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Research Article

Mitigation of Salinity Stress in Rice through Zinc Silicate Application

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Abstract | Pakistan is an agricultural country with massive natural resources. Rice is among few of the vital crops in Pakistan in terms of production, consumption, area under growth and export. Silicon (Si) is ranked second by its presence in soil. Si has not yet been classified as a essential nutrient for plants; although it has shown to be beneficial for plant development. Crop production is seriously affected by salinity worldwide. This research was performed in the research zone of Department of Soil and Environmental Sciences during the summer, 2018 in College of Agriculture, University of Sargodha, Sargodha, Pakistan. In the present study growth response of rice under normal and saline soil conditions was checked using Randomized Complete Block Design (RCBD) under divided plot arrangements with nine treatments and three replications was used. Rice plants were grown in plots having normal soil (EC = 2.32 dS/m) and salty soil (4.93 dS/m). Si as phosphate industry waste was applied @ 0, 50 and 100 µg Si/g soil. Results showed that application of Si reduced the adverse impact of salinity and significantly enhanced the growth of rice plant. Maximum height of rice plant (106 cm), fertile tillers number per spike (6), 1000-grain weight (21.76 g), shoot fresh biomass (25.62 g) and shoot dry matter (12.86 g) were found under saline environment when maximum concentration of Si was applied i.e. 100 µg Si/g and least values were obtained when no Si was applied. Thus, application of Si as higher concentration (100 µg Si/g soil) proved superior to mitigate harmful effects of salts on rice plants.

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Keywords | Rice, Silicon, Salt affected soil, Growth parameters, Normal soil

Introduction

Rice (*Oryza sativa* L.) is widely cultivated crop throughout the world. Almost 90% rice is cultivated in Asia; of which Pakistan contributes to 18% (Lou *et al*., 2012). Rice is an important grain crop in Pakistan being used by huge population. It has great potential in terms of yield but at present average yield is quite lower than potential. Numerous causes contributing to this yield reduction include different types of stresses (including salinity), nutritional insufficiencies and poor management practices. Rice is sensitive to higher than normal salt contents in growth media. Growth of rice plant and all growth related parameters suffered negatively due to salt contents (Hussain *et al*., 2017).

Silicon (Si) is ranked second by its presence in soil.

Plants are categorized into 3 types on basis of Si, non-accumulating, intermediate and accumulating plant types based on their ability to absorb and accumulate Si (Broadley *et al*., 2012). Even though, Si has not yet been classified as an essential nutrient for plants, it has shown to be useful for plant development, particularly the plants of Gramineae family (Hajiboland, 2012). Si in the middle of growth mitigates the effects of several environmental factors such as salinity, chilling, deficiency of water, ultraviolet radiation, freezing and metallic toxicity (Zhu and Gong, 2014). A number of studies has revealed Si functions in mitigating salt stress in Si accumulation types such as rice (Gong *et al*., 2006), barley (Liang *et al*., 1996), zucchini (Savvas *et al*., 2009) as well as in some non-cumulative species such as tomatoes (Al-aghabary *et al*., 2005), tobacco (Hajiboland, 2012), canola (Hashemi *et al*., 2010).

Silicon (Si) plays a significant role in hull development in rice and has an impact on quality of grain (Sawant *et al*., 1997). Silicon deposited in leaf blade promoted photosynthesis by decreasing water stress, enhancing transmission of light, type of light received and silicon set down in the husk increase percent filled spikelets by decreasing excessive loss of water (Maas and Grattan, 1999). The hulls of poor-quality and milky-white grains are usually low in silicon amount, which is directly proportional to the concentration of silicon in the rice straw (Hussain *et al*., 2017).

It is claimed that there are different mechanisms responsible in such improved effects of silicon under salt pressure such as the stimulation of antioxidant defences and improved plant's water uptake capacity and nutrients present in soil (Corrie and Perry, 2007). Under salt stress, Si is said to reduce Na^+ absorption but increase K^+: Na^+, which reduces the effect of ion toxicity in various varieties of plant like rice (Yeo *et al*., 1999) and barley. Another mechanism to improve salt stress by Si is by detecting that Si-facilitated Mn^{2+} (Rogalla and Römheld, 2002) and Al^{3+} (Wang *et al*., 2004) are toxic agents of the cell wall binding. In the presence of Si, Mn^{2+} is more strongly attached to the cell wall to reduce the concentration of Mn^{2+} in symplast (Rogalla and Römheld, 2002).

Silicon fortifies the plant, defends plants from pests, enhances crop yield and quality, upsurges plant nourishment and inhibits toxicity of heavy metals in acidic soils. Plants differ greatly in their ability to accumulate silicon. Because of the continued and intensive cultivation of cereal crops such as rice, the soil concentration of Si is reduced which could be the reason of reduced rice yields (Mali *et al*., 2008). Chemical substances and organic sources of Silicon can also be used as fertilizers of silicon. Therefore, it will be necessary to provide a continuous amount of this particular ingredient for the healthy development and productivity of plants during all stages of development.

Salinity decreases development of rice plantlets that mount up excessive extent of Na and Cl ions in the buds. To assess how silicon reduced the flow of bypass and ionic absorptions in xylem sap in rice, Gong *et al*. (2006) conducted a trial by growing seedlings under the stress of sodium chloride. They found that salt lowers (50mM NaCl) the growth of shoots and roots. But addition of silicate to salt solution has enhanced development of the buds without affecting the root. Improved sprout development by adding silicates is associated to lower Na levels in buds. The rate of gross transfer of Sodium from roots of the bud (stated as unit of root mass) is also declined by addition of silicate. However, the effect of silicate on total transfer of K was none. Moreover, plants affected by saline-stress showed that transpiration was not reduced by silicate; instead it was enhanced in seedlings previously processed with silicate for seven days before salt processing, suggesting the following: decrease in sodium absorption by silicates was not simply by restricting the flow of volume to bud from the root. Results indicated that the deposition of silicon in the exodermis and the subcutaneous has lowered the absorption of sodium in rice seedlings under the pressure of sodium chloride by reducing the transfer of apo-plastic through the root.

Zhu and Gong (2014) also documented that soil salinity and dehydration are key non-biogenic factors that limit crop development and yield worldwide. Soil salinity and dehydration actually disturb ionic balance and cellular osmosis. Although Si is normally considered unnecessary for plant development and evolution, only the Si absorption of plants can relieve both biological and non-biological stress. Thus, the use of silicon can improve crop yield under intense climatic situations and soil states. Numerous reports studied the advantages of applying silicon to crop development, but silicon mechanisms have not been analytically reviewed. Literature documented following mechanisms about absorption, transfer and accumulation of silicon in plants and how it reduces salinity poisonousness and dehydration stress: (1) Passive and active Si absorption both might occur in plants; (2) Although some silicon vectors have been identified in plants, more silicon vectors remain unidentified and the transportation process remain a little vague. (3) Silicon-tolerance mechanisms of salinity and dehydration have been widely examined at the physical and biochemical levels. Physical features consists of growing water absorption by roots, keeping nutrients stability, reducing loss of water from leaves, and increasing rate of photosynthesis. The biochemical aspects include that silicon might advance antioxidant defence by heightening the function of antioxidant enzymes and non-enzymatic antioxidant content; Si might also help in osmotic modification and raise the activity of the photochemical enzyme and (4) Si can adjust the levels of internal plant hormones under intense situations, while the involvement of silicon in signalling and adjustment of gene expression associated with improved endurance and tolerance remains to be discovered.

Therefore, the present research trail was executed in order to justify the impact of exogenous application of Silicon on the growth of rice and to estimate the combined effect of exogenous Silicon application on salinity in root zone and on the growth and development of rice crop.

Materials and Methods

The research was performed in the research area of Department of Soil and Environmental Sciences during the summer, 2018 in College of Agriculture, University of Sargodha, Sargodha, Pakistan. In the present study growth behaviour of rice variety Super Basmati was performed on the normal and saline field. The research was carried out in Randomized Complete Block Design (RCBD) under divided plot arrangements through nine treatments and each replicated three times. The net plot dimensions were 1m×1m having strips spacing of 75 cm and distance between each plant was 25cm. Rice were established in plots with normal soil (EC= 2.32 dS/m) and salt affected soil (4.93 dS/m). Si as phosphate industry waste was applied @ T_1 = 0, T_2 = 50 and T_3 = 100 µg Si/g soil. Before propagating and after reaping of the harvest, soil analysis was done. The soil sample was collected at the deepness of 0-30 cm by using dirt auger. Mud samples were taken from every plot and were prepped for laboratory examination. The procedures described in handbook 60 of U.S Laboratory Staff (1954) were the inspiration for lab analysis. Procedures apart from these are specified distinctly. Samples of mud dried out in oven were utilized for all determination. Various physio-chemical traits of soil before cultivation are revealed in Table 1. Data of following constraints were noted using their accepted techniques: The data was noted at the time of development for various plant traits including height of plant, length of a panicle, No. of fertile tillers, 1000-grain, shoot fresh weight and shoot dry weight was calculated using standard protocols.

Table 1: *Soil physio-chemical characteristics before crop sowing.*

Characteristics	Unit	Normal Soil	Saline Soil
EC	dS/m	2.32	4.93
Soil pH	-	7.9	8.62
Organic matter	%	0.5	0.3
Total Nitrogen	%	0.04	0.02
Available P	ppm	7.75	5.6
Extractable K	ppm	130.5	110.5
Available Si	(mg/kg soil)	30	25
Total Si	(mg/kg soil)	229	205

The noted data were statistically analysed by using statistix 8.1 analysis of variance (ANOVA) procedure and significant of treatments means were compared using Tukey's (HSD) test at 5% probability level (Steel *et al*., 1997).

Results and Discussion

Plant height (cm)

Regarding plant height of rice, among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest plant height (106 cm) and lowest plant height (98 cm) was observed where no silicon (0 µg Si/g) was applied when rice was grown under salt affected soil conditions (Figure 1). Under normal conditions, the maximum plant height (109 cm) was observed with 100 µg Si/g under normal condition. Whereas, the lowest plant height (100 cm) of rice was recorded with 0 µg Si/g under salt affected soil. Hence, silicon deprived treatment was not good and silicon accumulative treatments are very good for crop and has shown great response even in salt affected condition. Results of this study were in line with the experimental outcomes of Rohanipoor et al. (2013) depicting that the plant height of plants was considerably reduced by salinity but it was also increased by applying Si. While Ibrahim et al. (2016) also reported that heights of plants were increased through the Si application.

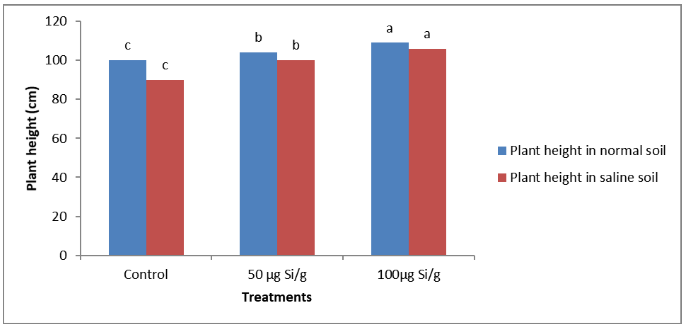

Figure 1: *Impact of various silicon concentrations on plant height (cm/plant) of rice plants under normal and salt affected soils.*

Number of fertile tillers per plant

It is apparent from the data shown in Figure 2 that various concentrations of silicon have varying impacts on the number of fertile tillers of rice crop. In rice crop under normal soil, maximum number of fertile tillers (08) was noticed with 100 µg Si/g silicon concentration under normal conditions and minimum number of fertile tillers (04) was recorded with 0 µg Si/g silicon concentrations. However, among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest number of fertile tillers (06) and lowest number of fertile tillers (02) was observed where no silicon (0 µg Si/g) was applied. Similarly, it was also indicated that silicon deprived treatments performed poor and silicon acquisitive treatments are good for crop and has shown great response even in salt affected condition. Parallel outcomes were also indicated by Ahmed et al. (2007) who revealed that foliar application of silicon and boron pointedly affect the number of fertile tillers in wheat and highest number of fertile tillers were achieved with silicon and boron use under saline conditions.

1000-grain weight (g)

Among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest 1000-grain weight (22.17 g) while the lowest 1000-grain weight (21.33 g) was observed where no silicon (0 µg Si/g) was applied under normal soil. Under salt affected conditions, the maximum 1000-grain weight (21.76 g cm) was noted with 100 µg Si/g under normal condition (Figure 3). Whereas, the lowest 1000-grain weight (18.1 g) of rice was recorded with 0 µg Si/g under salt affected soil. It was shown that silicon deprived treatment performed poor and silicon accumulative treatments are very good for crop and has shown great response even in salt affected condition. Ibrahim et al. (2016) revealed such outcomes in wheat crop regarding applying Si amended salinity stress and augmented biomass, 1000 grain weight, yield, nutrient extent. Further, application of silicon amplified Si levels in wheat straw and it was proportionate to the increase in silicon amended growth medium.

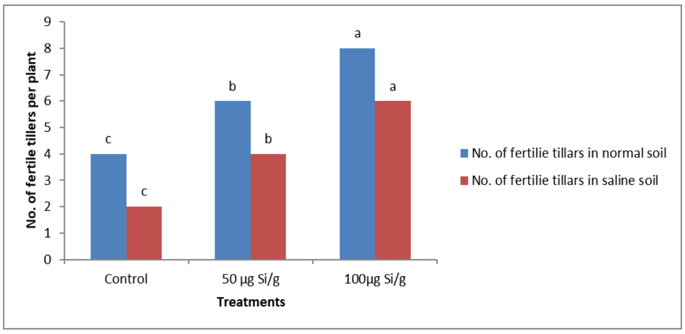

Figure 2: *Impact of various silicon concentrations on No. of fertile tillers of rice plants under normal and salt affected soils.*

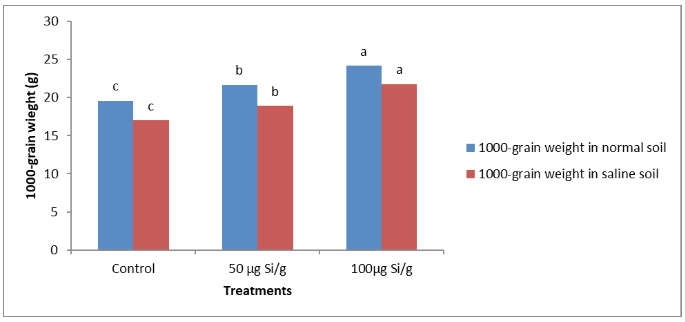

Figure 3: *Impact of various silicon concentrations on 1000-grain weight (g) of rice plants under normal and salt affected soils.*

Shoot fresh biomass (g/plant)

Maximum shoot fresh biomass (35.74 g) was noticed with 100 µg Si/g silicon concentration under normal conditions and minimum shoot fresh biomass (21.29 g) was documented with controlled silicon concentrations under salt affected soil conditions (Figure 4). However, among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest shoot fresh biomass (35.74 g) and lowest shoot fresh biomass (21.29 g) was observed where no silicon (0 µg Si/g) was applied. After that, it can be concluded that silicon destitute treatment performed poor and silicon acquisitive treatments are good for crop and has shown great response even in salt affected condition. Hajiboland (2012) also concluded that Si supplementation resulted in higher shoot and root fresh biomass in the control plants of rice while a bit of such effect was observed in the salt-stressed ones.

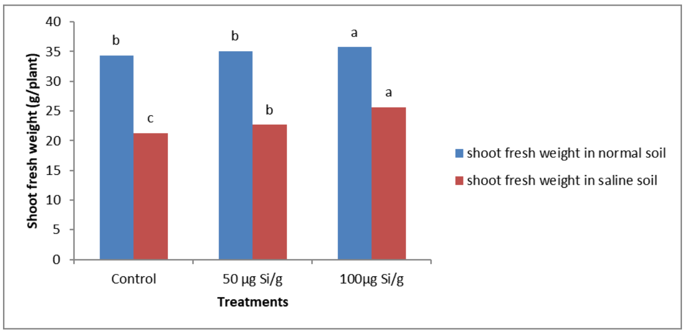

Figure 4: *Impact of various silicon concentrations on shoot fresh weight (g/ plant) of rice plants under normal and salt affected soils.*

Shoot dry matter (g/plant)

Regarding shoot dry matter of rice, among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest shoot dry matter (14.35 g) and lowest shoot dry matter (8.71 g) was observed where no silicon (0 µg Si/g) was applied (Figure 5). Under normal and salt affected conditions, the maximum shoot dry matter (14.35 g) was noted with 100 µg Si/g under normal condition. However, the lowest shoot dry matter (8.71 g) of rice was recorded with 0 µg Si/g under salt affected soil. Hence, silicon deprived treatment performed poor and silicon accumulative treatments are very good for crop and has shown great response even in salt affected condition. Ahmad *et al.* (2007) also stated similar outcome, which indicated that application of silicon augmented dry matter production of wheat at all soil types and water contents levels. Dry matter reduction was expressively increased in plants when silicon was applied where they have low water contents, signifying increased in tolerance of wheat plants to drought.

Paddy yield (t/ha)

Data related to paddy yield of rice was plotted in Figure 6. Among all the tested silicon levels the application of 100 µg Si/g was performed better and produced highest paddy yield (2.8 t/ha) and lowest paddy yield (2 t/ha) was observed where no silicon (0 µg Si/g) was applied in case of salt affected soil. Under normal conditions, the maximum paddy yield (3.4 t/ha) was noted with 100 µg Si/g. Similarly, the lowest paddy yield (2.4 t/ha) of rice was recorded with 0 µg Si/g. Hence, silicon deprived treatment performed poor and silicon accumulative treatments are very good for crop and has shown great response even in salt affected condition. Gong *et al.* (2006) and Ahmad *et al.* (2007) also stated similar outcome, revealing that application of silicon augmented paddy yield at all soil types and water contents levels.

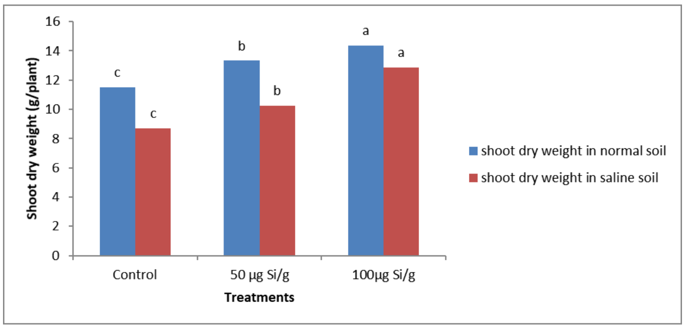

Figure 5: *Impact of various silicon concentrations on shoot dry weight (g/plant) of rice plants under normal and salt affected soils.*

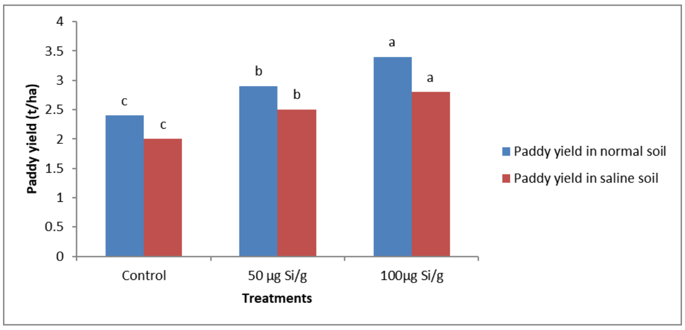

Figure 6: *Impact of various silicon concentrations on paddy yield (t/ ha) of rice plants under normal and salt affected soils.*

Conclusions and Recommendations

Silicon application improved growth and production of rice under normal in addition to saline field conditions. Growth enhancement in rice by application of silicon was more noticeable under salt stress. There was significant improvement in plant tallness, total number of productive tillers, thousand grains weight, fresh biomass and dry matter over control due to silicon application. Thus, application of active Si in growth medium enhanced soil fertility, increased quantity and quality of crops and also reduced the negative impact of adverse environmental condition especially salinity in rice crop.

Novelty Statement

Role of Si as beneficial element is well documented. Si alleviates salinity stress in rice plants grown in salt affected soil.

Author's Contribution

Mukkram Ali Tahir: Designed and conducted the research.

Noor-us-Sabah: Supervised the laboratory analysis.
Ghulam Sarwar: Overall supervision of all research activities (field and lab.).
Muhammad Aftab and Muhammad Zeeshan Manzoor: Drafting of manuscript
Abdul Moeez: Carried out the Laboratory analysis
Humaira Ramzan and Mudassir Hafeez: Assisted in Laboratory analysis.
Aneela Riaz: Statistical analysis of data.

Conflict of interest

The authors have declared no conflict of interest.

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