence, addition of a sufficient amount of Si to areas, which are Si-deficient may substantially increase the rice yield (Seebold et al. 2000), as shown in this study. Many studies have demonstrated that Si addition can considerably increase rice resistance against different plant diseases, and hence, increase rice yield (Rodrigues et al. 2000, Seebold Jr et al. 2004, Seebold et al. 2000).

Silicon-treated plants may have higher resistance to diseases because of the formation of papillae, which produce callose and glycosilated phenolic compounds (Rodrigues et al. 2004). Also, according to these scientists, foliar application of Si may enhance plant resistance to diseases through making a physical barrier by Si deposition on the leaf surface, and/or increasing the osmotic potential as a result of silicate addition. Folliar application of Si may not increase the plant systematic acquired resistance compared with the root application of Si.

Si may enhance the activity of peroxidase, polyphenoloxidase, and chitinase in plants infected with diseases (Chérif et al. 1994) resulting in the accumulation of polymerized phenolic compounds (Chérif et al. 1992). Also, it is because of the important involvement of Si in the metabolism of phenolic compounds that lignin biosynthesis of cell walls has been determined (Marschner 1995). Moreover, parameters such as Si (Chérif et al. 1992) and salicylic acid (Lian et al. 2000) are able to increase plant resistance capability (systematic acquired resistance) against biotic and abiotic stresses through the regulation of plant resistance genes.

On the basis of the results of the present study, it seems that an increase in the number of filled grains play an important role in the enhancement of the rice performance. A positive significant correlation between GW and FG confirms this assumption. The increase in FG was possibly because of balanced nutrition, optimal metabolic activities or nullification of the stresses, by silicic application. The outcome was in agreement with the findings of Ahmad et al. (2013) and Mauad et al. (2003). In agreement with the results of this study, Fotokian & Agahi (2014) also reported a positive correlation between GW and FG. However, Li et al. (2002) and Rodrigues et al. (2003) reported that an increase in rice yield through foliar silicon was mainly because of the observed enhanced number of productive tillers and total number of tillers per square meter.

As reported by Ahmad et al. (2013) and Ghanbari-Malidareh (2011) in this study, silicon application significantly affected GW and FG.

The accumulation of Si in the root symplast of rice after 12 hours exposure to 0.5 mM Si was 6.0 mM (Mitani & Ma 2005). This statement is in agreement with the results of this research, as the highest rate of Si (250 mg l⁻¹) resulted in the highest amount of rice yield, which is because of the great capability of rice to accumulate Si. Also, addition of 1000 kg ha⁻¹ of Si increased the yield of upland rice by more than 60% (Seebold et al. 2000).

In conclusion, it may be beneficial for rice farmers, economically and environmentally, to spray Si at 250 mg l⁻¹ at the stem-producing stage. Identifying the new genes responsible for Si uptake through the shoots or roots may greatly help to manage Si efficiently and increase rice yield and grain enrichment. This can be very helpful for the nutrition and health of societies.

References