WENNECK, G. S.; SCHMOELLER, K.F.; SAATH, R.; REZENDE, R.; GONÇALVES, A. C. A.; OCON, M. C. Silicon dynamics in a utissol of southern Brazil under different element sources. **Revista de Agricultura Neotropical**, Cassilândia-MS, v. 12, n. 4, e9388, Oct./Dec., 2025. ISSN 2358-6303. DOI: https://doi.org/10.32404/rean.v12i4.9388.

Revista de Agricultura Neotropical

Silicon dynamics in a utissol of southern Brazil under different element sources

Gustavo Soares Wenneck[1], Kailane Fialho Schmoeller[1], Reni Saath[1], Roberto Rezende[1], Antônio Carlos Andrade Gonçalves[1], Mariana Caetano Ocon[2]

[1] Universidade Estadual de Maringá, Maringá, Paraná, Brasil. E-mail: gustavowenneck@gmail.com, ra123516@uem.br, rssath@uem.br, rrezende@uem.br, acagoncalves@uem.br

[2] Centro Universitário Integrado, Campo Mourão, Paraná, Brasil. E-mail: oconm079@gmail.com

Received: 02/03/2025; Accepted: 30/07/2025.

ABSTRACT

Silicon (Si) is typically found in low concentrations in weathered soils, and its application can benefit crop production. This study aimed to assess the dynamics of silicon in weathered soils of southern Brazil following the application of different silicon sources. The experiment followed a completely randomized design in a 4 × 5 factorial scheme, with four silicon sources (silicon oxide, potassium silicate, calcium–magnesium silicate, and Yoorin), five evaluation periods (1, 2, 3, 4, and 5 months after application), and five replicates. Silicon content was analyzed at three soil depths: 0-5, 5-10, and 10-15 cm. Data were subjected to analysis of variance and multivariate analysis. Among the sources evaluated, potassium silicate resulted in higher silicon accumulation in the surface layer, while calcium-magnesium silicate and Yoorin led to greater silicon levels in the deeper layers, indicating differences in solubility and mobility of the sources over time.

Keywords: Agriculture, Beneficial element, Fertilizers, Weathered soil.

Dinâmica do silício em Ultissol no sul do Brasil sob diferentes fontes do elemento

RESUMO

O silício (Si) é um elemento presente em baixas concentrações em solos intemperizados, e sua aplicação tende a trazer benefícios à produção agrícola. O estudo objetivou analisar a dinâmica do silício em solos intemperizados no sul do Brasil, em função da aplicação de diferentes fontes do elemento. O experimento foi conduzido em delineamento inteiramente casualizado, em esquema fatorial 4 x 5, com quatro fontes de silício (óxido de silício, silicato de potássio, silicato de cálcio e magnésio e Yoorin), cinco períodos de avaliação (1, 2, 3, 4 e 5 meses) após a aplicação do elemento e cinco repetições. O teor do elemento foi analisado nas camadas 0-5, 5-10, 10-15 cm de profundidade. Os dados foram submetidos à análise de variância e análise multivariada. Dentre as fontes avaliadas, o silicato de potássio promoveu maior acúmulo de silício na camada superficial do solo, enquanto o silicato de cálcio e magnésio e o Yoorin resultaram em maiores teores em camadas mais profundas, evidenciando diferenças na solubilidade e mobilidade das fontes ao longo do tempo.

Palavras-chave: Agricultura, Elemento benéfico, Fertilizantes, Solo intemperizado.

1. Introduction

Silicon (Si) is one of the most abundant elements on Earth; however, its availability in tropical and subtropical regions - particularly in highly weathered soils - is naturally low (Camargo and Keeping, 2021). Although not classified as an essential element for plant growth, silicon provides several agronomic benefits (Zhang et al., 2019; Zhu et al., 2019). Long-term increases in soil Si levels typically require the use of mineral sources (Yan et al., 2018).

Exogenous application of silicon enhances plant development, improves tolerance to abiotic and biotic stress, and increases crop yield (Hoffmann et al., 2020; Nascimento et al., 2020; Katz et al., 2021). In agricultural systems, Si enrichment in soil can occur through fertilization, irrigation, biomass decomposition, mineral dissolution, or desorption from iron and aluminum oxides and hydroxides (Malavolta, 2006; Menegale et al., 2015).

Wenneck et al. (2022) reported low Si availability in a Ultisol in northwestern Paraná, with potential for improvement through external applications. Under similar conditions, silicon supplementation has shown positive effects on the productivity and economic performance of horticultural crops, including non-accumulator species (Lozano et al., 2018; Santos et al., 2021; Wenneck et al., 2021).

Given these benefits - especially in low-Si soils- studies recommend continuous inclusion of Si fertilization as part of nutrient management strategies across growing seasons (Yan et al., 2018; Zhu et al., 2019; Chakma et al., 2021; El-Saadony et al., 2021).

Moreover, silicon may provide residual benefits to subsequent crops due to its persistence in the soil after initial application (Shen et al., 2019; Wenneck et al., 2022). The bioavailability of Si depends on several factors, including soil properties, application method, source material, plant species, and the interactions among these variables (Menegale et al., 2015; Leroy et al., 2019; Nocchi et al., 2021; Schaller et al., 2021; Souri et al., 2021).

Despite its growing relevance, there is still a lack of information regarding the dynamics of Si in tropical and subtropical soils (Malavolta et al., 2006; Menegale et al., 2015; Wenneck et al., 2022). This study aimed to evaluate the dynamics of silicon in a Ultisol in northwestern Paraná, Brazil, in response to different Si sources.

2. Material and Methods

The experiment was conducted at the Irrigation Technical Center (CTI) of the State University of Maringá (UEM), located in Maringá, Paraná (23°25'S, 51°57'W; altitude 542 m). A completely randomized design was adopted, arranged in a 4 × 5 × 3 factorial scheme, consisting of four silicon sources (silicon oxide, potassium silicate, calcium and magnesium silicate, and Yoorin), five evaluation periods (1, 2, 3, 4, and 5 months after application), three soil depths (0-5, 5-10, and 10-15 cm), and five replicates.

The study was carried out using a dystroferric Red Nitosol as per the Brazilian Soil Classification System, which corresponds to a Typic Hapludult (Ultisol) in the USDA Soil Taxonomy (Santos et al., 2018), with an initial silicon content of 4.03 mg dm^{-3}. The soil was collected on site, air-dried, sieved to obtain fine earth (TFSA), and stored in polyethylene pots (experimental units) with a nominal volume of 8 dm³. Initial soil samples were analyzed for chemical and granulometric properties. The soil had 72% clay, 16% silt, 7% fine sand, and 5% coarse sand.

Chemical properties in the 0-20 cm soil depth layer were as follows: pH ($CaCl_2$): 6.30; organic matter: 1.99%; Ca^{2+} : 7.62 cmol$_a$ dm^{-3}; Mg^{2+}: 1.80 cmol$_a$ dm^{-3}; K^+: 0.46 cmol$_a$ dm^{-3}; P: 84.01 mg dm^{-3}; S: 21.63 mg dm^{-3}; B: 0.70 mg dm^{-3}; Cu: 15.24 mg dm^{-3}; Fe: 55.86 mg dm^{-3}; Mn: 127.98 mg dm^{-3}; Zn: 9.06 mg dm^{-3}; Si: 4.00 mg dm^{-3}.

Silicon sources were applied to the soil surface at a rate of 100 kg ha^{-1} of Si, with the applied amounts adjusted according to the silicon concentration in each source (Table 1) and the soil volume per pot. The application rate was defined based on studies by Lozano et al. (2018) and Wenneck et al. (2021).

The pots were kept in a protected environment, and water was applied to the soil surface at a rate of 100 mm per month, divided into biweekly applications. The water used for irrigation was sourced from a semi-artesian well with the following chemical characteristics: electrical conductivity of 158.55 µS cm^{-1}; total hardness (as $CaCO_3$) of 48.85 mg L^{-1}; calcium hardness of 36.30 mg L^{-1}; magnesium hardness of 12.55 mg L^{-1}; and dissolved silica (SiO_2) content of 45.94 mg L^{-1}.

Soil samples were collected at one-month intervals following fertilizer application. Probe-type augers were used to sample the soil at different points within each pot to avoid cross-contamination of silicon content between soil layers.

After collection, the samples were oven-dried in a forced-air circulation oven at 45 °C until they reached a constant weight.

Silicon content in the soil was determined using UV-VIS spectrophotometry, with calcium chloride ($CaCl_2$) as the extractant, according to the method proposed by Korndörfer et al. (2004). Data were subjected to analysis of variance (ANOVA) using the F-test, and means were compared using Tukey’s test at a 5% significance level. Multivariate regression analysis was also performed.

Table 1. Properties of the silicon sources used in the experiment.

Source	Si content (%)	Physical trait	Material nature
Calcium and magnesium silicates	10.5	Solid	Steelmaking aggregate (steel mill slag)
Potassium silicate	25	Solid	Rock dust
Yoorin	10	Solid	Thermophosphate
Silicon oxide	94.6	Wettable powder	Diatomaceous rock powder

3. Results and Discussion

Exogenous application of silicon significantly altered its content in the soil across all evaluated months, with an increase observed over time for all application sources (Table 2).

According to the study data (Table 2), the effects of silicon application can be distinguished by source and soil depth. Calcium and magnesium silicate and potassium silicate promoted greater increases in the upper soil layer, while Yoorin and silicon oxide resulted in higher silicon levels in deeper layers.

Although potassium silicate has high water solubility, its rapid release tends to lead to greater retention in surface layers due to the adsorption of monosilicic acid to soil colloids, particularly in highly weathered soils rich in iron and aluminum oxides (Schaller et al., 2021; Pandey et al., 2025).

Table 2. Content of silicon in the soil after application of different silicon doses.

Silicon source	Depth	Silicon content (mg dm^{-3})				
		Time after silicon application (months)				
		1	2	3	4	5
Calcium and magnesium silicate	0 to 5	4.25 cC	4.88 aA	5.10 aB	5.56 aA	5.56 bC
	5 to 10	4.35 bB	4.79 bB	5.12 aA	5.43 aA	5.57 bB
	10 to 15	4.55 aC	4.62 cC	4.68 bC	5.26 bC	5.62 aB
Potassium silicate	0 to 5	4.28 bC	4.70 bB	5.23 aA	5.55 aA	6.17 aA
	5 to 10	4.10 bC	4.71 bB	4.95 bB	5.43 aA	6.06 aA
	10 to 15	4.46 aC	4.89 aB	4.84 bB	5.56 aB	5.41 bC
Yoorin	0 to 5	4.68 aA	4.88 bA	4.86 bC	5.29 cA	5.76 bB
	5 to 10	4.24 bC	4.93 bA	4.94 bB	5.5 bA	5.45 cB
	10 to 15	4.61 aB	5.17 aA	5.35 aA	5.94 aA	6.18 aA
Silicon oxide	0 to 5	4.39 bB	4.65 bB	5.05 bB	5.56 aA	5.55 abC
	5 to 10	4.61 aA	4.67 bC	4.98 bB	5.13 bB	5.43 bB
	10 to 15	4.74 aA	4.88 aB	5.13 aA	5.14 bC	5.64 aB
Mean		4.44	4.81	5.02	5.45	5.70
Coefficient of variation(%)		4.54	3.25	3.65	4.10	4.94
Source		*	*	*	*	*
Time		*	*	*	*	**
Depth		**	*	**	*	**
Source x Time x Depth		**	**	**	**	**

*significant at 1%, **significant at 5%. Different letters within columns indicate significant differences by the Tukey test, with lowercase letters referring to soil depth and uppercase letters to silicon sources.

Less soluble sources, such as calcium and magnesium silicate, release silicon slowly and continuously, promoting its gradual migration to deeper layers, especially under conditions of continuous irrigation (Tubana et al., 2016; Korndörfer et al., 2004). Additionally, the granulometry and physical form of the fertilizers can influence their solubilization and movement through the soil profile (Savvas and Ntatsi, 2015). Therefore, the patterns observed in this study align with the expected dynamics of silicon release and mobility in soil, based on the characteristics of the applied sources.

The availability of silicon in soil depends on factors such as source characteristics, formation process, pH, organic matter, and temperature (Lopez-Perez et al., 2018). Evaluating the element in different soils would allow for broader comparisons of these factors; however, by focusing on a single soil type in this study, it was possible to isolate the effects of the silicon sources as the only variable.

Given the significant interaction among source, time, and depth (Table 2), multivariate regression analysis was performed to estimate soil silicon content following the application of different sources. The resulting models showed coefficients of determination (R^2) ranging from 0.90 to 0.94 (Table 3). According to the equations presented in Table 3, the estimated maximum silicon content for calcium and magnesium silicates, Yoorin, and silicon oxide would occur in the deepest soil layer (up to 15 cm) at the longest evaluation time after application, with predicted concentrations of 5.75 mg dm^{-3}, 6.00 mg dm^{-3}, and 5.61 mg dm^{-3}, respectively.

Table 3. Multivariate regression of silicon content in the soil as a function of time after application (T) and soil depth (P).

Fertilizer	Mathematical model*	R²
Calcium and magnesium silicate	Si = 0.0025P + 0.317714T + 4.0867	0.94
Potassium silicate	Si = -0.0128333P + 0.3782857T + 4.09373	0.93
Yoorin	Si = 0.02966667P + 0.346857T + 3.8273	0.90
Silicon oxide	Si = 0.0055P + 0.286T + 4.097222	0.92

*Si - silicon content (mg dm^{-3}), P = soil depth (cm), T = time (months).

Potassium silicate, however, exhibited a distinct behavior, with the estimated maximum content of 5.98 mg dm^{-3} occurring in the surface layer five months after application. The results presented in Table 2 indicate a gradual increase in silicon content over time, influenced by soil reactions (Menegale et al., 2015). Except for potassium silicate, the increase was more pronounced at greater depths, suggesting vertical mobility of the element in the soil profile. This finding supports the commonly observed low silicon availability in highly weathered soils (Malavolta, 2006).

Figure 1 shows response surface graphs illustrating the variation in silicon content in the soil for each source as a function of evaluation time and depth.

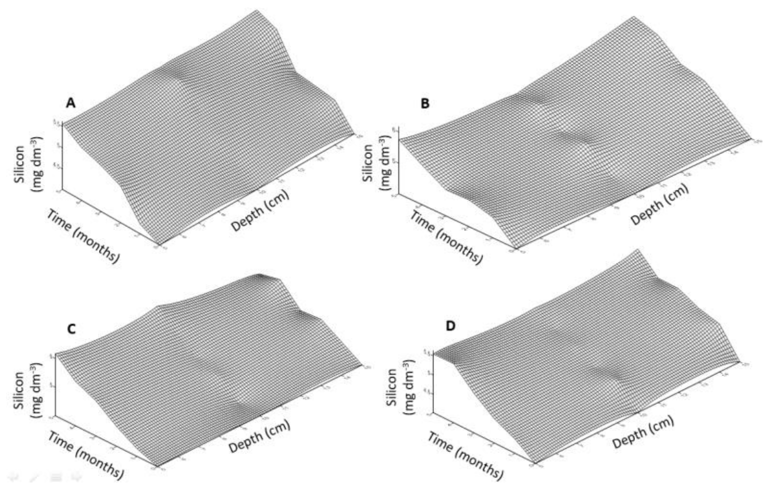

Figure 1. Response surface for silicon content as a function of soil depth and time after silicon application. A) Calcium and magnesium silicates; B) Yoorin; C) Potassium silicate; D) Silicon oxide.

The analysis of Figure 1 reinforces the patterns already observed in Table 2, indicating that potassium silicate promoted the greatest accumulation of silicon in the surface soil layer during the initial months. In contrast, less soluble sources-such as calcium and magnesium silicate and Yoorin-resulted in a more pronounced increase in deeper layers over time. These behaviors align with the solubility and gradual release characteristics of each source. Studies by Tubana et al. (2016) and Savvas and Ntatsi (2015) have reported that fertilizers with lower solubility release silicon more slowly, favoring its downward movement through the soil profile, especially under irrigation. Schaller et al. (2021) showed that highly soluble forms like potassium silicate promote immediate release, with greater retention in surface layers due to interactions with soil colloids and metal oxides, particularly in weathered soils.

The response surfaces shown in Figure 1 corroborate these findings and visually illustrate the complementary results presented in the statistical analysis (Table 2) and predictive models (Table 3).

Camargo et al. (2007) reported natural silicon concentrations in various soils ranging from 1.1 to 30.2 mg dm^{-3}, with the lowest values found in highly weathered soils. In the present study, conducted on an Ultisol, the initial silicon content was 4 mg dm^{-3}, and the application of 100 kg ha^{-1} of elemental silicon resulted in a moderate increase, with final concentrations ranging from 4.25 to 6.17 mg dm^{-3}, depending on the source and depth. As emphasized by Menegale et al. (2015) and Schaller et al. (2021), the dynamics of silicon in soil are influenced not only by dose and source but also by biological cycling and the crop's ability to absorb and translocate the element.

Given that silicon availability is affected by continuous losses through percolation, plant uptake, and immobilization (Savvas and Ntatsi, 2015; Yan et al., 2018), repeated or seasonal applications are often necessary to maintain adequate levels, especially in tropical soils with low natural reserves. For high-demand crops such as rice (*Oryza sativa*), application rates between 120 and 800 kg ha^{-1} of elemental silicon have been recommended, with optimal responses often observed within the 300-500 kg ha^{-1} range (Tubana, 2023). Nonetheless, even crops classified as non-accumulators or moderate accumulators, such as tomato and melon, have shown agronomic benefits from silicon application (Lozano et al., 2018; Hoffmann et al., 2020; Nascimento et al., 2020; Katz et al., 2021; Santos et al., 2021). These findings reinforce the importance of understanding silicon dynamics in the soil to optimize fertilization strategies under tropical and subtropical conditions. Considering the responses obtained by Lozano et al. (2018) and Wenneck et al. (2021) at higher doses than those used in the present study, future research should explore the element's behavior under increased application rates.

4. Conclusions

Applying different silicon sources influenced silicon dynamics in the soil, depending on their solubility and mobility. Potassium silicate led to the highest increase in silicon concentration in the surface layer (0-5 cm), particularly between 3 and 5 months after application, indicating rapid solubility and retention near the application site. In contrast, Yoorin and calcium and magnesium silicate showed a more gradual release, resulting in greater silicon accumulation in deeper layers (10-15 cm), suggesting increased vertical mobility over time.

Authors' Contribution

Conceptualization and methodology: Gustavo Soares Wenneck, Antônio Carlos Andrade Gonçalves. Data collection, curation and formal analysis: Kailane Fialho Schmoeller, Gustavo Soares Wenneck. Data interpretation: Gustavo Soares Wenneck, Kailane Fialho Schmoeller. Project administration and supervision: Reni Saath, Roberto Rezende, Antônio Carlos Andrade Gonçalves. Original draft preparation: Kailane Fialho Schmoeller, Mariana Caetano Ocon. Writing - review and editing: Gustavo Soares Wenneck. All authors read and approved the final version of the manuscript.

Bibliographic References

Camargo, M.S., Keeping, M.G. 2021. Silicon in Sugarcane: Availability in Soil, Fertilization, and Uptake. Silicon 13:3691-3701. https://doi.org/10.1007/s12633-020-00935-y

Camargo, M.S., Korndorfer, G.H., Pereira, H.S. 2007. Solubilidade do silício em solos: influência do calcário e ácido silícico aplicados. Bragantia 66(4):637-647. https://doi.org/10.1590/S0006-87052007000400014

Chakma, R., Saekong, P., Biswas, A., Ullah, H., Datta, A. 2021. Growth, fruit yield, quality, and water productivity of grape tomato as affected by seed priming and soil application of silicon under drought stress. Agricultural Water Management 256:107055. https://doi.org/10.1016/j.agwat.2021.107055

El-Saadony, M.T., Desoky, E.S.M., Saad, A.M., Eid, R.S.M., Selem, E., Elrys, A.S. 2021. Biological silicon nanoparticles improve *Phaseolus vulgaris* L. yield and minimize its contaminant contents on a heavy metals-contaminated saline soil. Journal of Environmental Sciences 106:1-14. https://doi.org/10.1016/j.jes.2021.01.012

Hoffman, J., Berni, R., Hausman, J.F., Guerriero, G. 2020. A Review on the Beneficial Role of Silicon against Salinity in Non-Accumulator Crops: Tomato as a Model. Biomolecules 10(9):1284. https://doi.org/10.3390/biom10091284

Katz, O., Puppé, D., Kaczorek, D., Prakash, N.B., Schaller, J. 2021. Silicon in the Soil–Plant Continuum: Intricate Feedback Mechanisms within Ecosystems. Plants 10(4):652. https://doi.org/10.3390/plants10040652

Korndörfer, G.H., Pereira, H.S., Nolla, A. 2004. Análise de silício: solo, planta e fertilizante. Uberlândia: GPSi-ICIAG-UFU. 34 p.

Leroy. N., Tombeur, F., Walgraffe, Y., Cornélis, J.T., Verheggen, F.J. 2019. Silicon and Plant Natural Defenses against Insect Pests: Impact on Plant Volatile Organic Compounds and Cascade Effects on Multitrophic Interactions. Plants 8(11): 444. https://doi.org/10.3390/plants8110444

Lozano, C.S., Rezende, R., Hachmann, T.L., Santos, F.A.S., Lorenzoni, M.Z., Souza, Á.H.C. 2018. Yield and quality of melon under silicon doses and irrigation management in a greenhouse. Pesquisa Agropecuária Tropical 48(2):140-146. http://dx.doi.org/10.1590/1983-40632018v4851265

Malavolta. E. (2006) Manual de nutrição mineral de plantas. São Paulo: Agronômica Ceres. 638p.

Menegale, M.L.C., Castro, G.S.A., Mancuso, M.A. 2015. Silício: interação com o sistema solo-planta. Journal of Agronomic Sciences, v.4, p.435-454, 2015.

Nascimento, C.W.A., Nunes, G.H.S., Preston, H.A.F., Silva, F.B.V., Preston, W., Loureiro, F.L.C. 2020. Influence of Silicon Fertilization on Nutrient Accumulation, Yield and Fruit Quality of Melon Grown in Northeastern Brazil. Silicon 12: 937–943. https://doi.org/10.1007/s12633-019-00187-5

Nocchi, R.C.F., Wenneck, G.S., Rezende, R., Furlani-Junior, E., Vila, V.V., Vieira, N.C.S., Paixão, A.P., Saath, R. 2021. Cotton fiber quality affected by water availability and silicon application. Colloquium Agrariae 17(6):80-86. https://doi.org/10.5747/ca.2021.v17.n6.a472

Pandey, R., Singh, C., Mishra, S., Abdulraheem, M.I., Vyas, D. 2025. Silicon uptake and transport mechanisms in plants: processes, applications and challenges in sustainable plant management. Biologia future 76:19-31 https://doi.org/10.1007/s42977-024-00247-x

Savvas, D.; Ntatsi, G. 2015. Biostimulant activity of silicon in horticulture. Scientia Horticulturae, 196:66–81. https://doi.org/10.1016/j.scienta.2015.09.010

Santos F.A.S., Rezende R., Wenneck G.S., Santi D.C., Saath R, Terassi, D.S. (2021) Produtividade do melão rendilhado fertirrigado com silício. IRRIGA 1(2):321–334. http://dx.doi.org/10.15809/irriga.2021v1n2p321-334

Santos, H.G., Jacomine, P.K.T., Anjos, L.H.C., Oliveira, V.Á., Lumbreras, J.F., Coelho, M.R., Almeida, J.Á., Araújo Filho, J.C., Oliveira, J.B., Cunha, T.J.F. 2018. Sistema brasileiro de classificação de solos 5th Brasília: Embrapa. 356p.

Schaller. J., Puppe, D., Kaczorek, D., Ellerbrock, R., Sommer, M. 2021. Silicon Cycling in Soils Revisited. Plants10(2):295. https://doi.org/10.3390/plants10020295

Shen, X.F., Zhao, Z.H., Chen, Y. 2019. Effects of Intercropping with Peanut and Silicon Application on Sugarcane Growth, Yield and Quality. Sugar Tech 21:437-443. https://doi.org/10.1007/s12355-018-0667-2

Souri, Z., Khanna, K., Karimi, N., Ahmad, P. 2021. Silicon and Plants: Current Knowledge and Future Prospects. Journal of Plant Growth Regulation 40:906-925. https://doi.org/10.1007/s00344-020-10172-7

Tubana, B.S. 2023. Dynamics of Silicon in Soil and Plant to Establish Silicate Fertilization. In: de Mello Prado, R. (eds) Benefits of Silicon in the Nutrition of Plants. Springer, Cham. https://doi.org/10.1007/978-3-031-26673-7_4

Tubana, B.S., Babu, T., Datnoff, L.E. 2016. A Review of silicon in soils and plants and its role in US agriculture. History and future perspectives. Soil Science 18(9/10):393-411. https://doi.org/10.1097/SS.0000000000000179

Wenneck, G.S., Saath, R., Rezende, R. 2022. Silicon accumulation in cauliflower grown in a protected environment with different water availability conditions. Pesquisa Agropecuária Brasileira 57:02392. https://doi.org/10.1590/S1678-3921.pab2022.v57.02392

Wenneck. G.S., Saath, R., Rezende, R., Andrean, A.F.B.A., Santi, D.C. 2021. Agronomic response of cauliflower to the addition of silicon to the soil under water deficit. Pesquisa Agropecuária Tropical 51:66908. https://doi.org/10.1590/1983-40632021v5166908

Yan, G.C., Nikolic, M., Ye, M.J., Xiao, Z.X., Liang, Y.C. 2018. Silicon acquisition and accumulation in plant and its significance for agriculture. Journal of Integrative Agriculture 17(10)2138-2150. https://doi.org/10.1016/S2095-3119(18)62037-4

Zhang, Y., Liang, Y., Zhao, X., Jin, X., Hou, L., Shi, Y., Ahammed, G.J. 2019. Silicon Compensates Phosphorus Deficit-Induced Growth Inhibition by Improving Photosynthetic Capacity, Antioxidant Potential, and Nutrient Homeostasis in Tomato. Agronomy 9(11): 733. https://doi.org/10.3390/agronomy9110733

Zhu, Y.X., Gong, H.J., Yon, J.L. 2019. Role of Silicon in Mediating Salt Tolerance in Plants: A Review. Plants 8(6):147. https://doi.org/10.3390/plants8060147