Eco. Env. & Cons. 28 (2) : 2022; pp. (879-885)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2022.v28i02.045

Silicon Fertilizer – An Imperative Source for Enhancing Yield and Phytolith Content of Maize Hybrid in Desilicated Soil *(Typic Rhodustalf)*

A.M. Prabha[1], P. Christy Nirmala Mary[2], P. Saravana Pandian[3], T.Sivakumar[4] and M. Shanthi[5]

[1,2,3]Department of Soils and Environment, Agriculture College and Research Institute, TNAU, Madurai 625 104, Tamil Nadu, India
[4]Department of Seed Science and Technology, Agriculture College and Research Institute, TNAU, Madurai 625 104, Tamil Nadu, India
[5]Department of Agricultural Entomology, Agriculture College and Research Institute, TNAU, Madurai 625 104, Tamil Nadu, India

(Received 8 September, 2021; Accepted 7 November, 2021)

ABSTRACT

Silicon is an important beneficial element for improving the photosynthetic efficiency and stress alleviation in crops. Phytoliths are silicon body accumulated in plant parts (plant stone) through bio-mineralization process and there is a significant positive correlation between Si content and phytolith content of crop materials including the leaves, stems and sheaths. A field experiment was focused on the effect of Soil Test Crop Response based fertilizers with silicon sources on growth, yield attributes and phytolith content of Maize hybrid Co 6 at Arasanur, Sivagangai district, Tamil Nadu under *Typic Rhodustalf* soil during 2021. The results showed that application of Soil Test Crop Response based N, P_2O_5, K_2O + calcium silicate @ 400 kg ha^{-1} and potassium silicate @ 1% foliar spray at knee high stage (25^{th} Days After Sowing) and vegetative stage (45^{th} Days After Sowing) performed well in enhancing growth and yield attributes *viz.*, Leaf Area Index (5.95), plant height (228 cm), cob length (24.95 cm), number of grains cob^{-1} (329), grain yield (6.98 t ha^{-1}), silicon content (6.07%) and phytolith content (1.22%), followed by STCR based N, P_2O_5, K_2O + calcium silicate @ 400 kg ha^{-1}+ silicate solubilizing bacteria @ 5 kg $ha^{-1}$and both are on par with each other. However, the treatments T_{10} and T_6 performed better in enhancing the growth and yield attributes of maize hybrid Co 6, the maximum Benefit Cost Ratio (2.28) was noticed in T_6 (STCR based N, P_2O_5, K_2O + calcium silicate @ 400 kg ha^{-1} + silicate solubilizing bacteria @ 5 kg ha^{-1}) should be recommended for maize production successfully in laterite soil (*Typic Rhodustalf*). In future study, it is advisable to conduct further research with different silicon sources on maize under varied soil and climatic conditions.

Key words: *Phytolith, Calcium silicate, Potassium silicate, Silica solubilizing bacteria (SSB) and Maize*

Introduction

Phytolith, a siliceous amorphous material like plant stone found within the plant cells due to bio-silicification of plant (Piperno, 2006) and it is generally referred as carbon sink available in plants and an accepted taxonomic tool to restore the ancient flora. This phytolith formation varied with crop genera and species, soil and plant parts. Carbon is occluded along with phytolith and called it as PhytOC which

([1]PG Scholar, [2]Associate Prof., [3]Prof., [4]Assistant Prof., [5]Prof. & Head) involve in carbon sequestration.

Silicon is the second most abundant element which accounts for 27.7 per cent in the earth crust and involve in biotic and abiotic stress in plants. Silicic acid [$H_4 SiO_4$] is the most suitable soluble form of silica available in soil solution which is radically absorbed by the root corticles (Sommer *et al.*, 2006). Among the cereals, sugarcane and rice are the highest silicon accumulators followed by wheat, sorghum and maize.

Maize is the third most important cereal crops after rice and wheat classified under *Poaceae* family. Application of silicon sources *viz.*, straw, basic slag, calcium silicate, potassium silicate, silicate solubilising bacteria etc., enhance the growth, yield and silicon content in plants especially in laterite soil.

Based on the above needs and importance of silica in maize plant under silica deficient soil (*Typic Rhodustalf*), a field experiment was conducted at Arasanur, Sivagangai district, Tamil Nadu with different silica sources *viz.*, calcium silicate, potassium silicate and silicate solubilising bacteria. The effect of different silica sources on maize growth, yield attributes and phytolith content were studied and summarised below.

Materials and Methods

A field experiment was conducted in Irugur soil series (*Typic Rhodustalf*) to investigate the effect of different source of silicon on maize growth and yield parameters during Thaipattam, 2021. The field experiment was conducted at Arasanur, Sivagangai district, Tamil Nadu in 9^o 8′ N latitude and 78^o 3′ E longitude.

Experimental details

A research trial was setup in Randomized Block Design with three replications. Ten treatments with different silicon sources and their combinations were imposed in maize hybrid Co 6 .The treatment details are as follows; T_1 - STCR based N, P_2O_5, K_2O, T_2 - T_1 + silicate solubilising bacteria @ 5 kg ha^{-1}, T_3 - T_1+ calcium silicate @ 200 kg ha^{-1}, T_4 - T_1 + calcium silicate @ 200 kg ha^{-1}+ silicate solubilizing bacteria @ 5 kg ha^{-1}, T_5 - T_1+ calcium silicate @ 400 kg ha^{-1}, T_6 - T_1+ calcium silicate @ 400 kg ha^{-1}+ silicate solubilizing bacteria @ 5 kg ha^{-1}, T_7 - T_1 + Foliar spray of 1% potassium silicate @ 25^{th} and 45^{th} DAS*, T_8 - T_1+ Foliar spray of 1% potassium silicate@ 25^{th} and 45^{th} DAS + silicate solubilizing bacteria @ 5 kg ha^{-1}, T_9 - T_1+ calcium silicate @ 200 kg ha^{-1}+ Foliar spray of 1% potassium silicate @ 25^{th} and 45^{th} DAS, T_{10} - T_1+ calcium silicate @ 400 kg ha^{-1} + Foliar spray of 1% potassium silicate @ 25^{th} and 45^{th} DAS. The spacing followed was 60 x 25cm.

[*DAS - Days After Sowing]

Measurement of growth parameters

Growth parameters *viz.*, plant height, leaf length and leaf breadth were recorded by using thread and measuring scale respectively. The chlorophyll index was obtained by SPAD meter. Leaf Area Index was calculated by using the formula,

$$LAI = \frac{L \times B \times \text{No. of leaves plant}^{-1} \times K}{\text{Area occupied by the plant}}$$

Where, L – length of the third leaf from the top (cm)

B – Width of the leaf (cm)

K – Constant factor (0.75)

Phytolith extraction in plants

Phytolith extraction from plant samples were done as per the procedure given by Rovner (1983) and Bowdery (1989). Dry ashing and acid digestion was done with hydrochloric acid and hydrogen peroxide. one gram of grained plant samples were taken in silica crucible and placed in muffle furnace for 8 hours at 500 ^{0}C. Samples were allowed to cool down and transferred into the test tubes. After the samples were transferred, 20 ml of 10 per cent hydrochloric acid was added. The content was centrifuged at 3500 rpm for 3 minutes and supernatant liquid was decanted. Residues remained in the centrifuge tube was rinsed with distilled water. Then 20 ml of 15 per cent hydrogen peroxide was added and placed in water bath for 20 minutes at 70 ^{0}C. Then it was centrifuged at 3000 rpm for 5 minutes and rinsed with distilled water. After decanting the solution, residues were rinsed with 1 ml of 100 per cent ethanol and kept for overnight. The residue was weighed as phytolith.

Statistical analysis

The average values of all parameters were recorded from the respective treatments and statistical analysis was done with SAS 9.4 software package.

Results and Discussion

Initial properties of soil

The pH of the experimental field soil was acidic in nature (6.63) and soluble salt content (EC) was very low (Table 1). The bulk and particle densities were in normal range. The texture of the initial soil was sandy clay loam. The cation exchange capacity of soil was 13.4 C mol (P^+) kg^{-1}. The available nitrogen and organic carbon content of soil were low, phosphorus content was in medium range and potassium content was in high range. The available silica content of soil was low (63 mg kg^{-1}).

Table 1. Initial Characterization of experimental soil

S.No	Parameters	Values
Physical properties		
1.	Texture	
	Clay (%)	21.3%
	Silt (%)	25.7%
	Sand (%)	52.75%
	Textural class	Sandy clay Loam
2.	Bulk density	1.25 Mgm^{-3}
3.	Particle density	2 Mgm^{-3}
4.	Porosity	37.5 %
Physico-chemical properties		
5.	pH	6.63
6.	EC	0.13 dSm^{-1}
7.	Cation Exchange Capacity	13.4 C mol (P^+) kg^{-1}
Chemical properties		
8.	Available N	140 kg ha^{-1}
9.	Available P	36 kg ha^{-1}
10.	Available K	350 kg ha^{-1}
11.	Organic Carbon	4.5 g kg^{-1}
12.	Available Silica	63 mg kg^{-1}

Effect of silicon fertilizers on growth parameters of maize

The data on growth parameters of maize as influenced by application of silicon fertilizers are given in Table 2. The results revealed that application of STCR based fertilizer + calcium silicate @ 400 kg ha^{-1}+ foliar spray of 1% potassium silicate@ 25th and 45th DAS (T_{10}) increased the plant height to 228.0 cm with 26.8 per cent increase over control and was statistically on par with T_9 (T_1 + calcium silicate @ 200 kg ha^{-1}+ foliar spray of 1% potassium silicate @ 25th and 45th DAS). The plant height of 211.5 cm was noted in the treatment received STCR based fertilizer application + calcium silicate @ 400 kg ha^{-1} + silicate solubilizing bacteria @ 5 kg ha^{-1} and 179.7 cm was recorded in the control plot. The plant height was significantly and positively correlated with silicon content of plant (0.977**) given in the Table 3. The increment in plant height might be due to the application of calcium silicate and foliar application of potassium silicate. The cell elongation and metabolism increased by silicon content of cell wall as confirmed with the findings of Jawahar *et al.*(2019) and Aziz *et al.* (2020).

The leaf area index was reported to be high as 5.95 and 5.63 in T_{10} and T_9 treatments respectively and both were statistically on par with each other, followed by T_6 treatment (5.15). The result illustrated by observing the positive correlation of silicon

Table 2. Effect of silicon fertilizers on growth and yield attributes of maize hybrid Co 6

Treatments	Plant Height (cm)	LAI	Cob length (cm)	Cob diameter (cm)	No. of grains cob^{-1}	Cob weight (g)	Test weight (g)	Yield (t ha^{-1})	Dry matter production (kg ha^{-1})
T_1	179.7	2.88	17.92	14.04	272	121.7	25.03	6.07	9367
T_2	185.2	3.51	18.73	14.62	283	129.3	25.34	6.32	9597
T_3	190.3	3.95	20.98	15.54	292	134.8	27.31	6.47	10575
T_4	196.4	4.51	21.6	16.89	298	139.3	27.84	6.72	11318
T_5	200.5	4.78	16.52	16.45	295	151.2	27.53	6.52	11840
T_6	211.5	5.15	23.67	17.94	313	169.1	28.07	6.85	12455
T_7	186.3	4.02	20.89	15.67	287	137.7	26.42	6.45	10185
T_8	189.4	4.23	21.14	16.82	291	142.4	26.63	6.63	10805
T_9	225.2	5.63	22.45	17.14	304	155.6	27.69	6.89	12242
T_{10}	228.0	5.95	24.95	17.32	329	162.4	27.72	6.98	12875
SEd	3.21	0.16	0.41	0.39	5.27	6.54	0.46	0.1	223.74
CD (P=0.05)	**6.74**	**0.33**	**0.85**	**0.82**	**11.06**	**13.73**	**0.96**	**0.2**	**470.07**

with LAI (0.948**). The supplemental silicate application in the form of either calcium or potassium recuperating the length and breadth of maize leaves might resulted in the highest LAI. The lowest LAI was reported in the control treatment (2.88). Silicon addition increased the LAI (Jawahar *et al.,* 2019).

Exogenous application of silicon fertilizers especially calcium silicate enhanced the silicon content of leaf (Fig. 1). The highest silicon content (6.07%) was observed in the treatment subjected to STCR based N, P_2O_5, K_2O + calcium silicate @ 400 kg ha^{-1}+ foliar spray of 1% potassium silicate @ 25th and 45th DAS (T_{10}) which was statistically on par with T_6 (5.98%) and T_9 (5.87%). The silicon content of plant was significantly and positively correlated with all growth parameters of maize might be due to the basal application of calcium silicate compared to foliar application as potassium silicate. The same trend was confirmed with the study of Aziz *et al.* (2020) in maize crop.

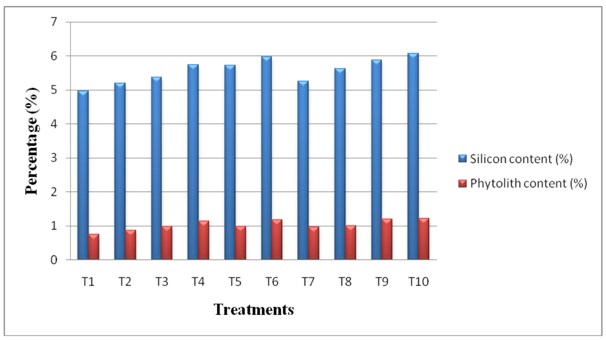

Fig. 1. Effect of silicate fertilizer on silicon and phytolith content in maize hybrid Co 6

The highest phytolith percentage (1.22 %) was observed in T_{10} treatment (STCR based N, P_2O_5, K_2O+ calcium silicate @ 400 kg ha^{-1}+ foliar spray of 1% potassium silicate@ 25th and 45th DAS) was statistically on par with T_9 (1.20%). The phytolith content of maize increased from 0.75 % (Control) to 1.20 % and 1.17% in T_9 and T_6 respectively and statistically on par with each other and also the enhancement percentage over control was 47.00 per cent (Fig 1). The silicon and phytolith percentage was significantly correlated (0.888**) in a positive manner (table 3) and the trend line was linearly fitted in the scatter diagramme (Fig. 2). The same result was confirmed with Sun *et al.* (2019) and Song *et al.* (2015) in rice crop.

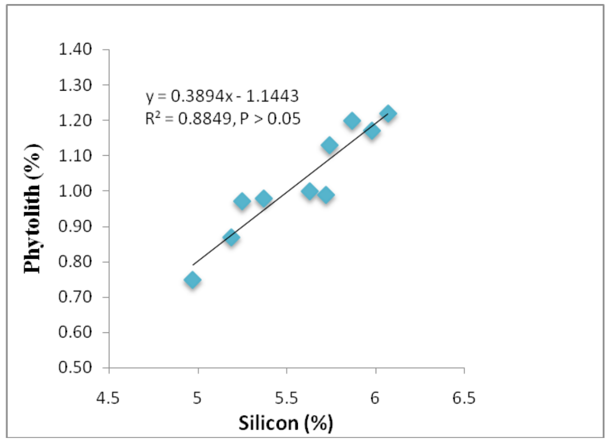

Fig. 2. Correlation between silicon and phytolith content of maize

Effect of silicon fertilizers on yield attributes

The result on yield attributes is presented in the Table 2. From the result, it could be understood that significant increment in cob length and was statistically observed in the silicon received plants analogous to control. Highest cob length of 24.95 cm (Plate 2) was observed in the plants received 1 per cent potassium silicate foliar spray combined with calcium silicate @ 400 kg ha^{-1} (T_{10}) followed by treat-

Table 3. Correlation coefficient analysis of silicon with other parameters

	Silicon	Plant height	LAI	Phytolith	Yield	DMP
Silicon	1					
Plant height	.977**	1				
LAI*	.948**	.960**	1			
Phytolith	.888**	.886**	.946**	1		
Yield	.903**	.891**	.955**	.989**	1	
DMP*	.886**	.926**	.970**	.920**	.926**	1

**. Correlation is significant at 1% significant level (2-tailed).
*LAI – Leaf Area Index
*DMP — Dry Matter Production

ment received calcium silicate @ 400 kg ha^{-1} in combination with SSB (T_6). The maximum cob width (17.94 cm diameter) was observed in the treatment received calcium silicate @ 400 kg ha^{-1} and silicate solubilising bacteria (T_6) followed by T_{10} with 17.32 cm. The lowest cob diameter was observed in control plants (T_1). Addition of silicon sources in the form of silicate fertilizers and silica solubilising bacteria enhanced the cob length and width due to the increased chlorophyll content of leaf, LAI and silicon content. This result was substantiated with the findings of Jawahar *et al.* (2019) and Sharma *et al.* (2013).

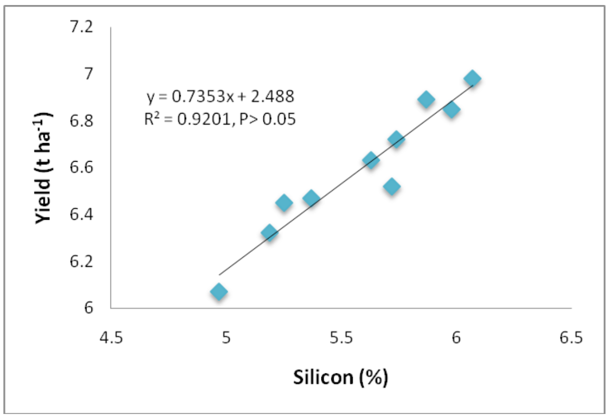

Fig. 3. Correlation between silicon and maize yield

The number of grains per cob was statistically varied among the treatments. The data revealed that maximum number of grains cob^{-1} (329) was obtained in the plants exposed to calcium silicate @ 400 kg ha^{-1} combined with 1% foliar application of potassium silicate at 25th and 45th DAS (T_{10}) followed by the treatments T_6 (313) and T_9 (304).

Application of calcium and potassium silicate uniformly increased the test weight of maize in the treatments viz., T_{10},T_9,T_6,T_3,T_4 and T_5 and all were statistically on par each other. The maximum test weight of cob (28.07 g) was observed in the treatments received STCR + calcium silicate @ 400 kg ha^{-1}+ silicate solubilizing bacteria @ 5 kg ha^{-1}. This result was validated with the study of Castro and Crusciol (2015) and Jawahar *et al.* (2019), they reported that silicon significantly improved the number of grains cob^{-1} and 100 grain weight.

The supplemental application of silicate fertilizers in combination with NPK significantly increased the dry matter production and furnished in the Table 2. The highest dry matter production of 12875 kg ha^{-1} was obtained from the plots received calcium silicate @ 400 kg ha^{-1} and foliar spray of 1% potassium silicate at 25 and 45 DAS and on par with T_6 (12455 kg ha^{-1}). The combined application of basal and foliar generated greater result compared to either of their application. The lowest value (9367.5 kg ha^{-1}) was recorded in the control plot. The silicon content of maize plants enhanced the biomass by photosynthetic activity and translocation of source to sink. This result corroborated with the investigations of Jawahar *et al.* (2020) and kaya *et al.* (2006).

The grain yield of maize was notably influenced by the silicon amendments which are represented in Table 2. The highest grain yield of maize (6.98 t ha^{-1}) was registered in the treatments received STCR based N, P_2O_5, K_2O + calcium silicate @ 400 kg ha^{-1}+ Foliar spray of 1% potassium silicate @ 25th and 45th DAS (T_{10}) followed by T_9 (6.89 t ha^{-1}) and T_6 (6.85 t ha^{-1}), both were on par with each other. The lowest yield was attained in T_1 (STCR alone–control). The result was corroborated with the study of Stepano *et al.* (2021), maize straw and grain yield was significantly raised by 10.6 % and 4.8 % respectively in silicon subjected plants compared to control. This result

Table 4. Effect of STCR based N, P_2O_5, K_2O and silicon sources on BC ratio of maize hybrid Co 6.

Treatments	Cost of cultivation (Rs.)	Gross Return (Rs.)	Net Return(Rs.)	BC Ratio
T_1	35085	66770	55965	1.90
T_2	35385	75840	59415	2.14
T_3	39085	80875	57965	2.06
T_4	39385	82320	61415	2.09
T_5	43085	81500	54715	1.89
T_6	43385	99325	59365	2.28
T_7	39405	80625	41220	2.04
T_8	39705	82875	43170	2.08
T_9	43405	96460	59945	2.22
T_{10}	47405	104700	57295	2.21

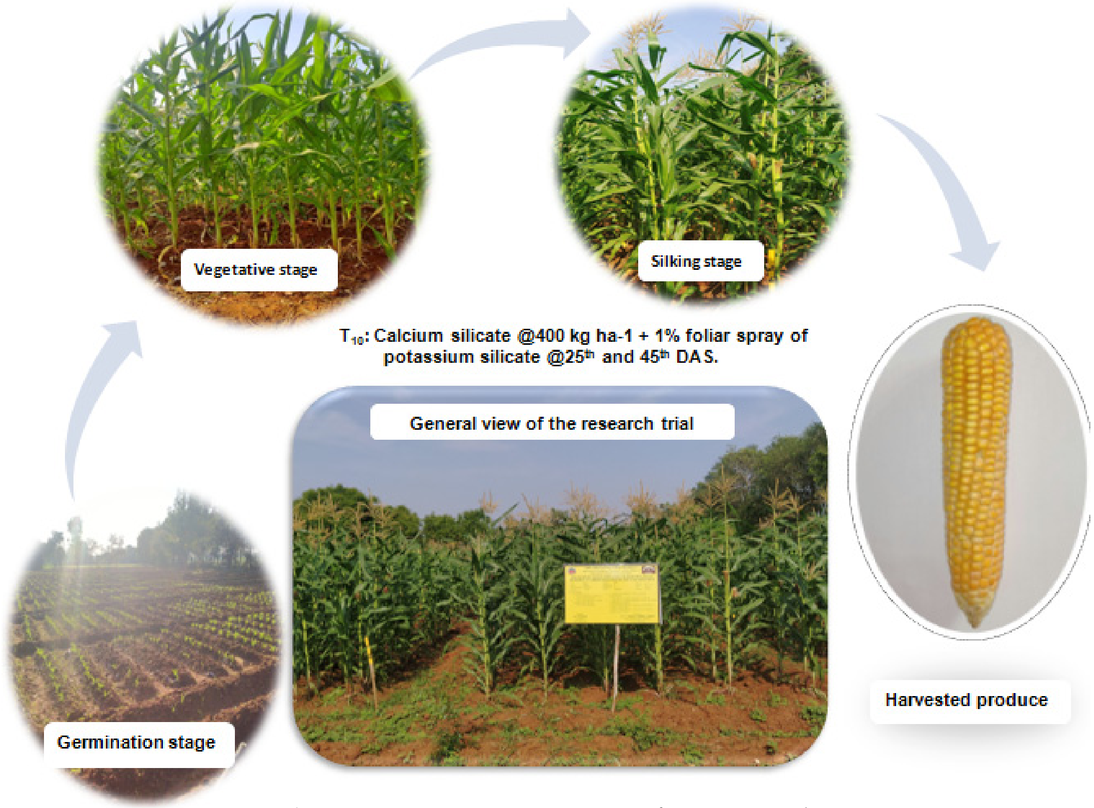

Plate 1. Stage wise representation of maize growth

Plate 2. Cob length between the treatments

also confirmed with the investigation of Korndorfer and Lepsch (2001), reported that low silicon content correlated with relatively low yield. Existence of positive correlation between the silicon content and maize yield (0.903**) was represented in table 3 and also the linear trend was noticed between silicon and maize yield (Fig 3).

Economics

The Gross Return, Net Return and Benefit Cost Ratio were worked out for this field experiment (Table 4). The results illustrated that the highest gross return of Rs.1,04,700 was obtained in T_{10} treatment (STCR based N, P_2O_5, K_2O+ calcium silicate @ 400 kg ha^{-1}+ Foliar spray of 1% potassium silicate@ 25th and 45th DAS) followed by T_6 (T_1+ calcium silicate @ 400 kg ha^{-1}+ silicate solubilizing bacteria @ 5 kg ha^{-1}). But the BCR was observed to be maximum (2.28) in T_6 treatment followed by T_9 (2.22) and T_{10} (2.21).

Acknowledgements

Authors are acknowledging the help furnished by Department of Soils and Environment, Agriculture College and Research Institute, Madurai for conducting research trials.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Aziz, A., Tahir, M. A., Sarwar, G. and Sher, M. 2020. Effect of Rice and Wheat Straw and K-Silicate Application on Maize Growth. *Pak. J.Agric Res.* 33(4): 905-910.

Bowdery, D. 1989. *Phytolith Analysis: Introduction and ap-*

plications, plants in Australian archaeology and material culture studies in anthropology. Brisbane: Watson, Ferguson and Company.

Castro, G. S. A. and Crusciol, C. A. C. 2015. Effects of surface application of dolomitic limestone and calcium-magnesium silicate on soybean and maize in rotation with green manure in a tropical region. *Bragantia*. 74 : 311-321.

Frank Stephano, M., Geng, Y., Cao, G., Wang, L., Meng, W. and Meiling, Z. 2021. Effect of silicon fertilizer and straw return on the maize yield and phosphorus efficiency in Northeast China. *Commun Soil Sci Plant Anal*. 52(2) : 116-127.

Jawahar, S., Ramesh, S., Suseendran, K., Kalaiyarasan, C. and Kumar, S. V. 2019. Effect of ortho silicic acid formulations on productivity and profitability of maize. *Plant Arch.* 19(1) : 1214-1218.

Jawahar, S., Suseendran, K., Kalaiyarasan, C., Ramesh, S., Vinodkumar, S. R. and Arivukkarasu, K. 2020. Effect of silicon on dry matter yield and nutrient uptake of hybrid maize. *Plant Arch.* 20(1): 3211-3215.

Kaya, C., Tuna, L. and Higgs, D. 2006. Effect of silicon on plant growth and mineral nutrition of maize grown under water-stress conditions. *J. Plant Nutr.* 29(8): 1469-1480.

Korndörfer, G. H. and Lepsch, I. 2001. Effect of silicon on plant growth and crop yield. *Stud. Plant Sci.* 8: 133-147.

Piperno, D. R. 2006. *Phytoliths: A Comprehensive Guide for Archaeologists and Paleoecologists.* Rowman Altamira.

Rovner, I. 1983. Plant Opal Phytolith Analysis: Major Advances in Archaeobotanical Research. *Adv. Archaeol Method Theory.* 6: 225–266. *DOI: 10.1016*. B978-0-12-003106-1.50011-0.

Sharma, J. D., Patel, K. C. and Bhavani, R, M. 2013. Yield Attributes, Chlorophyll Content and Biometric Yield of Maize (*Zea mays* L.) As Influenced by Silicon Application under Cadmium Contaminated Soil. *Asian J. Soil Sci*. 8(2): 334-338.

Sommer, M., Kaczorek, D., Kuzyakov, Y. and Breuer, J. 2006. Silicon pools and fluxes in soils and landscapes- a review. *J. Plant. Nutr. Soil Sc*. 169(3): 310-329.

Song, A., Ning, D., Fan, F., Li, Z., Provance-Bowley, M. and Liang, Y. 2015. The potential for carbon bio-sequestration in China's paddy rice (*Oryza sativa* L.) As impacted by slag-based silicate fertilizer. *Sci. Rep*. 5(1) : 1-12.

Sun, X., Liu, Q., Tang, T., Chen, X. and Luo, X. 2019. Silicon fertilizer application promotes phytolith accumulation in rice plants. *Front. Plant Sci*. 10 : 425.