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Effect of calcium silicate and fly ash on dynamics of silicon fractions in Alfisol

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Abstract
Silicon (Si) is the second most abundant element in the earth's crust and plays a number of important roles in the mineral nutrition of plants. The scientific documentation on the dynamics of Si fractions will help to establish the importance of Si fertilization. An incubation experiment was conducted to study the plant available silicon and its fraction from its native soil and applied sources *viz,* Calcium Silicate (CS) and Fly Ash (FA) along with the Nitrogen. The experiment was conducted in completely randomized design (CRD) having fourteen treatment combinations replicated thrice. Soil samples were collected and analyzed for Si fractions *viz.*, mobile Si, adsorbed Si and Plant available silicon(PAS) at 30 days interval (30, 60, 90 and 120 day). The results revealed that the PAS content in the soil without Si addition (absolute control) was low. Application of different levels of Si either through CS or FA significantly increased the mobile Si, adsorbed Si and PAS content of soil at all the stages of incubation periods when compared to control. The available Si increased to the tune of 2.9, 5.0 and 7.7 mg kg $^{-1}$ due to application of CS @ 200,400 and 600 kg ha^{-1} respectively at 30 days after incubation. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} significantly increased the available Si content to the tune of 1.5, 4.6 and 6.8 mg kg $^{-1}$ respectively over control at 30 days after incubation. It was also observed that application of N @ 75 kg ha^{-1} along with CS and FA further enhanced the mobile Si, adsorbed Si and PAS. The mobile Si and PAS content to soil slightly decreased after 60 DAI in CS applied treatments. However steady increase of mobile Si, adsorbed Si and PAS was noticed in FA applied treatment with the advancement of incubation period. The results revealed that FA can be effectively used as Si source to improve the various fractions of Si in soil.

Keywords: Calcium silicate (CS), fly ash (FA), plant available silicon (PAS), mobile silicon, adsorbed silicon

Introduction

Silicon is a beneficial mineral element commonly found in soil. It is the second most abundant element after oxygen in soil (Sahebi *et al*., 2015) [10]. Addition of silicate sources of fertilizer to the soil not only increased the available Si but also interacted with other nutrient and enhanced the solubility (Subramanian and Gopalswamy, 1990) [13]. Nitrogen is essential for plant growth and development, and is often a limiting factor for high productivities. The synergistic effect of Plant-available Si (H_4SiO_4) and nitrogen in soil is found as essential nutrient for enhancing the productivity of soil (Savant *et al*., 1997) [11]. Gontijo (2000) [6] observed that soil Si values decreased with increased content of the sand in the soil. He further found that a soil having high percentage of sand tends to show low available Si contents due to their poor capacity to supply Si to plants. Hence calcium silicate ($CaSiO_3$) and fly ash was used to sandy loam soil as silicon source for testing its effect on improvement in PAS and other silicon fractions. Therefore an incubation study was conducted to know the dynamics of plant available silicon and silicon fractions as influenced by silicon and nitrogen levels in Alfisol.

Materials and Methods

The incubation experiment was carried out in Sugarcane Research Station, Sirugamani, Trichy, India for 120 days. The soil was collected in the layer of 0 – 15 cm of sandy loam textural class, of Palaviduthi Soil Series (*Typic Rhodustalf*). The experimental soil was low in available nitrogen, medium in available phosphorus and available potassium. Plastic bowls were filled with 500g of soil samples, then mixed thoroughly with the calculated amount of different source of silicon and nitrogen. Calcium silicate (CS) and Fly ash (FA) were used as a source of silicon.

Urea was used as a source for nitrogen. The experiment was conducted in completely randomized design (CRD) having fourteen treatment combinations replicated thrice.

The fourteen treatments were T_1: Absolute control, T_2: N @ 75 kg ha^{-1} alone, T_3: Calcium Silicate 200 kg ha^{-1} alone, T_4: Calcium Silicate 400 kg ha^{-1} alone, T_5: Calcium Silicate 600 kg ha^{-1} alone, T_6: Calcium Silicate 200 kg ha^{-1} + N @ 75 kg ha^{-1}, T_7: Calcium Silicate 400 kg ha^{-1} + N @ 75 kg ha^{-1}, T_8: Calcium Silicate 600 kg ha^{-1} + N @ 75 kg ha^{-1}, T_9: Fly ash 10 t ha^{-1} alone, T_{10}: Fly ash 20 t ha^{-1} alone, T_{11}: Fly ash 30 t ha^{-1} alone, T_{12}: Fly ash 10 t ha^{-1} + N @ 75 kg ha^{-1}, T_{13}: Fly ash 20 t ha^{-1} + N @ 75 kg ha^{-1}, T_{14}: Fly ash 30 t ha^{-1} + N @ 75 kg ha^{-1}. Soil samples were collected and analyzed at 30 days interval (30, 60, 90 and 120 day) for plant available silicon (PAS) by Korndorfer *et al*. (2001) [8], the different Si fractions in soil were determined by the sequential Si extraction method developed by Georgiadis *et al*. (2013) [5]. Si fractions include: Mobile Si, extracted by $CaCl_2$; and adsorbed Si, extracted by acetic acid.

Result and Discussion

Plant available silicon

PAS in soil was influenced significantly by different silicon source and nitrogen. The PAS increased to the tune of 2.9, 5.0 and 7.7 mg kg $^{-1}$ due to application of CS @ 200,400 and 600 kg ha^{-1} respectively at 30 days after incubation. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} significantly increased the available Si content to the tune of 1.5, 4.6 and 6.8 mg kg $^{-1}$ respectively over control at 30 days after incubation. Since fly ash is rich in Si that increases the content of plant available Si compounds (Monosilicic acids) in the soil. However addition of nitrogen @ 75 kg ha^{-1} along with Si source was found to be on par with the above treatments.

Data presented in (Fig.1) revealed that combination of N @ 75 kg N ha^{-1} with FA 30 t ha^{-1} showed increase of Si content in soil during 120 DAI. The maximum release in fly ash treatment may be due to dissolution of fly ash matrix and solubilization of minerals (Korndorfer, 2001) [8]. The PAS increased to the tune of 1.4, 4.1 and 6.7 mg kg $^{-1}$ due to application of CS @ 200,400 and 600 kg ha^{-1} respectively at 120 days after incubation. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} significantly increased the available Si content to the tune of 5.0, 7.1 and 9.7 mg kg $^{-1}$ respectively over control at 120 days after incubation. Ponnamperuma (1965) [9] reported a concurrent increase in solubility of soil Si with submergence time. Application of N along with Si source has slightly increased plant available Si in soil.

Mobile Silicon

The data on mobile Si at different stages of incubation period reveled that application of different Si either through CS or through FA significantly increased the mobile silicon when compared to control. The mobile Si (Fig. 2) increased to the tune of 2.7, 4.4 and 6.4 mg kg $^{-1}$ respectively due to the application of 200, 400 and 600 kg ha $^{-1}$ of calcium silicate over control at 30 days after incubation. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} significantly increased the mobile Si to the tune of 1.5, 4.0 and 7.2 mg kg^{-1} respectively over control at 30 days after incubation. The sand fraction consists mostly of SiO_2, the chemical decomposition of this mineral is complex, which makes sandy soils more responsive than clay soils to silicate application (Dematte *et al.,* 2011) [3] helps in the increase of mobile fraction of silicon content to soil.

It was also observed that application of N @ 75 kg ha^{-1} along with CS and FA further enhanced the mobile Si content. However the increase due to N application was not significant over the application CS and FA alone. Similar trend was also observed at 60, 90 and 120 days of incubation period. It was also observed that the mobile Si content of soil slightly decreased after 60 DAI in CS applied treatment. However steady increase in mobile Si was noticed in FA applied treatments with the advancement of incubation period. The same result was reported by Kim *et al*., (2010) [7] where the application of silica fertilizer has revealed a significant impact on increasing OM and mobile silica contents in surface and subsurface soils.

Adsorbed Silicon

The adsorbed Si increased to the tune of 2.8, 7.0 and 9.1 mg kg $^{-1}$ due to application of CS @ 200,400 and 600 kg ha^{-1} respectively at 30 days after incubation. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} (Fig. 3) significantly increased the adsorbed Si content to the tune of 2.4, 6.5 and 8.2 mg kg $^{-1}$ respectively over control at 30 days after incubation. Danilova *et al*., (2010) [2], reported a large variety of silicon fractions may occur in soils where soil particles can adsorb dissolved silicic acid from the soil solution. Adsorbed silicon content was found to be significantly differ between 30 DAI to 120 DAI. Under flooding conditions, Si release into the soil solution may increase (Siipola *et al*., 2016) [12] because Si adsorbed on, or occluded in Fe and Mn oxides is released after reductive dissolution of the oxides forms. This result was in line with the findings of Dietzel (2002) [4] where the interaction of monosilicic acid with solid surfaces can be described as a surface complexation, and polymerization of polysilicic acid at the mineral surface is likely to occur under acidic conditions. This may be the reason to the increase of adsorbed silicon content in soil with the incubation period.

The adsorbed Si increased to the tune of 3.4, 8.0 and 10.4 mg kg $^{-1}$ respectively due to the application of 200,400 and 600 kg ha $^{-1}$ of calcium silicate over control at 120 days after incubation. The first increase of Si content in soils is probably due to the high efficiency of Fe–Mn oxides in adsorption of bioavailable Si released. (Chen *et al.* 2003) [1]. Similarly application of fly ash @ 10, 20 and 30 t ha^{-1} significantly decreased the adsorbed Si to the tune of 3.1, 7.8 and 9.1 mg kg^{-1} respectively over control at 120 days after incubation compared to CS applied treatment. It was also observed that application of N @ 75 kg ha^{-1} along with CS and FA further increased the adsorbed Si content of soil at 120 DAI respectively.

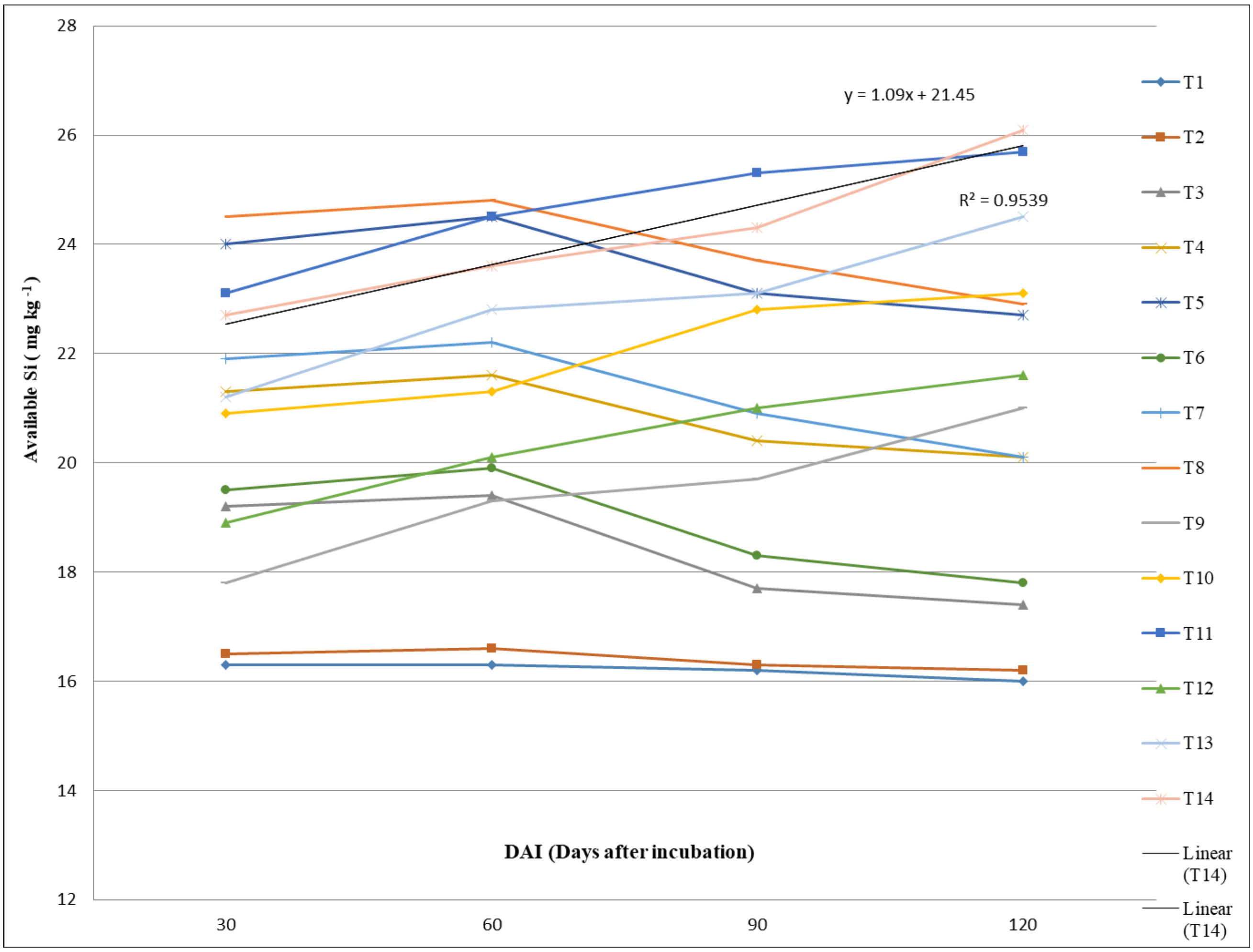

Fig 1: Effect of Calcium Silicate and Fly Ash on plant available silicon (mg kg^{-1}) in Alfisol during incubation:

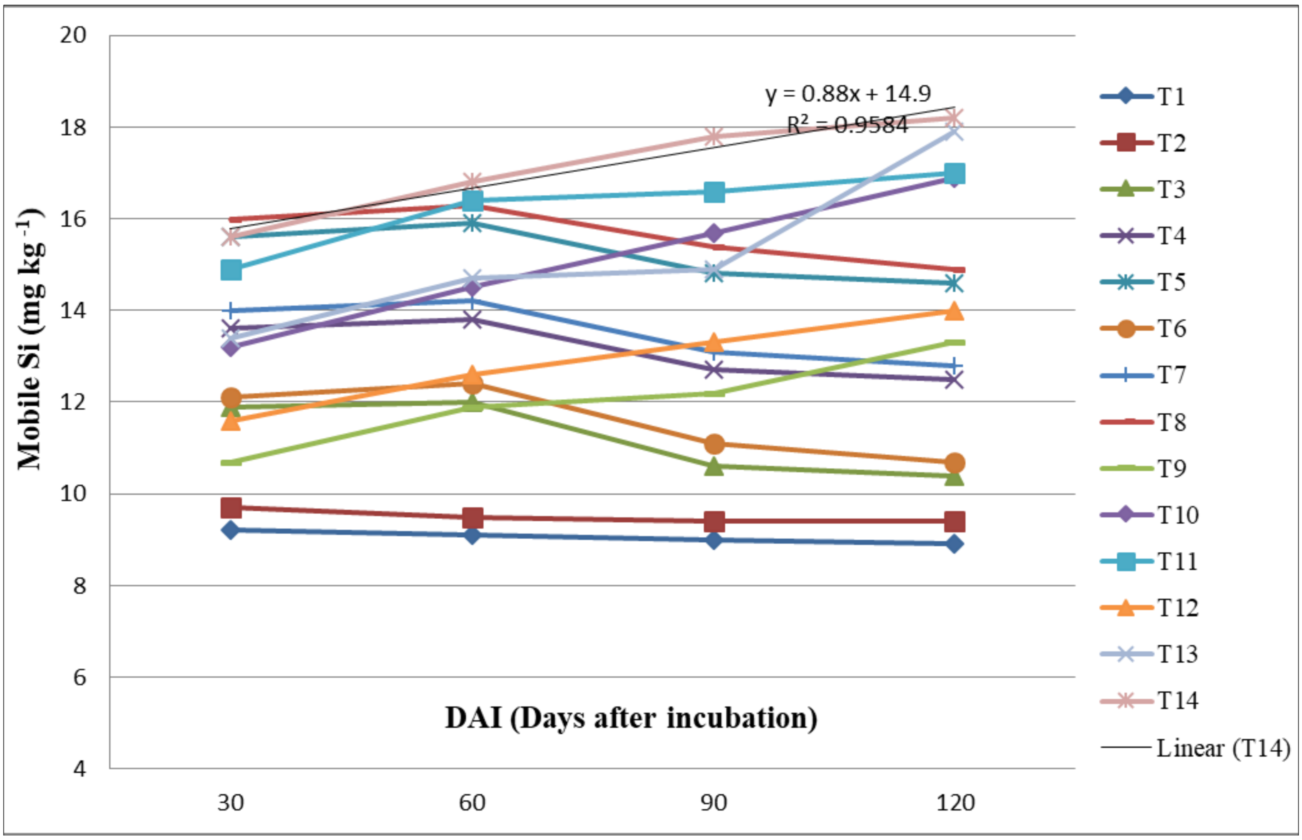

Fig 2: Effect of Calcium Silicate and Fly Ash on Mobile Silicon (mg kg^{-1}) in alfisol during incubation:

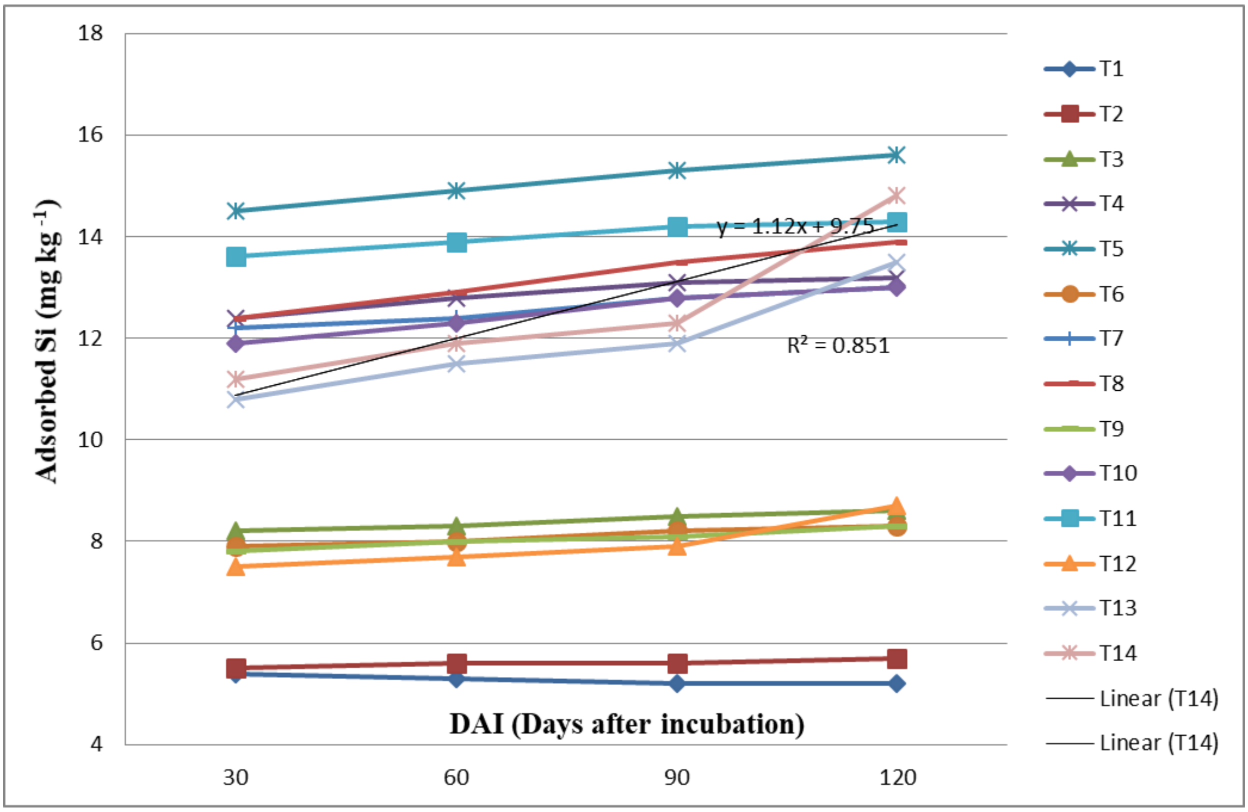

Fig 3: Effect of Calcium Silicate and Fly Ash on Absorbed Silicon (mg kg^{-1}) in Alfisol during incubation:

Conclusion

The different Si fractions were quantified using a sequential extraction method in *Alfisol*. The study demonstrates that sequential Si fractionation enables quantification of Si fractions in the soils. Soil treatment with bio-geochemically active silicon substances optimizes soil fertility through the maintenance of nutrients in plant-available forms. Prolonged water saturation and cyclic alternating reducing and oxidizing conditions in Alfisol affect accumulation of three distinct Si fractions: PAS, mobile Si, and adsorbed Si. Application of different levels of Si either through CS or FA significantly increased the mobile Si, adsorbed Si and PAS content of soil. And also application of N @ 75 kg ha^{-1} along with CS and FA further enhanced the mobile Si, adsorbed Si and PAS. Steady increase of mobile Si, adsorbed Si and PAS was noticed in FA applied treatment with the advancement of incubation period. The results revealed that FA can be effectively used as Si source to improve the various fractions of Si in soil.

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