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Original Article

Silicon application improve maize (*Zea mays* L.) performance through ionic homeostasis and ameliorating adverse effects of brackish water

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Abstract

Water scarcity is an alarming issue in arid and semi arid regions of Pakistan, which cause drought stress and reduced plant growth. A pot experiment was conducted to study the effective role of Si for the growth of maize hybrids (FH-922, FH-949, FH-988 and FH-1137) with brackish water application. The physical parameters like plant height, shoot fresh weight, shoot dry weight; number of leaves per plant and chlorophyll contents (SPAD Value) were recorded. The ionic parameters like sodium (Na), potassium (K), silicon (Si) concentration and K: Na ratio were also recorded. The results revealed a relatively different response of four maize hybrids among all the studied parameters. Among all the variable maize hybrids, FH-988 showed the considerable increase in plant height; shoot fresh and dry weight and leaf chlorophyll contents. However, maize hybrids FH-922 and FH-1137 were more sensitive as compared to FH-988 and FH-949 due to less production in dry matter, chlorophyll contents, K concentration and K: Na ratio.

Keywords: Chlorophyll contents, Hybrids, Potassium, K:Na ratio

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Introduction

Salinity is considered the major abiotic constraint for crops production. The presence of excessive soluble salts causes disorder in plants physiology and morphology, ultimately hinder vegetative growth. In case of salinity stress, plants enhance Reactive Oxygen Species (ROS) which damage the cell structure and organelles as well as reduce the normal functioning of the plants cell (Hasanuzzaman et al. 2013). The use of brackish water (having high sodium adsorption ratio) ultimately cause the dispersion of clods and clogging of soil micro pores which reduces soil aeration and water permeability and thereby cause ion imbalance and ion toxicity in the plant tissue (Anil et al., 2005; Saqib et al., 2012). The use of highly brakish water for irrigation purpose effectively reduces the plants growth because of high Na accumulation more over Ca in root zone. The deficiency of Ca led to leakage of ions and disintegration of membranes because Ca has a key role in cell membrane structure maintenance. The shortage of good quality irrigation water is forcing the farmers for implication of brackish water. It is important to adopt different application ameliorative strategies to compete with deleterious effects of sodic water to improve the economy and environmental concern (Vaghela et al., *2010*).

Climate of Pakistan is subtropical, improper leaching of soluble salts results the formation of salt affected soils (Qureshi et al, 2018). As a result of high evapo-transpiration and low precipitation salt accumulation in the root zone results into hindrance of plant growth. The salt-affected irrigated areas of Indus Basin results the total loss of 20 billion rupees (Aslam et al, 2017). The area of 18.78 mha is being cultivated for crop production, out of 22.94 mha and the salt affected area is 10 mha in Pakistan. Pakistani soils are saline-sodic (56 %) from which 84 % are affected in Punjab. As a result of high Residual Sodium Carbonate (RSC), Electrical Conductivity (EC) and Sodium Adsorption Ratio (SAR), the ground water of Punjab province is not suitable for irrigation purpose while the application of ground water reducing the crop yield adversely (Ghafoor et al., 2001).

Among the cereal crops, maize is a major source of fodder for different animals. It is the most important source of earnings for numerous farmers in the developing countries (Tagne et al., 2008). In Pakistan, especially in Punjab and KP, maize is cultivated about 98% as the 3rd major cereal crops after the rice and wheat. The grain of maize crop used for multi products and value additions of food grain and others products. Maize has 2.1 % share in agriculture sector and 0.4 percent to GDP and other value added items. The maize crop is cultivated on area of about 1334 thousand hectare in Pakistan with annual production of 6130 thousand tons of grain and average yield of 4549 Kg ha^{-1} (GOP, 2017).

Keeping in view the current scenario of the world population, the food demand is also increasing upto 38% for population by the year 2025 (Rengasamy, 2006). This increase is not possible only on the preexisting land which is already under cultivation. As a result of land degradation in the world, soil salinity and sodicity has been considered the serious threat for the sustainable food production. Thus, the reclamation of salt affected soil is an important task to control the food and water scarcity by adopting short gun approaches like mineral nutrition application, adopting different reclamative approaches and by cultivating salt tolerant crops (Ghafoor et al, 2001). Silicon (Si) is considered as the second most abundant element in the soil which is not an essential element but is beneficial for crop productivity. According to the previous studies, Si application considerably improve crop tolerance against salt, drought, and cold stresses and it have a key role in plant growth and production due to its role for maintenance of cell membrane (Ma and Yamaji, 2008). Silicon is effective against salinity stress in different plant species such as maize (Moussa, 2006) and wheat (Saqib et al., 2008). The accumulation of Si will take place in endodermis of root, epidermal cell of leaf, and bracts of inflorescence of rice which results due to passive mechanisms like transpiration (Ma et al. 2007). In grasses, the dominant modes of Si deposition are i-e. spontaneously silicification of cell wall, direct silicification of cell wall and silica cells paramural silicification (Lux et al. 2003; Gong et al., 2006). The sites for Si depositions in maize plant are embryo, pericarp and kerrnel (Bokor et al., 2017).

The application of silicon improves the plant growth as it has a key role to reduce the crop lodging, increases photosynthesis capacity and decreases transpiration losses. The deficiency of micronutrients is mostly dominant under saline conditions because of concentration of dominant cations like Na, Mg and Ca which have an inhibiting effect on the availability of Zn and Fe. Several studies were conducted in aspects to study the micronutrients impact for maize growth in past years. However, the related work regarding the efficiency of Si for soil salinity amelioration and improving maize crop yield under brackish water irrigation has not reported previously.

Material and Methods

Soil samples were collected from the research area of Ghazi University and transferred to laboratory for further experimental process. The physical and chemical properties of the selected soil were studied. The Electrical Conductivity (EC) was measured by using EC meter (DDS-307A) and pH of soil was measured by using pH meter (Mettler Toledo Delta 320). The content of organic matter was measured through wet oxidation. The cation exchange capacity (CEC) determined by ammonium acetate method at pH 7.00 (Khorshidi and Lu, 2017). The physico-chemical properties are given in (Table-1). The artificially prepared brackish water was developed by the given method of Haider and Ghafoor (1992) at a

constant range of EC= 2 dS m^{-1} by using $MgSO_4^-$ (99% pure), $Na_2SO_4^-$ (99.7% pure), NaCl (99.74% pure) and $CaCl_2$ (98% pure).
A factorial pot trial was carried out in the wire house of Soil and Environmental Sciences, Airport Campus, Ghazi University Dera Ghazi Khan. Pakistan. The experiment was statistically arranged with four treatments (Control, Si=3.00 mM, SAR_{iw}=8.00 mmol L^{-1} and Si=3.00 mM+SAR_{iw}=8.00 mmol L^{-1}) with three replicates. Four maize hybrids i-e. FH-922, FH-949, FH-988 and FH-1137 were used as a test plants in this experiment. All the maize hybrids were brought from AARI, Faisalabad. Each 20 kg pot was filled with sieved soil. Four maize hybrids (FH-922, FH-949, FH-988 and FH-1137) hybrids performance were evaluated with the application of two Si levels (Control and 3.00 mM) in the form of $Si(OH)_4$ having 96% purity and two levels of SAR_{iw} (distilled water control and 8.00mmolc L^{-1}). One week before sowing, the recommended dose of NPK soil was thoroughly mixed into the soil.
Maize seeds were selected for sowing in each experimental unit and then seed were soaked into distill water. After soaking, in each pot five seeds were sown. After seedling emergence, plants were thinned to maintain two plants in each plant. The pots were irrigated with distilled water for initial ten days. After that water of different SAR levels were applied to maintain the field capacity for more forty days. After plant harvesting, plant shoots were oven dried at 70°C to obtain a constant weight. A homogenous portion of finely ground shoots samples were passed through40-mesh sieve and samples were digested in a di-acid mixture which was prepared by mixing the ratio of HNO_3: $HClO_4$ (2: 1) respectively (Jones and Case, 1990).
Silicon in the digested plant samples was determined by spectrophotometer (Shimadzu, UV-1201, Kyoto, Japan) by using the method of (Elliott and Synder, 1991). The concentration of K and Na were determined by using flame photometer (Model 410, Thermo Electron Limited, Cambridge, UK) respectively. The mean data regarding the mineral content and shoot dry matter analyzed statistically by using *Statistix 9*®. Least significance difference (LSD) test used for mean separation. The variations of the data were expressed as standard deviation and significance of the data was calculated at the $p < 0.05$ (Steel et al., 1997).

Table 1: Soil analysis used for experiment

Soil Characteristics	Values	Units
Texture	clayey soil	
Saturation %age	60	%
pH_s	7.46	
EC_e	1.43	dS m^{-1}
Ca^{2+} + Mg^{2+}	03.80	mmol L^{-1}
Na^+	11.00	mmol L^{-1}
SAR	3.10	
Organic matter	0.90	%

Results and Discussion

Shoot fresh and dry biomass (g)

The present results showed that the application of brackish water and Si showed a significant difference ($p<0.05$) regarding the fresh and dry biomass of all maize hybrid (Figure1). The shoot fresh and dry biomass was significantly decreased when brackish water was applied . In case of normal condition, shoot fresh biomass was observed by 348.23 g and 331.17g for FH-988 and FH-1137, respectively. The minimum shoot fresh biomass i-e. 331.17 g and 329 g were observed in FH-949 and FH-949 maize hybrid respectively. The application of Si increased the shoot fresh biomass (310.15g and 301.67g) of FH-988 and FH-949 maize hybrids, respectively under the treatment where brackish water was applied. The significant increase was observed in Si treated soil relative to control and brackish water treated soil. Shoot fresh biomass decreased where brackish water was applied. The application of Si enhanced the shoot fresh matter in case of both normal and brackish water applied treatment. Over all, maximum shoot fresh matter was observed in FH-988 by applying Si at 3.00 mM soil under controlled conditions. A significant difference observed between the treatments as well as treatment variety interactive effect.
Similarly, the shoot dry weight was also significantly differed among all the treatment and maize hybrid. The significant reduction was observed in maize hybrid dry biomass under brackish water irrigation. Shoot dry biomass was increased in Si treated soil with and without brackish water irrigation. Over all, the maximum shoot dry matter was observed in FH-988 with the application of Si at 3.00 mM. In maize hybrid FH-988, greater increase (97.24g) in shoot dry biomass was observed while minimum shoot dry biomass (90.00g) was observed in FH- 113. However,

the minimum biomass was observed by 83.3 g for FH-922 and 80 g for FH-949, relative to control.
The application of brackish water significantly reduced the shoot dry weight of all maize hybrids. The maize hybrid FH-988 showed maximum shoot dry weightby70.67g, while minimum shoot dry weight was observed by58.67g in FH-922 maize hybrid. In case of brackish water and Si application, maximum shoot dry weight was observed by 73.54g for FH-988 while minimum shoot dry weight was observed by 68.07g for FH-922 maize hybrid. Comparing the genotypic performance FH-988 produced maximum drier biomass as compared to FH-922 under both controlled and the treatment where brackish water was applied.

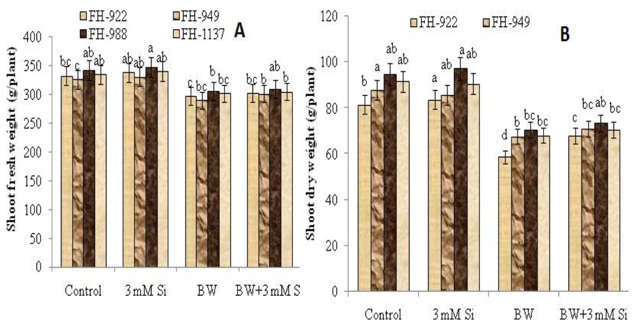

Figure 1. Effect of silicon and brackish water application on A) shoot fresh weight B) shoot dry weight of maize hybrids

According to our results, the application of brackish water with and without silicon application in soil could significantly affect performance of all maize hybrids. The application of brackish water significantly reduced the fresh weight of all maize hybrids. The reduction in plant growth and yield was observed due to the toxic effects of brackish water which reduced the development of root and shoot due to Na and Cl accumulation by plants roots from soil solution. In addition, the excess of soluble salts in soil solution may have contribution to reduce the nutrients uptake by plants roots which might induce the ion imbalance and reduced the nutrient uptake (Pascale et al., 2005; Keutgen and Pawelzik, 2008). Many researchers (Hutchings and John, 2004) reported that the plants biomass strongly influenced under salt stressed conditions. The previous study reported by Tuna et al. (2008) confirmed that the excessive accumulation of Na in wheat roots showed the prominent stress on wheat growth due to the Na movement in plant main stream line from root to leaves. However, the application of silicon into controlled and brackish water combination showed profound difference among all the maize hybrids. Present results showed that Si could increase plant fresh and dry shoot biomass of all maize hybrids.

Plant height (cm)

The plant height of all maize hybrids was significantly ($p<0.05$) decreased, when brackish water was applied. Maximum plant height was observed by 100 cm in FH-988 and by 90 cm for FH-1137 while minimum plant height (96 cm) was observed in FH-922 and by 89 cm for FH-949 maize hybrid (Figure 2) in control condition. The significant reduction in plant height was observed among the all maize hybrid under treatment where brackish water was applied. In case of treatments where brackish water was applied, maximum plant height (84.00 cm) was observed in FH-988 while minimum plant height (73.33 cm) was observed in FH-922 maize hybrid.
In case of combined application of Si and brackish water, maximum plant height (88.00 cm) was observed in FH-988 while minimum plant height (75.66cm) was observed in FH-922 maize hybrid. Comparing the genotypic performance, more plant height was recorded in FH-988 as compared to FH-922.
Similar findings were observed by Parveen and Ashraf (2010) as they observed that the Si application increased the dry biomass of Sahiwal-2002 and Sadaf maize genotypes. Similar findings were also reported by Tuna et al. (2008) in case of Si application to wheat crop as they observed an increment in plant shoot and root growth relative to control. The unfavorable impacts of salinity as respects to the plant's development parameters were essentially reduced after Si supplement incorporation. The change of the growth was more observed at the second level of Si (3.00 mM). These results are in agreement with Tuna et al. (2008) where Si application noteworthy increased the plant height of wheat plants. Silicon treatment prominently affects most physical growth parameters of maize plants relative to the control (Vaculika et al., 2009). The impact of salinity can be reduced by the Si application as it has a significant role in plant development and control the excess loss of water by transpiration (Fahad and Bano, 2012). Actually, below the epidermal cell of leaves and stem Si application formed silicate gems which can reduce the water loss through cuticle (Trenholm et al., 2004). The exchange between cuticle water loss and stomatal

control is minimum then the water stress of soil and atmosphere (Burghardt and Riederer, 2003).

Chlorophyll contents (SPAD value)

The chlorophyll contents of all maize hybrids showed significant decrease when brackish water was applied. The chlorophyll contents significantly increased under both controlled and the treatment where brackish water was applied with Si (Figure 2). Over all, maximum shoot fresh matter was observed in FH-988 with the application of Si at 3.00 mM. In case normal conditions, maximum chlorophyll contents (40.34 SPAD Value) were observed in FH-988 followed byFH-1137 (38.05 SPAD Value) applying silicon while minimum chlorophyll contents (34.83 SPAD Value) were observed in FH-949 followed by FH-949 (35.50 SPAD Value) maize hybrid.

The chlorophyll contents of all maize hybrids significantly (p<0.05) reduced by application of brackish water. Maximum chlorophyll contents (34.52) were observed in FH-988 while minimum chlorophyll contents (28.30 SPAD Value) observed by in FH-949 maize hybrid. In case of combined application of Si and brackish water, maximum chlorophyll contents (36.15 SPAD Value) in FH-988 while minimum chlorophyll contents (33.26) observed in FH-949 maize hybrid. Comparing the genotypic performance under both normal and the treatment where brackish water was applied, more chlorophyll contents were recorded in FH-988 maize hybrid produced as compared to FH-949 maize hybrid. The application of silicon also enhanced the chlorophyll contents of all maize hybrids as compared to control and brackish water treatments.

The reduction in chlorophyll contents might be due to the Na and Cl accumulation to higher extent. Results revealed additionally that Si application reduced the salinity impact and increased the chlorophyll substance. In this concern, it was observed that the application of Si increased the photosynthesis rate in cucumber and barley which was related with chlorophyll contents, leaf ultra-structure and ribulose bis phosphate carboxylase movement (Rehman et al., 2019). Silicon application reduced the H_2O_2 production and increased the efficiency of PS-II of tomato plants Al-Aghabary et al. (2004). Fish et al. (2008) found that supplementary Si brought about critical increments in chlorophyll substance of wheat plants developed at high NaCl level.

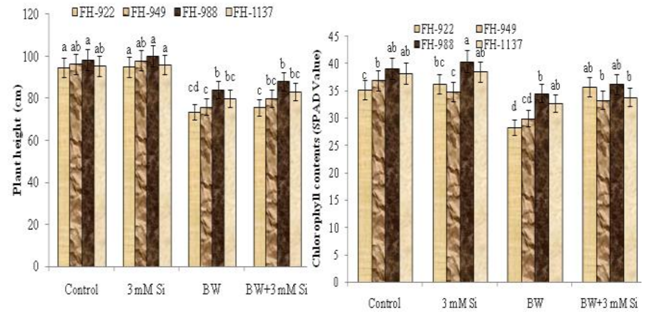

Figure 2. Effect of silicon and brackish water application on A) plant height B) chlorophyll contents of maize hybrids

Leaves per plant

The number of leaves per plant of all maize hybrids significantly varied among all the treatment. The maximum number of leaves per plant was recorded by 16 for FH-988 when Si was applied at 3.00 mM in normal condition. The minimum number of leaves (12.66) was recorded in FH-922 in the treatment where Si was applied (Figure 3). Number of leaves per plant of all maize hybrids were significantly (P<0.05) affected when plants irrigated with brackish water. In case of brackish water treatments, maximum number of leaves per plant (13) was recorded in maize hybrid FH-988. However, the minimum number of leaves per plant (8.66) was recorded in FH-949 maize hybrids. In case of combined application of Si and brackish water application, maximum leaves (12.00) were observed in FH-988 while minimum numbers of leaves per plant (9.66) were observed in FH-922 maize hybrid. Comparing the genotypic performance of all maize hybrids, greater number of leaves per plant was observed in FH-988 as compared to FH-949. The application of Si increased the number of leaves per plant of all maize hybrids as compared to control and brackish water treatments.

Results of the present experiment showed that Si application increased number of leaves. Similar findings were also observed by Tuna et al. (2008) in case of wheat and in case of tomato by Mercedes et al. (2006). Different scientists were likewise observed that number of leaves of wheat plants was altogether decreased with increasing salinity level. Similar evidences regarding number of leaves also observed by different researchers (Koyro and Eisa, 2008, Artyszak, 2018).

Potassium contents (mM)

The K concentration in all maize hybrids decreased in the treatments where brackish water was applied. In case of controlled conditions, maximum K concentration was observed by (207.4 mM) in FH-988 when silicon was applied while minimum K concentration was observed by (192.2 mM) in FH-922 maize hybrid (Figure 3). Results showed that when the brackish water was applied to maize plants then the significant ($P<0.05$) reduction in the K concentration was observed. The maximum K concentration was observed by (168.3 mM) in FH-988 while minimum K concentration was observed by (15.4 mM) in FH-949 maize hybrid.

The concentration of K increased through the applied Si as compared to the plants grown without Si in saline conditions. Si uptake is negatively increased with Na uptake while positively correlated with K. Possibly, Si application improves the selective transport of K as its effect on the flux through K ion transporters (Liang et al., 2007).

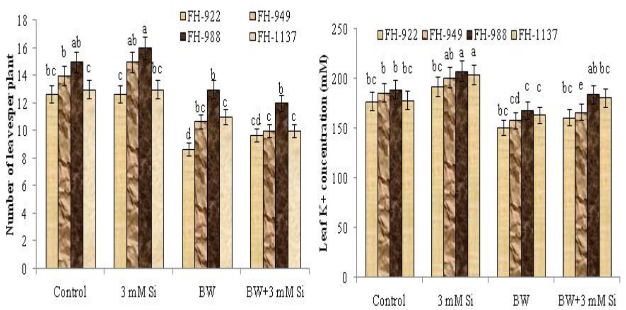

Figure 3. Effect of silicon and brackish water application A) number of leaves B) leaf K concentration of maize hybrids

In case of combined application of brackish water and Si, maximum K concentration by (184.2 mM) for FH-988 and minimum by (161.1 mM) for FH-922 maize hybrid. Comparing the genotypic performance, more K concentration was observed in FH-988 as compared to FH-949. The application of Si increased the K concentration of all maize hybrids as compared to control and brackish water treatments.

These findings are also similar with the findings of Tahir et al. (2006) in case of Si application in wheat crop. As they observed Si application improved the wheat growth under saline condition and enhanced K: Na ratio. The K: Na in both cultivars significantly reduced under salt stressed conditions as compared with non-stress conditions. K: Na ratio increased with increase in exogenous Si saline as well as non-saline conditions in all maize hybrids. The K: Na ratio in SARC-5 cultivar was higher when compared with Auqab-2000 under both saline and non-saline conditions (Saqib et al., 2005).

Sodium contents (mM)

Sodium concentration of all maize hybrids increased where brackish water was applied. The application of Si decreased the sodium concentration (Figure 4). Over all, minimum Na concentration was observed in FH-988 by applying Si at 3.00 mM soil under normal conditions. A significant difference was observed between the treatments effect interactive effect of treatment and hybrids interactive effect.

In case of non-saline conditions maximum Na concentration (198.0 mM) was observed in FH- 922. However, the minimum Na concentration was observed in FH-988 by (180.9 mM) when Si was applied. The application of brackish water significantly ($P<0.05$) increased the Na concentration of all maize hybrids. Maximum Na concentration was observed in FH-922 by (395.84 mM) and the minimum Na concentration was observed in FH-988 by (295.3 mM). In case of combined application of Si and brackish water application, maximum Na concentration was observed in FH-922 by (325.2 mM), while the minimum Na concentration was observed in FH-988 maize hybrid by (290.5 mM).

Leaf K:Na ratio

The K: Na ratio of all maize hybrids decreased where brackish water was applied. The application of Si increased the K: Na ratio in case of both controlled and the treatments where brackish water was applied. Over all, maximum K: Na ratio was observed in FH-988 with the application of Si at 3.00 mM in soil under non-saline conditions. There was a significant difference between the treatments effect and treatment variety interactive effect. In case of non-saline conditions maximum K: Na ratio was observed in FH-988 by (1.11) and the minimum K: Na ratio was observed in FH-922 by (0.97) after the addition of Si. The application of brackish water significantly ($P<0.05$) reduced the K: Na ratio of all maize hybrids. Maximum K: Na ratio was observed in FH-988 by (0.57) while the minimum potassium to sodium ratio was observed in FH-949 maize hybrid by (0.46). In case of combined application of Si and brackish water, the maximum K: Na ratio was observed in FH-988 by (0.63) while the minimum K: Na ratio was observed in FH-922 maize hybrid by (0.57).

The more uptake of K and low uptake of Na is an indication of salinity tolerance as it was observed in SARC-5 (Saqib et al., 2005). Highest concentration of sodium results into a reduction in shoot dry matter which is also observed in correlation between Na concentration and Shoot Dry Matter (SDM) in both maize genotypes. Silicon is known also to reduce Na uptake (Matichenkov and Kosobrukhov, 2004). Silicon when deposited in exodermis and endodermis of roots reduces Na uptake in plants (Gong et al., 2003).

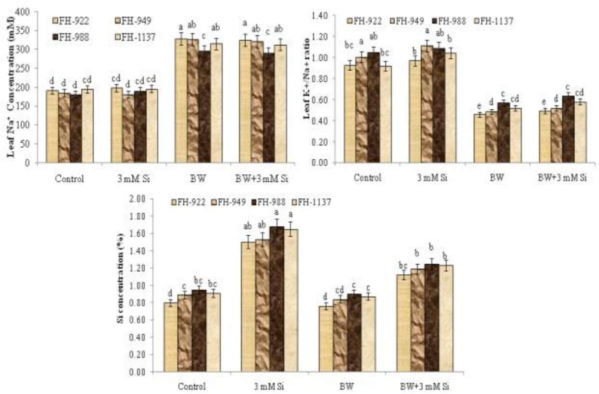

Figure 4. Effect of silicon and brackish water application on A) Leaf Na concentration B) Leaf K: Na ratio C) Si concentration

Si contents (%)

The silicon concentration of all maize hybrids decreased where brackish water was applied. Maximum Si concentration was observed by 1. 68% in FH-988 while the minimum Si concentration was observed in FH-922 by 1.50% when Si was applied at 3mM (Figure 4).The application of brackish water significantly (P<0.05) reduced the Si concentration of all maize hybrids. The maximum Si concentration was observed by 0.90% in FH-988 while the minimum Si concentration was observed in FH-922 maize hybrid by (0.76%) after Si incorporation in saline soil condition. In case of combined application of Si and brackish water application, the maximum Si concentration was observed by0.63% in FH-988 while the minimum Si concentration was observed by 0.50% in FH-922 maize hybrid.

Comparing the genotypic performance, more Si concentration was observed in FH-988 maize hybrid as compared to FH-949 under both non-saline and saline conditions. Silicon application increased the Si concentration of all maize hybrids as compared to control and brackish water treatments.

Si-content in flag leaves of wheat increased significantly by the Si application under both non-saline and saline conditions. Silicon accumulated within the roots (Gong et al., 2003) which inhibited the transportation of Na as it makes a complex with Na (Al-Aghabary et al., 2004; Saud et al., 2016).

Conclusion

In present investigation, it has been observed that all the four maize hybrids had a quite divergent response to salinity stress and their response to Si. Silicon application increased the dry biomass production, fresh biomass production, plant height, number of leaves per plant, shoot K, K: Na ratio and Si concentration. FH-988 was regarded as salt tolerant genotypes compared to FH-922 because it produced drier biomass, shoot Si, K concentration and K: Na ratio and FH-922 genotype which is considered as salt sensitive. The soil application of Si increased the plant growth under both saline and non-saline conditions. The application of Si increased the growth of all maize hybrids as compared to control and brackish water treatments. Comparing the genotypic performance of maize hybrid, FH-988 performed better under both saline and non-saline conditions. The genotypic order performance order was FH-988>FH-1137>FH-949 >FH-922. The maize hybrid FH-988 considered a salt tolerant genotype while maize hybrid FH-922 is considered as salt sensitive.

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Contribution of Authors

Jan M: Conceived Idea, Designed Research Methodology, Data Collection, Data Interpretation
Haq MA: Statistical Analysis, Manuscript Writing, Manuscript final reading and approval
Haq T: Statistical Analysis, Literature Review, Manuscript Writing
Ali A: Data Collection, Data Interpretation, Literature Search, Literature Review
Yousaf M: Data Analysis, Data Collection, Data Interpretation
Bashir S: Data Analysis, Data Interpretation,

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