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Dynamics and Nutrient Release Pattern of Silica Sources in a Typical Entisol of Tropical Humid Region of Kerala

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ABSTRACT

Silicon is considered as a beneficial element for crop nutrition especially for monocots. In order to study the effect of addition of different silica sources on the nutrient release pattern from an Entisol, a laboratory incubation study was conducted with three silica sources viz., sodium silicate, calcium silicate, and potassium silicate each @ 200 ppm and 400 ppm per kilo gram soil. The positive effect of addition of silicates was obvious on soil reaction, available Si, P, K, Ca, and Mg. Release of plant available silicon was the highest at 60th day after incubation (DAI) with potassium silicate @ 400 ppm per kg soil. Sodium silicate @ 200 ppm resulted in the highest exchangeable magnesium concentration at 45th DAI. The result of the study implies the positive influence of silicates on soil acidity as well as on enhancing the availability of phosphorus, potassium, calcium, and magnesium in an Entisol.

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Coconut; Entisol; plant nutrition; silicon; soil fertility

Introduction

Sustaining crop productivity is the major challenge before the policy makers as far as feeding the ever increasing population is concerned. Invariably, maintenance of soil productivity as the prime factor for enhancing crop production needs a greater emphasis. Production potential of a crop can be realized, only when the congenial conditions are assured in terms of soil quality, climatic and other biotic and abiotic factors. Soil quality is the factor which has to be maintained over the years considering the non renewable nature of the entity. Soil nutrient status, the contributing factor to soil fertility and sustainability has to be periodically monitored and suitable remedial measures for correcting the imbalance arising out of the over exploitation of the same has to be taken.

Management practices often lay emphasis on the supply of essential nutrients through the addition of external inputs, for sustaining crop productivity. In this regard, the enhancement of crop productivity through the management of beneficial elements has also to be thoroughly understood. Being an element associated with the plant defense mechanism as well as having the potential for imparting of abiotic and biotic stress resistance, the importance of silica, the element which is most abundant next to oxygen in the lithosphere and comprising 28% by weight and 3–17% weight in soil solution need to be understood.

Studies on the importance of silica on crop nutrition began in the early 1990s. The beneficial role of silica in crop production has been documented in graminaceous plants such as rice and sugarcane and in cyperaceous and cucurbitaceous plants (Guntzer, Keller, and Meunier 2012; Liang 1999; Liang et al. 2005; Ma, Miyake, and Takahashi 2001).

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Silica is taken up by plants as mono silicic acid and is deposited as amorphous silica. It is regarded as a quasi essential/beneficial element in crop production. Silica is translocated from the roots as silicic acid through the xylem and is deposited in the cuticle and the intercellular spaces as phytoliths (Epstein 1999). External application of silica sources has been reported to impart tolerance to pest and diseases as well as the abiotic stress such as salt injury, lodging, and toxicity of iron, manganese and aluminum in acid soils. It has been reported that monocotyledonous crops such as rice and sugar cane take up silica from the soil @ 300 and 500 kg/ha, respectively (Makabe et al. 2009; Meyer and Keeping 2001). Matichenkov and Bocharnikova (2000) calculated that 210–224 million tons of silicon is removed from cultivated soil every year.

Though the agricultural soils are largely composed of silicate minerals, majority of the soils are deficient in plant available silicon. Intensive cultivation of silica accumulating crops such as rice can result in the over depletion of this mineral nutrient from the soil. Non incorporation of straw after harvest leads to the decrease in the content of plant available silicon in soil and can affect crop yield. Other factors affecting the silica availability to plants include soil pH and the concentration of iron and aluminum oxides present in soil (Savant, Synder, and Datnoff 1997).

Coconut based cropping system is predominating in state crop map of Kerala. Being a monocot, the demand and uptake of silicon in coconut needs to be studied for which the release pattern of different silicate sources needs to be studied. Fox et al. (1967) recorded that the critical level of silicon extracted through 0.5 M ammonium acetate is 20 mg kg^{-1}. The content of plant available silica in the Onattukara sandy soil was found to be 1.81 ppm which is below the suggested critical level in soil. In order to avail the beneficial effects of silicates in crop production, different sources and dose need to be standardized. Hence it is imperative to understand the beneficial role of external application of silica through different carriers in the sandy soil where coconut is the major component of cropping system. The present study was conducted to understand the kinetics of dissolution and nutrient release pattern of three different silica sources in Onattukara sandy soil. Understanding the temporal variability in nutrient status after the addition of different silica sources will help in the formulation of management strategies to enhance nutrient use efficiency.

Materials and methods

The study was carried out with soils of a typical Entisol in the humid tropics belonging to the Agro Ecological Zone I and the Agro Ecological Unit-3 called Onattukara region in Kerala. The soil in this region is characterized with very low organic matter, depleted levels of base nutrient ions coupled with adverse effects of soil acidity.

Soil sampling and analysis

The experiment was done during 2014–15 in ICAR-Central Plantation Crops Research Institute (Regional Station), Kayamkulam. Representative bulk samples were collected (0–25 cm) from the Research farm of the Regional station. The soil belongs to the taxonomic class Oxi Aquic Quartzipsamment. The soil samples were air dried and ground to pass through 2 mm stainless steel sieve. The initial chemical characteristics of soil samples such as pH, organic carbon, plant available silica, available phosphorus, available potassium, exchangeable calcium, exchangeable magnesium, iron, manganese, copper, and zinc were estimated.

The samples were having pH (5.7), organic carbon (0.35%), available phosphorus (26.5 ppm), available potassium (105.5 ppm), exchangeable calcium (320.85 ppm) and magnesium (36.5 ppm), available sulfur (5.08 ppm), iron (1.85 ppm), manganese (5.42 ppm), copper (0.75 ppm), zinc (1.2 ppm), and plant available silicon (1.81 ppm).

Field capacity of the soil samples was determined with the help of pressure plate apparatus with the pressure maintained at 1/3rd atmosphere. Two kg soil per treatment was incubated at field capacity in the analytical laboratory with the periodical replenishment of soil moisture lost by evaporation.

Incubation study

The experiment was carried out as an incubation study in the laboratory. There were seven treatments replicated four times in completely randomized design. The treatments were, T_1 – absolute control, T_2 (sodium silicate @ 200 ppm per kg soil), T_3 (sodium silicate @ 400 ppm per kg soil), T_4 (calcium silicate @ 200 ppm per kg soil, T_5(calcium silicate @ 400 ppm per kg soil), T_6 (potassium silicate @ 200 ppm per kg soil), and T_7(potassium silicate @ 400 ppm per kg soil).

Soil samples were collected from the pots during 15th, 30th 45th, 60th, and 75th day after incubation (DAI). They were analyzed for the major, secondary and micro nutrients as per the standard procedures outlined by Jackson (1973). Soil pH (1:2 soil water suspension) was measured with a glass electrode. Organic carbon was estimated by the Walkely and Black titration method (1934). Available P was estimated using Bray No. 1 extractant consisting of 0.03 N ammonium fluoride and 0.025 N hydro chloric acid. Available K, Ca, and Mg was estimated after extraction with neutral normal ammonium acetate and determined by flame photometer and atomic absorption spectrophotometer. Micronutrients were extracted with DTPA consisting of 0.005 M DTPA and 0.01 M $CaCl_2.2H_2O$, buffered at pH 7.3 by 0.1 M triethanolamine (TEA) and estimated with Atomic Absorption Spectrophotometer, Lindsay and Norvell (1978).

Plant available silica was estimated as per the procedure of Haysom and Chapman (1975). Two grams air dried soil was shaken with 20 ml of 0.01 M calcium chloride in polyethylene container for 16 h and the sample extract was centrifuged at 2000 rpm for 10 min. To the filtrate, sequentially, 2.5 ml 0.5 M sulfuric acid and 2.5 ml ammonium molybdate solution was added. This was shaken in a vortex stirrer. After 5 min, 1.25 ml tartaric acid was added followed by the addition of 0.25 ml ANSA solution. Absorbance was read at 820 nm wave length. Data was statistically analyzed using SAS 9.3 software. Orthogonal polynomial trend analysis was done for fitting regression lines using Microsoft Excel and Statistical Package for Social Sciences (SPSS Inc. Chicago, IL) software.

Results and discussion

Plant available silicon

Application of different silicates had an influence on the release of silica from the soil as evidenced from the statistical significance on the content of silicon from the soil at different stages of incubation. From all the three sources of silica, a declining trend on the release of silicon was observed either after the third or after the fourth stage of incubation (Figures 1 and 2). It has been found that T_7 recorded the significantly highest value among all the treatments for the available silica content (4.81 ppm).

The content of available silica at 60th DAI in the treatment with potassium silicate @ 400 ppm was 6.85 ppm and was followed by 6.03 ppm with the calcium silicate @ 400 ppm at the same stage which implies that the highest percentage increase in plant available silicon was observed in this treatment. The decline in the release of silicon was observed at the 75th DAI.

After the 60th DAI, there might have been an adsorption of silicates on the exchange sites. This implies that, for the effective utilization of silica released from its carriers, the application of the same should be done at split intervals which increase the silicate use efficiency. Considering the individual effects of various treatments, the highest value of 4.81 ppm was recorded with the application of potassium silicate @ 400 ppm per kg soil. The pattern of release is confirmed by the orthogonal polynomial trend analysis.

The solubility of silicates and consequent effect on pH might have facilitated the release of plant available silicon after the application of different silicate sources. Castro et al. (2010) observed that

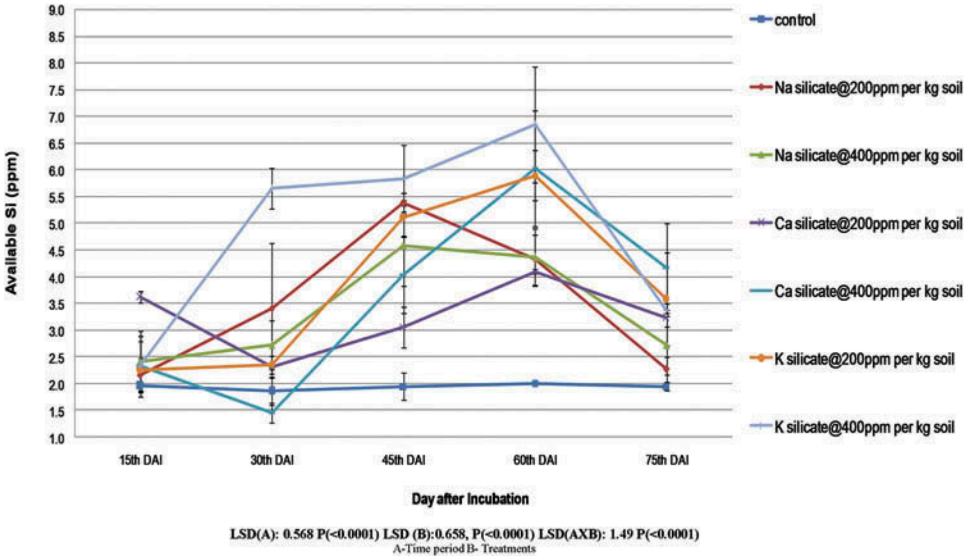


Figure 1. Effect of treatments on available silicon.

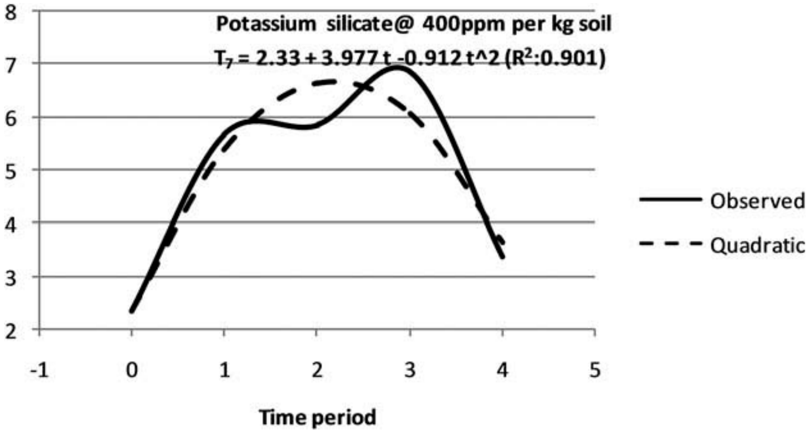
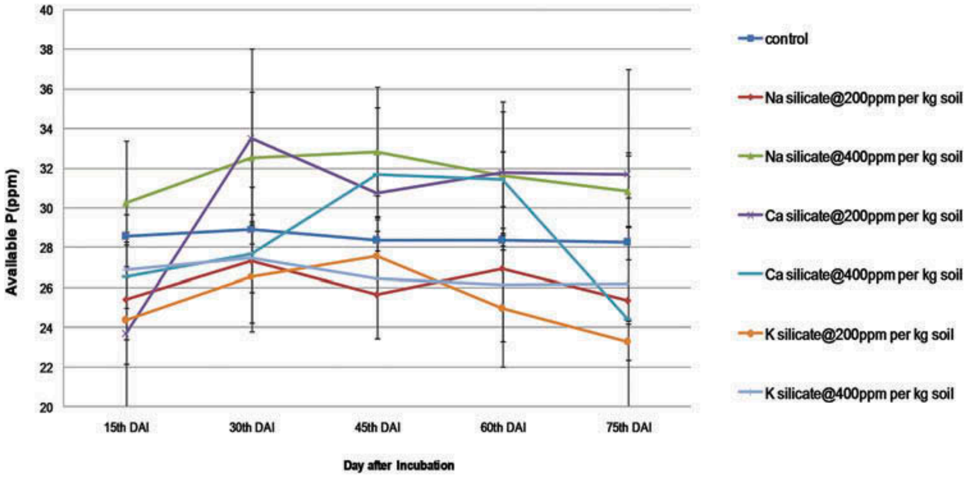


Figure 2. Orthogonal trend analysis showing the release of Si as influenced by potassium silicate @ 400 ppm per kg soil.

silica concentration in soil increases with the application of different rates of calcium and magnesium silicates.

Available phosphorus

Application of different doses of silicates has an influence on the release of phosphorus (P) from the exchange sites as evidenced by the gradual increase in the available P content except that in the absolute control treatment, where the release was more or less constant. In all other treatments, the gradual increase in the available P content was observed up to either the 30th or to the 45th day of incubation (Figure 3). Considering the individual treatments, the significantly superior value of 31.69 ppm was recorded by calcium silicate @ 200 ppm per kg soil. Among all the treatment combinations, the highest



LSD(A): NS LSD (B):6.01 P Level <0.0001) LSD(AXB): 5.89 P Level< 0.0001)
A-Time period B- Treatments

Figure 3. Effect of treatments on available phosphorus.

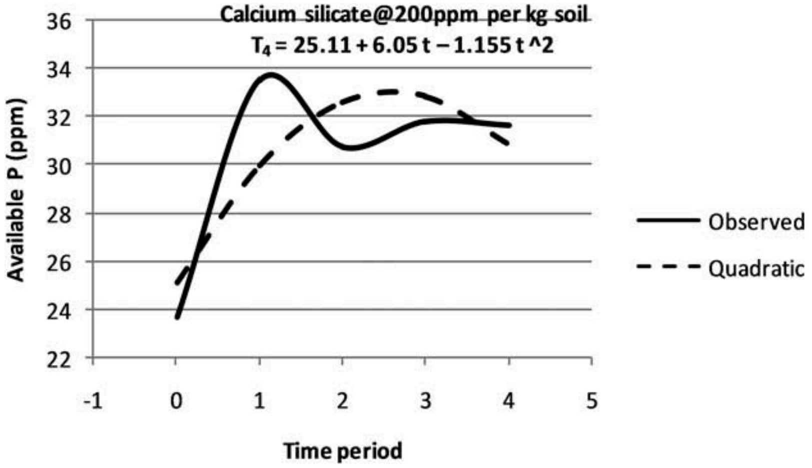


Figure 4. Orthogonal trend analysis showing the release of phosphorus as influenced by calcium silicate @ 200 ppm per kg soil.

value of 33.52 ppm was recorded by calcium silicate @ 200 ppm per kg soil. The quadratic response curve depicts the trend on the release of P over the period of incubation (Figure 4).

Castro and Crusciol (2013) observed the enhanced availability of phosphate ions in the soil solution with the application Ca and Mg silicates in acidic soils of Brazil. The increase in the hydroxyl ion concentration as well as the ionic activity in soil solution has increased the negative charges which may repel the phosphate ions and causes its release into the soil solution. Moreover due to the competition between Si and P for the same sorption sites (McBride 1994; Pulz et al. 2008) might have resulted in the increase in the content of available P in soil.

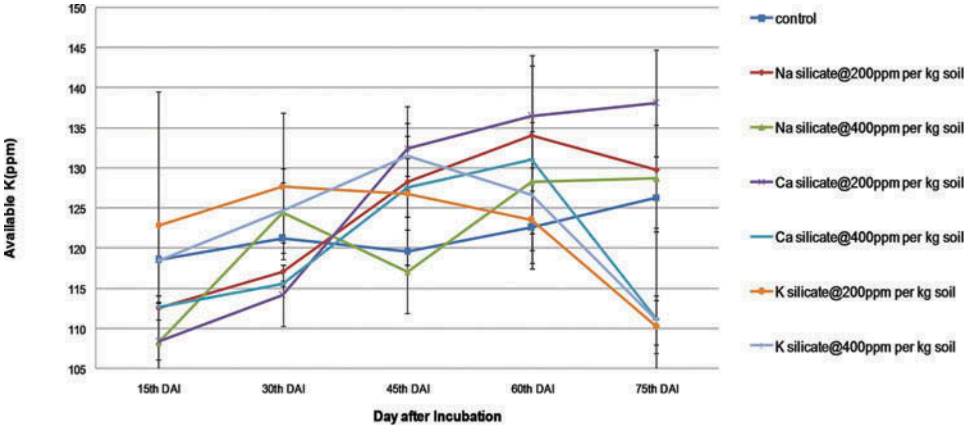
The role of silicates on reducing the P fixation and thereby increasing the content of available P in sugarcane grown soil and consequent increase in the available pool was recorded by Roy, Ali, and Fox (1971). Desorption of P from the anion exchange sites might have been increased in the presence of adsorbed Si. The capacity of sodium silicates to release sorbed phosphorus was emphasized by Hartono and Bilhaq (2014). Silicates could compete with phosphorus from the sorption sites enabling the release of fixed P.

Exchangeable potassium, calcium, and magnesium

Meyer (2012) emphasized the positive role of silicates on the enhancement of soil base saturation capacity through the release of base nutrient ions into the exchange pool.

The release of available potassium (K) (Figure 5 and Figure 6) over the different stages of incubation was nonsignificant, and no statistical significance was observed with regard to the different sources as well as to the interaction between the different stages of sampling and the sources of silicates. The highest value of 136.5 ppm was recorded by the application of calcium silicate @ 200 ppm per kg soil at the 60th DAI.

A gradual increase in the available K was observed and the rate of increase over the initial content (105.5 ppm) was higher with T_4 (25.8%) followed by T_3 (19.25%) which implies the effect of Ca and Na ions on the release of K from the exchange sites. As the concentration of calcium silicate increased, the corresponding incremental effect on the release of K^+ ions was not observed which may be due to the limited availability of exchangeable K in the sites.



LSD(A): NS LSD (B):NS LSD(AXB): NS
A-Time period B- Treatments

Figure 5. Periodical release of potassium as influenced by the treatments.

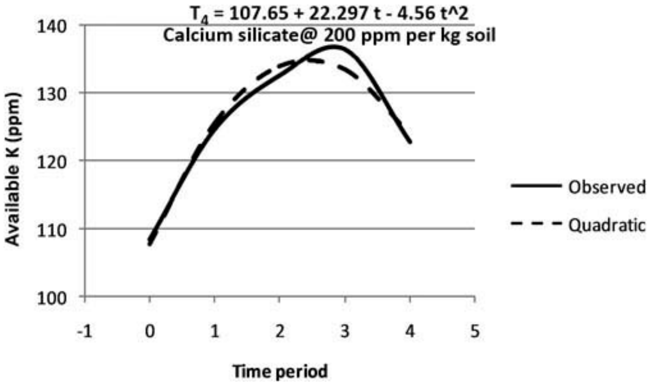
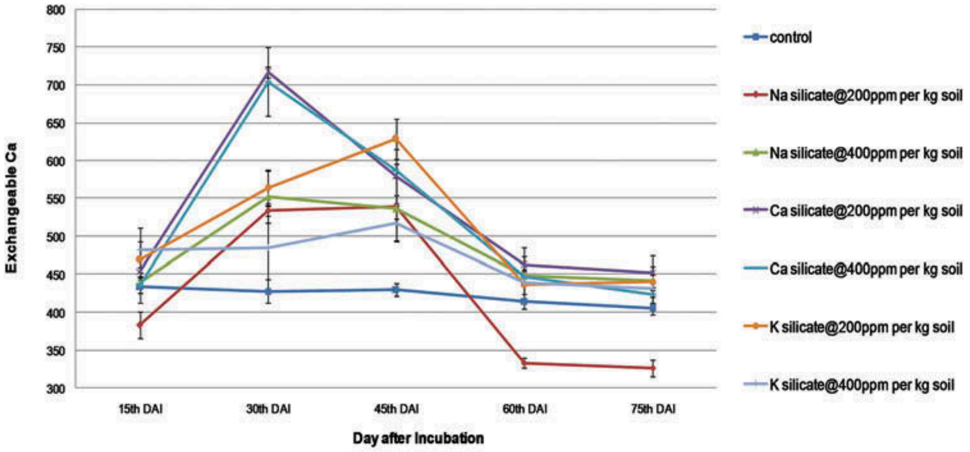


Figure 6. Orthogonal trend analysis showing the release of potassium as influenced by calcium silicate @ 200 ppm per kg soil.



LSD(A): 23.66 P Level <0.0001 LSD (B): 34.69, P Level <0.0001 LSD(AXB): 62.31 P Level< 0.0001
A-Time period B- Treatments

Figure 7. Periodical release of calcium as influenced by the treatments.

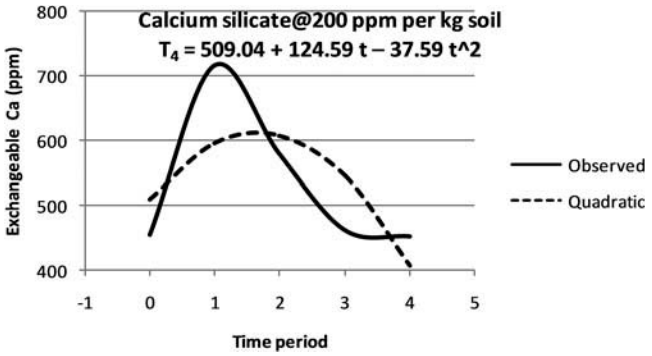
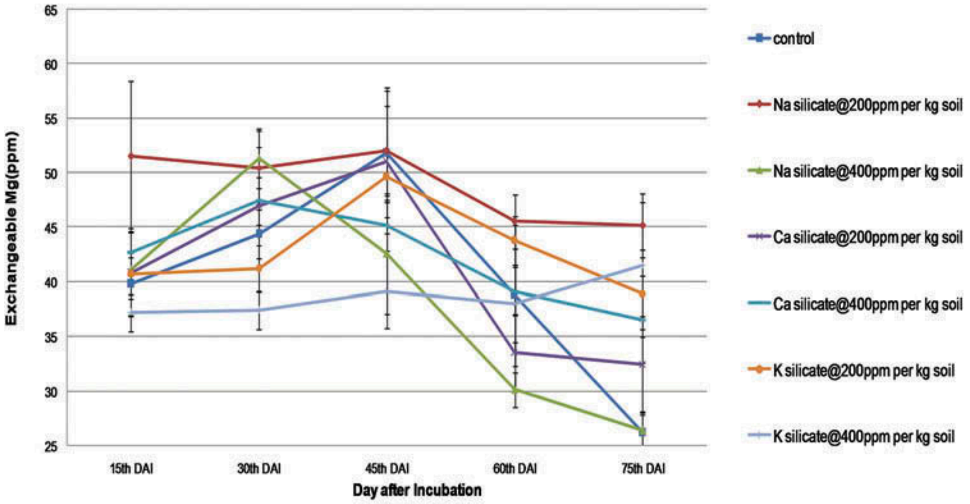


Figure 8. Orthogonal trend analysis showing the release of calcium as influenced by calcium silicate @ 200 ppm per kg soil.

With regard to the release of exchangeable calcium (Ca) in soil, application of calcium silicate @ 200 ppm (T_4) at 30th day of incubation recorded the highest value of 717 ppm followed by T_5 at the same stage (704 ppm) which are on par with each other. After that, a decreasing trend was observed (Figure 7 and Figure 8). Calcium present in the calcium silicate might have facilitated the release of Ca to the labile pool and thereby contributing to the exchange complex.

Significant relation was obtained with reference to the application of different doses of silicates and the content of Ca estimated at the sampling stages .All the treatments except that of the control recorded an increase initially followed by a decreasing trend. But the rate of increase over the initial content of 320.85 ppm was the highest for T_5 (61.76%) followed by T_4 (58.15%). On comparing sodium silicate and potassium silicate, the former @ 200 ppm per kg soil is more effective in the release of exchangeable Ca.

The relationship between the exchangeable magnesium (Mg) and the different treatments at the different sampling stage were found to be significant statistically (Figure 9 and Figure 10). The soil was innately deficient in Mg and the addition of various silicates with Ca, Na, and K as the carrier has a significant influence on the release of Mg from the exchange complex. Sodium silicate @ 200 ppm per kg soil recorded the highest value (52.02 ppm) for the exchangeable Mg at 45th DAI



LSD(A): 3.87 P Level 0.0002 LSD (B): 4.68, P Level <0.0001 LSD(AXB): NS P Level 0.042
A-Time period B- Treatments

Figure 9. Periodical release of magnesium as influenced by the treatments.

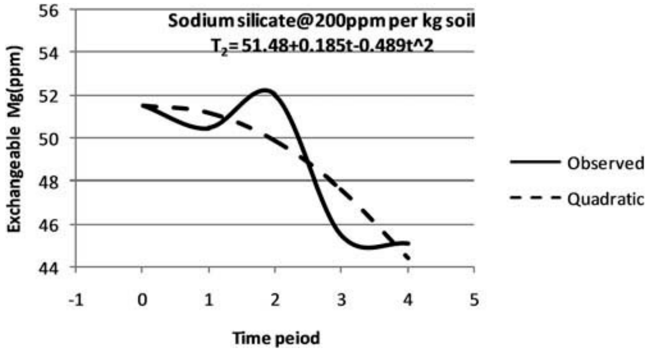


Figure 10. Orthogonal trend analysis showing the release of Mg as influenced by sodium silicate @ 200 ppm per kg soil.

evidently due to the higher solubility of the same. On comparing the individual effects of each treatment also, this recorded the significantly highest value of 48.92 ppm. Castro and Crusciol (2013) found that silicate application increases the exchangeable Ca and Mg content in soil. Correction of soil pH might result in the increase in the soil base saturation.

The positive influence of silicates on the release of exchangeable Ca and Mg in soil was emphasized by Lalithya et al. (2014).

Available sulfur

The interaction between the different treatments and the different stages of incubation was not significant with regard to available sulfur content in soil. The highest value (5.57 ppm) among all the treatment combinations was recorded by T_2 at 30th DAI. The gradual decrease in the content of

Table 1. Comparison of mean nutrient availability as influenced by the application of different treatments.

Treatments	Si (ppm)	P (ppm)
Absolute control	1.95	28.47
Sodium silicate @ 200 ppm per kg soil	3.51	26.11
Sodium silicate @ 400 ppm per kg soil	3.37	31.69
Calcium silicate @ 200 ppm per kg soil	3.27	30.27
Calcium silicate @ 400 ppm per kg soil	3.61	28.33
Potassium silicate @ 200 ppm per kg soil	3.84	25.32
Potassium silicate @ 400 ppm per kg soil	4.81	26.60
LSD (5%)	0.658	6.01
SE	0.419	2.40

available sulfur may be due to the adsorption of sulfates on the soil colloids. The carriers which were applied did not contain sulfur and hence there is no resultant chance for the gradual release of S from them. However, the interaction between Si and the major nutrients such as sodium, Ca, and K in sodium silicate, calcium silicate, and potassium silicate, respectively might have contributed for the significant difference in treatment means.

The influence of different treatments on the available nutrients over the period of incubation is depicted in Table 1. It can be seen that the trend was similar to that obtained by the interaction between the different stages of sampling and that of the treatments. The significantly highest value of 4.81 ppm with regard to the plant available silicon was shown by the application of potassium silicate @ 400 ppm per kg followed by the same applied at 200 ppm per kg soil. Sodium silicate @ 200 ppm and 400 ppm were the treatments which recorded the significantly highest values for the release of available sulfur and phosphorus in soil. Another significant parameter was with regard to the availability of calcium and magnesium in soil (Figure 11). Treatments with calcium silicate recorded the significantly highest values among all the other treatments, owing to the content of calcium in it (37%). Again, the higher release of magnesium from the exchange sites with the application of sodium silicate can be attributed to its greater solubility (22.2 g 100 ml^{-1}).

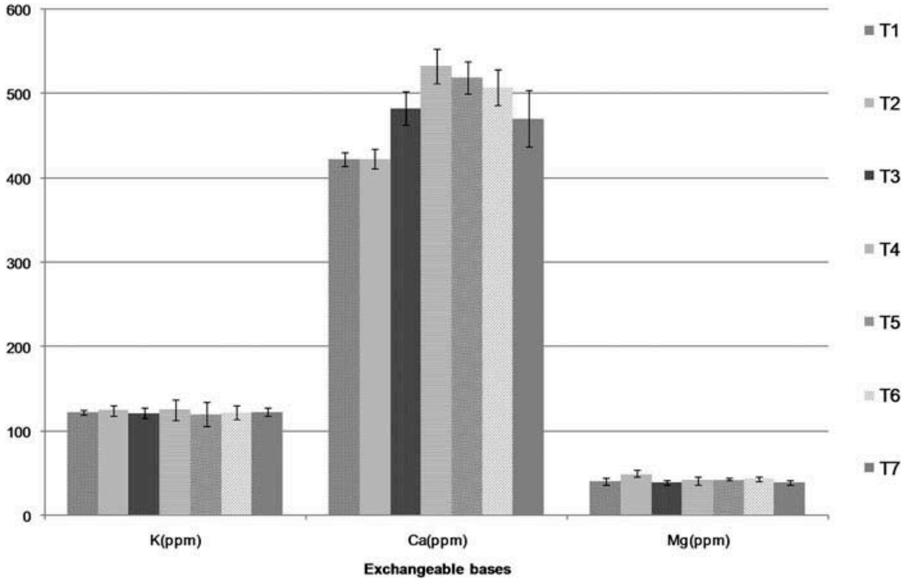


Figure 11. Exchangeable bases as influenced by different silica sources.

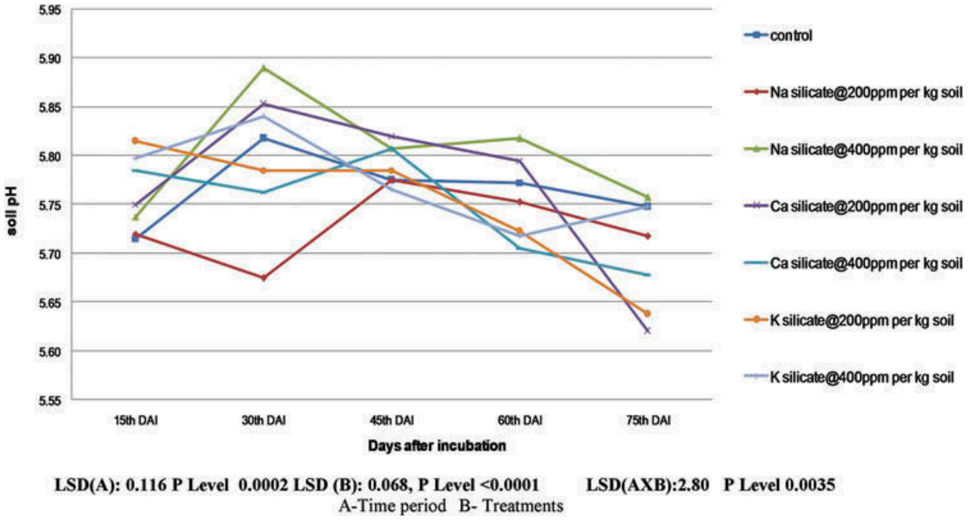


Figure 12. Soil pH as influenced by the treatments at different stages of incubation.

Soil reaction

Soil pH is a critical indicator in soil fertility management. Maintenance of proper pH in soil is essential for the uptake of essential nutrients. Figure 12 depicts the periodical change in pH brought about by the application of different treatments. Sodium silicate @400 ppm per kg soil at 30th DAI recorded the highest value (5.89) among all the combinations followed by calcium silicate @ 400 ppm per kg soil at 30th DAI (5.85). The highest percentage increase among all the treatment combinations over the different periods of incubation was shown by T_3 (2.61%) over the pre treatment pH of 5.70. The reaction between silicate anions and the protons in the soil solution can neutralize soil acidity. The positive influence of silicates on the enhancement of soil pH and thereby for the alleviation of soil acidity was emphasized by Savant, Synder, and Datnoff (1997). Ma and Takahashi (1991) found that pH increased by 1 unit after the addition of sodium silicate @ 0.47 mg Si g soil^{-1}.

The specific role of sodium silicate and calcium silicate on the enhancement of soil pH in acidic soil was emphasized by Ma and Takahashi (1990), Luz et al. (2011) and Sarto et al. (2014). Because of the higher reaction rates and mobility, silicates have the capacity for the correction of soil acidity due to the formation of an alkalinization front in the upper layers in a short period. Alcarde and Rodella (2003) recorded that the solubility of calcium silicate is 6.78 times higher than that of lime which implies their enhanced ability on the amelioration of soil acidity compared to that of lime.

Micronutrients

There is a gradual increase in the content of iron in the soil for the treatments such as T_4, T_5, T_6, and T_7 i.e., calcium silicate and potassium silicate at 200 ppm and 400 ppm, respectively. In the absolute control, there was no definite trend for the release of iron over the different stages of incubation. The highest value of 5.01 ppm was recorded by calcium silicate @ 400ppm per kg soil on the 60th DAI. In the case of manganese, treatment with the application of sodium silicate @ 200 ppm and 400 ppm per kg soil showed a gradual decreasing trend over the different stages of incubation as in the case of the treatment with calcium silicate. Potassium silicate @ 200 and 400 ppm (T_6 and T_7 respectively) showed a trend of slow release of Mn up to the 30th DAI (7.78 ppm) and thereafter showed a decreasing trend.

Silicates might have enhanced the oxidation of Fe^{2+} and Mn^{2+} and thereby reducing the bioavailability of these elements. This can prevent the abiotic stress for plants resulting from the toxicity of iron and manganese present in the soil. Silicon alters the distribution of manganese in the leaf tissues, thereby preventing it from collecting into localized areas that become necrotic.

The effects of different treatments as well as the interaction between the different treatments and the stages of sampling are not significant with regard to the available copper content at the different stages of incubation. General trend indicates the reduction in content of available Cu over the different stages of incubation. The highest value (1.19 ppm) among all the treatment combinations was registered at the 30th DAI by T_7. In the absolute control there was no definite trend on the release of Cu from the soil. The interaction between the silicon and the chelated Cu might have resulted in the initial increase in the content but toward the later stages, there have been a gradual occlusion of the element in the exchange sites of the soil.

Zinc content in the soil was significantly influenced by the application of different doses of silicates at the different stages of sampling. The highest value of 1.59 ppm was recorded by T_2 at the 45th day of incubation. A decreasing trend on the release of Zn as influenced by the application of different treatments was observed over the period. Considering the individual effects of different treatments, the highest value of 1.52 ppm was observed with the application of sodium silicate @ 200 ppm per kg soil.

Conclusion

Application of silicates in the sandy soil of Onattukara has an influence on the nutrient dynamics which facilitates the uptake of nutrients. Coconut forms the predominant component of the cropping system in this region. From the results of the incubation study, it can be seen that potassium silicate @ 400 ppm per kg soil facilitated the release of the highest amount of silicon at the 60th DAI followed by a decline in the content.

Significant influence of calcium and sodium ions from their silicates on the release of exchangeable potassium was observed and the highest value for the exchangeable K was observed at the 60th DAI followed by the decline in the content. Sodium silicate @ 200 ppm per kg soil facilitated the highest release of exchangeable Mg at 45th DAI. The release of calcium was the highest with the application of calcium silicate at 30th DAI. Results of the incubation study reveal the positive influence of the different silicates on the release of nutrient ions as well as on the soil reaction at the different stages of sampling.

Sodium silicate @ 400 ppm per kg soil recorded the highest pH at 30th DAI among all the treatment combinations. Since silicates have a role on the alleviation of soil acidity, this can be considered as an alternative to lime in crop management strategies.

For all the treatments, a gradual decreasing trend on the release of nutrients was observed and hence the split application of silicates considering the crop requirement is essential to maintain the nutrient use efficiency.

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