Vol. 3 Issue-10, June 2023 (e-ISSN: 2582-8223)

JUST AGRICULTURE
multidisciplinary e-Newsletter

Silicon in Soil and Plant Systems

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ARTICLE ID: 71

Introduction

In the earth's crust, silicon(Si) is the 2nd most abundant element after oxygen (O). It is present in the form of silicon dioxide (SiO_2) associated with many Si-containing minerals in amorphous, poorly crystalline and crystalline phases. The essentiality of Si for higher plants is still questionable due to lack of evidence proving Si's direct role in the metabolism of plants and Si-bearing organic compounds production. The crops produced mostly in 2012, according to FAOSTAT (2014), were cereals (rice, *Oryza sativa* and wheat, *Triticum aestivum*) and sugarcane (*Saccharum officinarum*). On the basis of content of Si in these crops, seven were classified under Si accumulators, i.e., those plant species which have greater than 1% accumulation of Si on dry matter basis. On the global scale, it is estimated that plants can remove up to 210 to 224 million tonnes of Si per year (Bazilevich et al., 1975; Reimers, 1990). Si contributes 28% by weight to the earth's crust. It has not been considered as an essential element for plants, but for rice and silicifer horsetail, Si absence incurs increased susceptibility to fungal infection. Si is present in carbonaceous rocks like carbonates and dolomites, in traces, while it is present in high amounts (about 23-47%) in basaltic rocks and orthoquartzites (Monger and Kelly, 2002). Dissolved Si (in the form of monosilicic acid, H_4SiO_4) is derived from the chemical weathering of minerals containing silicates, which results in the formation of soil with the help of linked biogeochemical reactions. The release of Si to soil solution from the weathering of silicate containing minerals is a slow process, and is dependent on the processes like precipitation and production of authigenic Si substances, desorption or adsorption of Si on various solid particles or phases, assimilation and uptake by microbes in soil and vegetation, accumulation of Si in the soil profile, and additional inputs from the atmosphere (Cornelis et al., 2011). These processes are linked with each other, and the interpool transfer of Si that takes place between biomass (phytoliths and microorganisms derived biogenic Si) and soil solution ranging from 1.7 to 5.6 × 10^{12} kg Si y^{-1} (Conley, 2002) is the largest. The largest interpool transfer of Si, in the oceans, happens between diatoms derived biogenic silica and dissolved Si at 6.7 × 10^{12} kg Si y^{-1}(Matichencov and Bocharnikova, 2001).

Silicon in soils

Si is categorized into liquid, solid and adsorbed phase in the soils (Fig.1). Si in solid phase is found largely in crystalline forms, in the form of primary and secondary silicates, and silica minerals. Silica in solid amorphous phase is derived from either plant residues and remains of microorganisms (biogenic) or complex formation of silica with heavy metals, Al, Fe and soil organic matter (litho/pedogenic). The content of Si in the liquid phase is highly dependent on the Si solubility in the solid phase. The contribution of biogenic silica to the plant available Si in soil solution is significant, with 17 times higher solubility than quartz (Fraysse et al., 2006).The fractions of Si in adsorbed and liquid phase consist of monosilicic acid, polysilicic acids and those complexes dissolved with organic and inorganic compounds.The plant-available form of Si in soil are monosilicic and polysilicic acids, which get adsorbed on the soil particles. When solids rich in Si are dissolved, polysilicic acids are mobilized, while at equilibrium soil solution contains Si in the form of monosilicic acid. This silica is made available for uptake by plants and is liable for precipitation and can bind to secondary minerals.

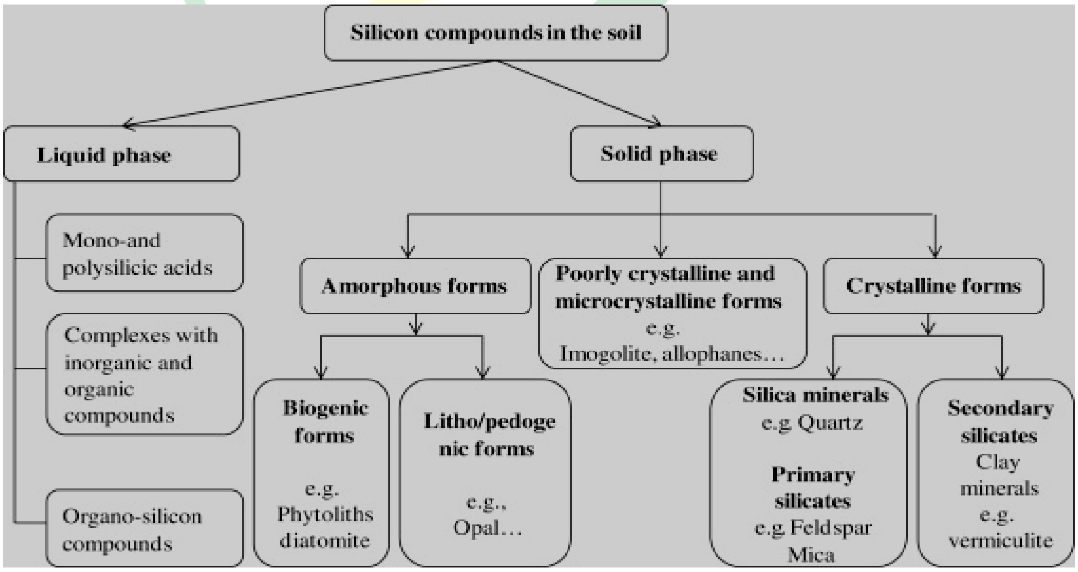

Figure 1 Fractions of Silicon present in the soil (Matichenkov and Bocharnikova, 2001).

Silicon in Plants

Si is absorbed by the plants as H_4SiO_4. Its concentration in the soil solution of most of the agricultural soils is from 0.1 to 0.6 mM. Through active, passive and rejective mechanisms, the absorption of H_4SiO_4 takes place by lateral roots. It is a versatile element giving different benefits in plant growth especially under stress situations (Zargar et al. 2012). It helps in enhancement of plant growth, crop quality and yield, nitrogen fixation, photosynthesis and tolerance to biotic and abiotic stresses like high and low temperatures, toxicity of heavy metals, UV radiation, deficiency of nutrients, salinity, drought, attacks of pathogen and fungus (Van Bockhaven et al. 2013). The International Plant Nutrition Institute (IPNI) has recently declared Si to be an element of nutrition for plants. The Association of American Plant Food Control Officials (AAPFCO) have also declared Si as a beneficial substance for plants. Si makes the tissues of plants stronger and rigid, thus providing strength to the plants (Marxen et al. 2015). Through its interactions with a number of essential components of the plant's stress signalling system, soluble Si can improve disease resistance in plants. It is also found that the accumulation of Si in plants causes a release of phenolics and phytoalexins, which gives plants the ability to tolerate various plant pathogens (Miyake and Takahashi 1982a, b). Insect resistance is obtained through Si in rice plants by priming of jasmonate-mediated antiherbivore defense responses (Ye et al. 2013).

The concentration of Si significantly differs within and between the plant species, and this difference in concentration is lower within the species than between the species. The reason behind the differences in accumulation of Si in various plants is due the specific ability of plant’s roots to uptake Si. In Bryophyta, Lycopsida and Equisetopsids (Pteridophyta), higher accumulation of Si was found. While a low concentration of Si was found in Filicopsida (Pteridophyta), Gymnospermae and some of Angiosperms. It was also observed that >4% Si accumulation was found in few families of Angiospermae such as Cyperaceae, Poaceae, and Balsaminaceae, 2-4% accumulation of Si was observed in Cucurbitales, Urticales and Commelinaceae, and the species called Si excluders were Solanaceae (e.g., tomato) and Fabaceae (e.g., faba bean).

Conclusion

Silicon is found to be a versatile element with several benefits in context of plant growth, providing tolerance to biotic and abiotic stresses in plants. Therefore, its accumulation, toxicity and lower concentrations, their benefits and drawbacks must be carefully studied to benefit the plants in various ways possible.

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