Effect of silicon addition to different fertilizer on yield of rice (Oryza sativa L.) plants. I- Macro Nutrients by Different Rice Parts

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ABSTRACT

Silicon (Si) is one of most prevalent macro elements, performing an essential function in healing plants in response to environmental stresses.

Two pot experiments were conducted during two successive seasons to study the effect of silicon addition to different fertilizer on the yield and macro nutrients of rice plants. The important results can be summarized in the following:

- The dry matter of roots, shoots and grain yield significantly increased by Si addition to all the used fertilizers.
- The highest values of dry matter of roots, shoots and grains were obtained by using the NPK + Si treatment followed by NP + Si, NK + Si and N + Si in decreasing order.
- Si addition to the different fertilizers decreased the content on N, P, and K in roots of rice plant than those without Si addition.
- On the other hand, N, P and K content and uptake by shoots, and grains increased by Si addition as they compared with those without Si addition.

Key words: Yield, macro nutrient, Si, uptake, fertilizers.

Introduction

Rice is the staple food of about 3 billion people and demand is expected to continue to grow as population increases (Carriger and Vallee, 2007). Globally rice is grown over an area of about 149 million ha with an annual production of 600 million tons (Bernier et al., 2008). Silicon (Si) is the second most abundant element in the earth's crust and soil. It has been considered to be quasi essential element for plant growth (Epstein and Bloom, 2005). Rice is a known silicon accumulator (Takahashi et al., 1990) and the plant is benefiting from Si nutrition (Singh et al., 2005). Consequently, there is a definite need to consider Si as an essential minor element to increase sustained rice productivity (Sudhakar et al., 2006). Also silicon (Si), as a macro element, has a vital role in plants cycles. This element is the eighth most common element in nature and the second most common element found in soil after oxygen. One of the main functions of Si is improving the plants growth and yield especially in stress condition. To achieve plant tolerance. Si promotes plant photosynthesis by favourably exposing leaves to light. On the other hand, the role of the macro element has proven to be in response to different abiotic and biotic stress (Eptein, 2001). Plant growth depends on several elements existing in the soil. These elements can be categorized into beneficial, essential, and toxic groups (Bienert et al., 2008).

Nitrogen is one of the most important plant nutrients and plays a vital role in plant photosynthesis and biomass production and increased the chlorophyll concentration in leaves and thereby higher photosynthetic rate and ultimately plant of photosynthetic available during grain development (Mahzoor et al., 2006). Furthermore nitrogen fertilizer has played an important role in increasing rice yields, and total consumption of N for rice production has increased gradually worldwide (Singh et al., 2012). However, fertilizer N use efficiency of rice is generally low for rice grown in a transplanted culture ranging from 25 to 45% and average about 35% (Dobermann and Cassman, 2002).

Many studies have suggested the positive growth effects of silicon, including increased dry mass and yield, enhanced pollination Korndorfer and Lepsch (2001) and most commonly increased
disease resistance Rodrigues et al., (2004). Also, Malav et al., (2015) reported that the applied Si up to 200mg kg\(^{-1}\) soil significantly increased higher grain and straw yield over control. Also, Yogendra et al., (2014) revealed that higher grain and straw yield was noticed with application of calcium silicate at 2 t ha\(^{-1}\) along with application of N at 100 kg ha\(^{-1}\) recommended dose of fertilizer (RDF), in this concern Malav et al., (2015) reported that the interaction affect of soil and Si levels was significant for P, K, S and Na contents of rice grain and straw. Also silicon reduced leaching of phosphorous (P) and potassium (K) (Sadgrove, 2006). The content of silica in plants is equivalent to or more than the major nutrients N, P, K supplied through fertilizers. Silicon affects plant growth, crop quality, stimulation of photosynthesis, reduction of transpiration and enhancement of plant resistance to a biotic stresses (Lu and Cao, 2001, Raven, 2003 and Savvas et al., 2002). Also, Ghanbari et al., (2011) concluded that if the nitrogen application was high and water supplied was available we could have silicon application until increase grain yield of rice. Silicon was increased N, P and K concentrations in shoots and grains of rice Chen et al., (2002) and Whet Hanafy Ahmed et al., (2008). Nutrients concentration and uptake were affected significantly with foliar treatment (silicate and sulphate solutions) Abou-Baker et al., (2011).

Sufficient supply of Si to rice is effective in producing low protein rice and reduced activity of micro-organisms (such as the critical nitrification of Ammonium-N to nitrate). (Mason et al., 1994).

This work designed to investigate the effect of silicate to different plant fertilizer on yield and micronutrients status of rice.

Materials and Methods:

Two pot experiments were conducted during two successive seasons to study the effect of silicon addition on the yield and macro nutrients by different rice parts. Soil samples at a depth from (0-30 cm) from the surface layer of clay loam soil, has a 26.7% sand, 39.6% silt and 33.7% clay, pots contain air dried soil were arranged in a complete randomize design.

Saturation capacity 27.08, pH 8.0, CaCO\(_3\) 4.0% organic matter 1.6%, available N 18.5 ppm, available P 2.5 ppm, available K 280 ppm, and available Zn 0.77 ppm.

The experiment included of four fertilizer treatments: a) Nitrogen alone (0.8 gm/pot (Urea), b) Nitrogen + Phosphorus (0.8 gm/Pot (Urea + 0.8 gm/pot superphosphate), c) Nitrogen + Potassium (0.8 gm/pot Urea + 0.8 gm/pot Potassium Sulphate) and d) Nitrogen + Phosphorus + Potassium (0.8 gm/pot Urea + 0.8 gm/pot Superphosphate + 0.8 gm/pot Potassium Sulphate).

Silicon was added to four pots at a rate of 1.87 gm Si/pot in the form of sodium meta silicate (Na\(_2\)SiO\(_3\).5H\(_2\)O) with irrigation water. The plants of the four other pots of each treatment were not supplied with silicon. Throughout the growth period which lasted 140 days, the pots received sufficient distilled water for flooding.

Total silica, nitrogen phosphorus and potassium were determined and chemically analyzed for N, P and K (determination was carried out as described by Jackson (1982) and Cottenie (1982) and silica was determined according to Wolf (1982) in the different parts of the rice plant (roots, shoots and grains).

Statistical analysis were performed using the least significant difference (L.S.D.) method at 1% and 5% according to Stell and Torrie (1980).

Results and Discussion:

Yield parameters:

Data in Fig (1) indicated that dry matter of roots, shoots and grain yield of rice plants were affected by the application of sodium meta silicate to the different fertilizers when compared without Si addition, these results confirm by Abou-Baker et al., (2012) who found that the highest basic branch, pods numbers, biological yield, Stover yield and plant high were obtained from potassium silicate application to bean plants. Therefore, the results shown the highest dry matter of roots, shoots and grain yield of rice plant was obtained by adding Si to the NPK fertilizer treatment followed by NP + Si, NK + Si and N + Si in decreasing order, application of sodium meta silicate to the NPK fertilizer
treatment increased the dry matter of roots (29.48 g/pot) shoots (48.86 g/pot) and (41.61 gm/pot) for grain yield at first season. These results attributed to the highest grain yield response to, Si application may be due to increased leaf erectness, decreased mutual shading caused by dense planting and high N application (Yogendra et al., 2014 and Prakash et al., 2002a and 2010b).

Fig. 1: Effect of silicon application on dry weight production (gm/pot) of different parts of rice plant.
Furthermore, the NP + Si treatment gave higher roots, shoots and grains dry matter as they compared with those obtained by using NK + Si or N+Si treatment. Confirm these results were confirmed by Ghanbari et al., (2011) who indicated that silicon application to rice increased number of filled spikelet, grain, straw yield. The positive effect of NK + Si on increasing growth and yield of rice plants if compared with those obtained by using N+Si treatment these results may be attributed that Si plays an active role in the biochemical processes of plant and also may plays an important role in the intercellular synthesis of organic compounds Matichenkov and Bocharnikova (2008).

The effect of Si addition on the growth and grain yield of rice plants are in a good agreement with those previously reported by Hellal et al., (2012a) and Saeed et al., (2009) found that added 180 kg ha⁻¹ of silicon increased dry matter, yield, nitrogen and phosphate levels in the grain and straw of rice. This suggests that silicon in lesser amounts can be beneficial in increasing grain yield and growth of cereal crops.

**Chemical composition:**

**Effect on macronutrients:**

**Nitrogen:**

Data presented in Table (1) and Fig. (2) indicate that addition of Si as sodium meta silicate to the different fertilizer treatments significantly decreased N content in the roots of rice plants grown for two seasons. The significantly lower content of N in the rice roots may be explained by its vigorous growth, which diluted the N in the tissue as explained by Osuna-Canizalez et al. (1991). On the other hand, data revealed that Si application significantly increased N content in shoots and grains of rice plants Abou-Baker et al., (2011), though not significant for the shoots of NK treatment. These results were true for the two growing seasons. These results were confirmed by Hellal et al., (2012b) and Ma and Takahashi (1991).

Data presented in Table (1) and illustrated in Fig. (2) show that N uptake under all treatments was highly significantly increase in roots, shoots and grains was obtained when Si was added. However, N application along with silicon recorded higher N content than recommended dose of fertilizer (RDF) of N alone. This might be due to the possibility of dilution effect with Si fertilized with less application of N. Due to a synergistic effect, the application of Si has the potential to raise the optimum N rate, thus enhancing productivity of existing lowland rice fields (HO et al., 1980). The highest increase of N content and uptake were obtained by NPK + Si treatment. The maximum N content and uptake in grain (1.60% and 665.76 mg/pot) for NPK + Si in first season while the maximum N content and uptake (1.69% and 587.28 mg/pot) in second season. This stimulating effect of Si on N content may be due to the pH rise by sodium meta silicate application which stimulates ammonification. These results attributed to the Si accumulation in the leaf blades and stems of rice decreases the mutual shading and sensitivity of plants to diseases caused by high nitrogen availability. The occurrence of blast disease considerably decreased in the field after Si treatment. Particularly when over dosage of N happened in soil with dense planting (Ohyama 1985). These results are in a good agreement with those obtained by Singh et al., (2006) who stated that silicon increased nitrogen and phosphate levels in the grain and straw of rice, suggests that silicon in lesser amounts can be beneficial in increasing grain yield and growth of cereal crops. In this connection, also Hwang et al., (2008) reported that higher chlorophyll contents.

Data also revealed that N content was higher by using NP + Si treatment than NK + Si. These increases were significantly only in roots and shoots of rice plant grown at the second season.

The N + Si treatment significantly increased N content values in shoots and grains than the NK + Si treatment, which was true for the two growing seasons. On the other hand, data in Table (1) reveal no significant differences between NK + Si and N + Si treatments on N uptake by roots, shoots and grains of rice plant, except in shoots of the second season which was highly significant in N + Si treatment compared with NK + Si. Furthermore, data show that NP + Si treatment significantly increased N uptake by roots, shoots and grains as compared with the NK + Si treatment. These increased the uptake of nitrogen resulted application of Si with N fertilizer may be attributed to lead erectness which facilitated better penetration of sunlight leading to higher photosynthetic activity of
plant and higher production of carbohydrates (Korndorfer et al., 2001).

Abou-Baker et al., (2011) confirmed that nitrogen concentration and uptake value were affected significantly with foliar treatments (silicate) of agriculture whereas it fallow the order, KSiO$_4$ > MgSiO$_4$ > MgSO$_4$ > content.

Also Singh et al., (2006) and Savvas et al., (2002) those found that Si-rich amendments are recommended for the reduction in leaching of nitrogen, phosphorus and potassium based fertilizers. Silicon increased nitrogen and phosphate levels in the grain and straw of rice, suggests that silicon in lesser amounts can be beneficial in increasing grain yield and growth of cereal crop. Finally Yogendra et al., (2013) reported a significant increase in the grain yield of wetland rice and nitrogen use efficiency was noticed with the application of calcium silicate at 2t ha$^{-1}$. in Si treatments resulted in photosynthetic activity improvement and higher productivity.

Table 1: Effect of silicon application on N content and uptake by different parts of rice plants grown for two seasons.

<table>
<thead>
<tr>
<th>Fertilizer treatments</th>
<th>1st Season</th>
<th></th>
<th>2nd Season</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Roots</td>
<td>Shoots</td>
<td>Grains</td>
<td>Roots</td>
<td>Shoots</td>
</tr>
<tr>
<td></td>
<td>-Si</td>
<td>+Si</td>
<td>-Si</td>
<td>+Si</td>
<td>-Si</td>
</tr>
<tr>
<td>N</td>
<td>0.75</td>
<td>0.67</td>
<td>0.70</td>
<td>0.74</td>
<td>1.32</td>
</tr>
<tr>
<td>NK</td>
<td>0.67</td>
<td>0.65</td>
<td>0.67</td>
<td>0.69</td>
<td>1.30</td>
</tr>
<tr>
<td>NP</td>
<td>0.72</td>
<td>0.67</td>
<td>0.56</td>
<td>0.70</td>
<td>1.23</td>
</tr>
<tr>
<td>NPK</td>
<td>0.80</td>
<td>0.73</td>
<td>0.49</td>
<td>0.76</td>
<td>1.12</td>
</tr>
</tbody>
</table>

L.S.D. at Level

| 5% | 0.03 | 0.04 | 0.03 | 0.03 | 0.04 | 0.05 |
| 1% | 0.04 | 0.05 | 0.04 | 0.04 | 0.05 | 0.07 |

N uptake (mg / pot)

| N       | 146.70 | 164.69 | 230.58 | 313.83 | 363.53 | 543.85 | 133.30 | 151.40 | 235.47 | 316.30 | 296.00 | 400.00 |
| NK      | 136.08 | 167.80 | 223.18 | 304.50 | 373.36 | 537.28 | 122.85 | 153.90 | 218.00 | 283.80 | 393.37 |
| NP      | 151.20 | 181.44 | 189.22 | 326.90 | 368.14 | 573.93 | 142.80 | 176.00 | 289.04 | 277.20 | 433.10 |
| NPK     | 178.08 | 215.20 | 169.44 | 371.34 | 344.29 | 665.76 | 162.43 | 202.11 | 245.28 | 403.47 | 362.10 | 587.28 |

L.S.D. at Level

| 5% | 14.59 | 16.99 | 44.82 | 7.76 | 16.02 | 23.19 |
| 1% | 19.85 | 23.12 | 61.01 | 10.57 | 21.81 | 31.56 |

- Si without silicon addition. + Si with silicon addition.
**Fig. 2:** Effect of silicon application on N uptake (mg/pot) by different parts of rice plant.
Phosphorus:

The effect of sodium meta silicate on P content and uptake by different parts of rice plants grown for two seasons is presented in Table (2) and illustrated in Fig. (3). Phosphorus content in rice roots significantly decreased in all fertilizer treatments containing silicon (+ Si), compared with these without silicon (- Si). On the other hand, the phosphorus uptake by rice roots increased by all the fertilizer treatments with Si addition as compared without Si. However, these increases did not reach the significance level of 5%. These results were true for both seasons.

The decreasing trend of P content in roots as a result of Si addition may be due to the high amounts of Si content in the roots (Table 2), which may partial by substitute for phosphorus. Although the partial substitution of Si for P in physiological processes is doubtfull, an interaction between Si and P in plants may occur Hinman and Lindstrom (1996). In this connection (Kabata-Pendias 2001), suggested that silicate and phosphate ion compete for sites on mineral soil particles. These results a good agreement with those obtained by Lux et al., (2003), who stated that silicon deposited on the roots and/or Si induced decrease of transpiration may be responsible for the decreased uptake of P when the P concentration in the medium is high. Si has been found to be deposited in the endodermal cells of roots in many plant species.

Table 2: Effect of silicon application on P content and uptake by different parts of rice plants grown for two seasons.

<table>
<thead>
<tr>
<th>Fertilizer treatments</th>
<th>1st Season</th>
<th>2nd Season</th>
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<tbody>
<tr>
<td></td>
<td>Roots</td>
<td>Shoots</td>
</tr>
<tr>
<td>-Si +Si</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>0.18</td>
<td>0.16</td>
</tr>
<tr>
<td>NK</td>
<td>0.19</td>
<td>0.17</td>
</tr>
<tr>
<td>NP</td>
<td>0.22</td>
<td>0.19</td>
</tr>
<tr>
<td>NPK</td>
<td>0.24</td>
<td>0.20</td>
</tr>
</tbody>
</table>

P content (%)

L.S.D. at Level
5% 0.02 0.02 0.03 0.03 0.02 0.016 0.03
1% 0.03 0.03 0.03 0.03 0.023 0.04

P uptake (mg / pot)

L.S.D. at Level
5% 6.23 8.64 13.42 4.21 5.70 11.02
1% 8.48 11.76 18.26 5.73 7.76 14.99

- Si Without silicon addition. + Si With silicon addition.
Fig. 3: Effect of silicon application on P uptake (mg/pot) by different parts of rice plant.

Nagaoka (1998) and Rasheed et al., (2010) confirmed these results to reported that the larger beneficial effect of Si on plant growth under P deficiency stress may be attributed to the enhanced
availability of internal P through the decrease of excess Fe and Mn uptake. This is supported by the fact that Si supply increased the rate of P translocation to that panicles in rice.

Results given in Table (2) and illustrated in Fig. (3) clearly show that all treatments involving P applications (NP and NPK treatments) resulted in remarkable increase in P content in the different rice parts as compared with those without P addition (N and NK treatments). The mentioned trends were also true for the P uptake for both seasons.

Data also revealed high P content and uptake in grains of rice plants fertilized with NPK + Si followed by NP + Si, NK + Si and N + Si in decreasing order. Generally, the highest uptake of P value in grain was observed when applied of NPK + Si fertilizer treatment, these values were (153.96 mg/pot) at the first season and (170.28 mg/pot) at the second season, while the lowest value of P uptake when addition of N fertilizer alone (without Si) these values in grain were (77.11 mg/pot) at first season and (76.00 mg/pot) at second season. Add silicon increased the translocation rate of absorbed phosphorus to the grain, especially at the phosphorus deficient level (Okuda and Takahashi 1962b). Also, Lima (2011) showed that, Si application via soil led to a reduction in P fixation and an increase in P uptake by the plant.

On the other hand, Matichenkov et al., (1997) stated that plant can use only about 30% of applied phosphate fertilizer, if leaching is low. The mixture of active Si with P fertilizer can increase the efficiency of P fertilization by 40-60%. Furthermore, Marschner et al. (1990) found in nutrient culture experiments, that Si had no direct effect on P uptake or translocation to the roots. It is suggested that Si could act as beneficial element under conditions of nutrient imbalance.

Finally, the beneficial effect of Si may be ascribed to the isomorphus replacement of the phosphate ions with the silicate ions, in addition to stimulating desorption of phosphate anions from soluble phosphates of calcium, aluminium, iron and magnesium, silica fertilizers also have a good adsorption capacity and decrease P leaching by 40-70% Matichenkov and Bocharkhikova (2001). It is argued that Si promotes growth by improving the imbalances of nutrients especially P.

**Potassium:**

Table (3) show that the effect of Si addition to the fertilizer treatments on K content in different parts of rice plant. Data reveal that K content in roots of rice plants grown for the two seasons. Potassium content in the roots is highly significant decreased with Si addition in roots which may decrease K content. These results of K content in roots may be due to the increase of Mg content. The decrease of K content in roots may be also due to the Na ions of the sodium meta silicate applied which competed the k ions in adsorbing on the root surface of rice plant. The highest uptake in grain was obtained by using NPK + Si treatment, these values were (0.73% and 303.75 mg/pot) in the first season and (0.78% and 271.05 mg/pot) in the second season.

These results are in harmony with those reported by Kaya et al., (2006), they found that addition of Si may increase concentration of Ca in plant tissue and hence restore membrane integrity in water-stressed plants. Disruption of ion homeostasis may result from reduced K+ concentration in water stressed plants. Data also, presented in Table (3) show that K content in shoots and grains of rice plant significantly increased by addition of sodium meta silicate although the increase did not reach the significance level of 5% for shoots (N and NP treatments at the first season). In this connection also, Guevel et al., (2007) found that Si interaction with potassium varies, depending on the anion in the fertilizer. Also, Tahir et al., (2006) reported that silicon concentration was positively correlated with K+ concentration in shoots and significantly (P < 0.01) increased K+ concentration and uptake in leaves of wheat genotypes under normal and in saline environments. These result are in accordance with those obtained by Liang et al., (1996) and Liang, (1999), whereas they found that silicon could increase K absorption, uptake and transport in barley plants.

The results in this study are in good agreement with those obtained by Rasheed et al., (2010) confirmed the potassium concentration declined significantly by the order. Control> Si+SA> Si. This finding may be refer to low values of leaves dry weight in control treatment render the K more concentrated. Also, K has a significant improving plant water status and mitigating the toxic effects of Na. Also, Tahir (2006) stated that the silicon concentration was positively correlated with K concentration in shoots.

Data in Table (3) and Fig. (4) show that K uptake by the different parts of rice plant (roots, shoots and grains) significantly increased by Si addition to all the used fertilizer treatments. This
effect, however, was not significant for roots (N treatment at the first season). These results were true for the both growing seasons. Sousa et al., (2010) observed an increase in the yield of corn foliarly applied with potassium silicate; however, the results were attributed to the joint effect of Si and K in the plant, not Si alone.

Generally, the data show that the highest K uptake was obtained by using NPK + Si treatment followed by NP + Si, NK + Si and N + Si in decreasing order.

Table 3: Effect of silicon application on K content and uptake by different parts of rice plants grown for two seasons.

<table>
<thead>
<tr>
<th>Fertilizers treatment</th>
<th>1st Season</th>
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<th>2nd Season</th>
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<tbody>
<tr>
<td></td>
<td>Roots</td>
<td>Shoots</td>
<td>Grains</td>
<td>Roots</td>
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<tr>
<td>-Si</td>
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<tr>
<td>+Si</td>
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<tr>
<td>N</td>
<td>0.72</td>
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<tr>
<td>NK</td>
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<td>0.72</td>
<td>1.90</td>
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<tr>
<td>NP</td>
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<tr>
<td>NPK</td>
<td>0.86</td>
<td>0.80</td>
<td>2.05</td>
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L.S.D. at Level

<table>
<thead>
<tr>
<th></th>
<th>5%</th>
<th>1%</th>
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<tbody>
<tr>
<td>K content (%)</td>
<td>0.03</td>
<td>0.05</td>
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<tr>
<td>K uptake (mg / pot)</td>
<td>0.26</td>
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<td></td>
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<td>0.04</td>
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- Si Without silicon addition. + Si With silicon addition.
Fig. 4: Effect of silicon application on K uptake (mg/pot) by different parts of rice plant.
Conclusion

Silicates soil amendments provide effective and efficient means to correct a number of soil chemical imbalances, nutrient deficiencies and toxicity issue. By far, silicon's greatest contribution to a successful fall fertilization program is that it improves, the availability of nitrogen, phosphorus, potassium and other nutrients required for a balanced nutrient fertilizer program, even when supplemented with fertilizers, can fail to reach the plant as they move through the soil profile.

References


