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Carbon Sequestration in Soil with Silicon: A Green Solution for Climate Change

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Introduction

Finding practical strategies to lower CO_2 in the atmosphere is essential as climate change picks up speed. Using silicon in agriculture to improve soil carbon sequestration is one possible approach. By storing carbon in the form of phytoliths, which are minute particles that stay stable in soil for thousands of years, silicon—which is already known for its role in enhancing plant health and soil fertility—is now recognized for its potential to aid in the fight against climate change. Particularly in grasses (monocots), which tend to absorb more silicon than broadleaf plants (dicots), silicon is absorbed by the plant and integrated into the tissues. By increasing the amount of carbon stored in phytoliths, this process makes the soil a permanent carbon sink. By boosting this natural process, silicon fertilizers can lower atmospheric CO_2 levels and provide a sustainable, natural remedy for global warming. Silicon-based methods can help reduce climate change, enhance soil health, and strengthen ecosystem resilience by increasing soil's ability to retain carbon. A straightforward yet effective tactic with long-term advantages for agriculture and the environment is the use of silicon for carbon sequestration.

Carbon Sequestration and Its Importance

Understanding carbon sequestration is crucial before examining silicon's role. With more carbon stored in them than in the atmosphere and vegetation combined, the soils on Earth are one of the biggest carbon sinks. The technique of absorbing and holding onto atmospheric carbon dioxide in liquid or solid form to stop it from causing global warming is known as carbon sequestration.

Terrestrial and oceanic carbon sequestration are the two primary forms. Because of microbial activity and the creation of organic matter from plant waste, soil is essential to the

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capture and storage of carbon in terrestrial ecosystems (Wani *et al.,* 2023). Plants collect CO_2 from the atmosphere and transform it into organic matter through a process called photosynthetic respiration. Through root systems, some of this material is moved to the soil, where it may be preserved for decades or even centuries. However, soil carbon stocks have frequently been weakened by agricultural practices, reducing the soil's capacity to sequester carbon and its overall health (Hussain *et al.,* 2021). Innovative methods to increase soil's capacity to store carbon are now required, and silicon is showing promise as one such method.

Why Silicon is Essential for Plant and Soil Health?

Silicon (Si) is a naturally occurring element found in soil, primarily in the form of silica (SiO_2). It is the second most abundant element in the Earth's crust, after oxygen. Mono-silicic acid (H_4SiO_4), the plant-available form of silicon, is found in soil solutions at concentrations ranging from 0.1 to 0.6 mM (Tonkha *et al.,* 2021). This is around two orders of magnitude greater than phosphorus (P) concentrations. Silicon is absorbed and moved throughout the plant, where it forms SiO_2 phytoliths in the intercellular gaps, cell walls, and lumen. Silicon is an important supporting element for plant growth and soil health, even though it is not categorized as an essential nutrient for plants like nitrogen, phosphorus, or potassium are (Sharma *et al.,* 2023). Silicon helps plants in several ways:

1. **Strengthening Cell Walls**: Plant cell walls are strengthened and made more stiff by the incorporation of silicon. This makes plants more resilient to physical stresses like wind and drought and increases their capacity to fight diseases and pest attacks.
2. **Improving Nutrient Uptake**: In order to improve the general health and productivity of plants, silicon can improve the uptake of other vital nutrients (macro and micronutrients).
3. **Enhancing Stress Tolerance**: Silicon improves root development, increases water retention, and lowers oxidative damage in plant cells, all of which help plants withstand abiotic challenges including heat, salinity, and drought.
4. **Promoting Soil Health**: By encouraging the aggregation of soil particles, silicon also plays a critical function in enhancing soil structure. This enhances soil porosity, decreases soil compaction, and promotes water infiltration—all of which are vital for plant growth and carbon storage.

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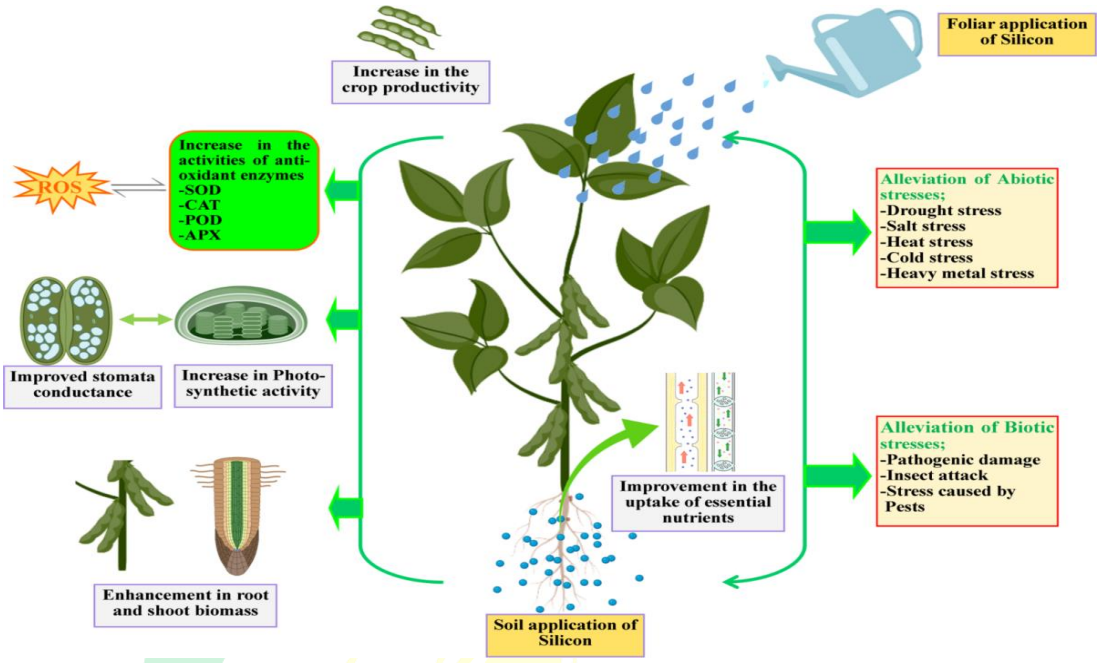

Fig. 1. Impact of silicon on plant growth under stress condition (Source: Khan *et al.*, 2022)

What Role Does Silicon Play in Carbon Sequestration?

Silicon aids carbon sequestration in multiple ways, both directly and indirectly. Here's how:

1. **Improving Carbon Storage in Soils:** Long-term carbon storage capacity in soil can be enhanced by the presence of silicon. The process known as silicon-induced stabilization of organic matter is responsible for this. Plants integrate silicon into their cell walls when they absorb it from the soil. The carbon contained in these plants' biomass is released into the soil upon their death, where it can settle and be held for a long time. In the soil, silicon encourages the development of stable organic-mineral compounds. This indicates that organic carbon, such as that found in decomposing plant debris, is bonded to soil minerals and cannot be released as CO_2 back into the atmosphere. Long-term carbon storage is facilitated by the increased amounts of stable soil organic matter found in silicon-enriched soils.
2. **Enhancing Soil Structure and Mitigating Soil Erosion:** Soil erosion is one of the biggest obstacles to efficient carbon sequestration. Important topsoil, especially the organic matter that stores carbon, can be washed away by erosion. By encouraging soil aggregation, silicon contributes to better soil structure by lowering soil erosion and increasing water retention. Soil microorganisms, which are essential to the decomposition and stabilization of organic

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carbon, benefit from the improved soil structure as well. Silicon helps to create a more robust and sustainable carbon sink by enhancing the soil's capacity to hold carbon and stop erosion.

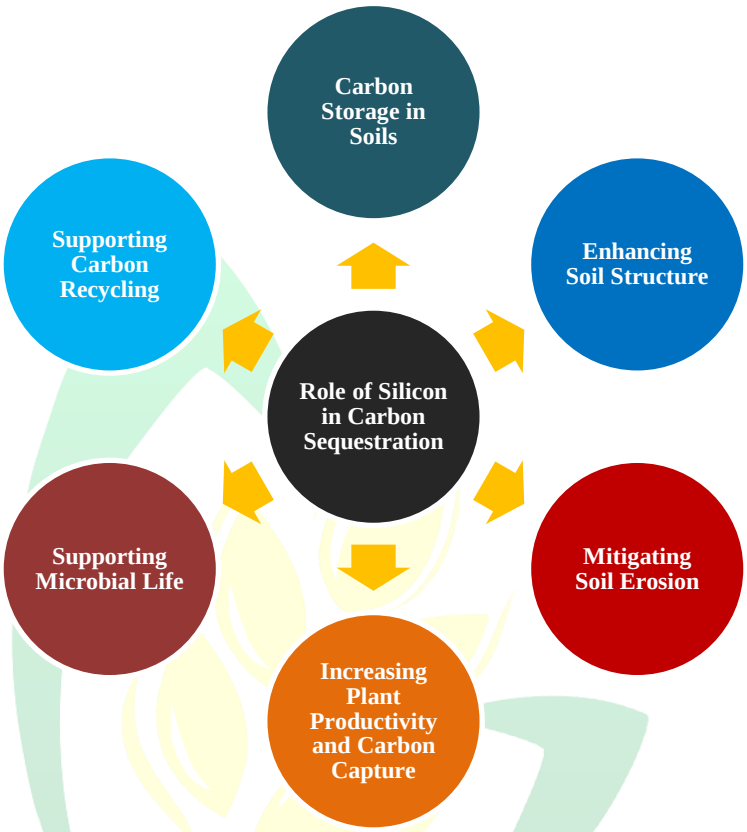

Fig. 2. Role of Silicon in Carbon Sequestration

3. **Increasing Plant Productivity and Carbon Capture:** Carbon sequestration is indirectly increased by silicon's capacity to increase plant growth and productivity. Through photosynthesis, plants absorb carbon dioxide; as they develop more efficiently, they are able to absorb more CO_2. Silicon helps plants grow stronger and quicker, which increases biomass production by enhancing plant health, stress resistance, and nutrient uptake. Carbon sequestration is further improved by increasing biomass, which increases the amount of organic carbon stored in the soil.
4. **Supporting Microbial Life and Carbon Recycling:** Microorganisms found in soil are essential to the carbon cycle. Microorganisms decompose the organic carbon that plants release into the soil and either store it there or release it as CO_2. By enhancing soil structure and nutrient availability, silicon can support a thriving microbial population. Additionally,

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silicon seems to play a part in encouraging advantageous microbial activities that improve the decomposition and soil stability of organic carbon.

Real-World Benefits of Silicon in Agriculture: Enhancing Crop Growth and Soil Health

Farmers seeking to increase crop yields and soil health while also aiding in carbon sequestration are increasingly turning to silicon-based agricultural products, such as silicon fertilizers and soil additives. The following are a few actual uses of silicon in agriculture:

1. **Silicon Fertilizers:** The silicon that plants require to grow is provided by silicon fertilizers, like potassium silicate, calcium silicate, sodium silicate and magnesium silicate, which are especially helpful in regions where soils lack silicon. By strengthening root systems, improving plant resistance to stress, and improving soil structure, these fertilizers can indirectly increase soil carbon storage through improved soil health and increased plant growth (Jalali *et al.*, 2024).
2. **Soil Amendments:** Additionally, silicon can be added straight to soil as an amendment (rice husk ash, diatomaceous earth, crushed quartz, volcanic ash, etc.). Amendments based on silica aid in enhancing the physical characteristics of the soil, including nutrient availability, drainage, and water retention (Zarebanadkouki *et al.*, 2022). By strengthening the soil's structure and lowering erosion, these amendments can boost the soil's capacity to retain carbon, ensuring that more of it stays in the soil.
3. **Carbon Farming Techniques:** Carbon farming strategies, which use certain agricultural techniques to improve soil carbon absorption, are being used by farmers more and more. Farmers can increase the efficacy of carbon farming initiatives by integrating silicon into these methods (Sharma *et al.*, 2021). To improve soil carbon storage, silicon-based products can be included into organic farming methods, crop rotation systems, and no-till farming.

Challenges and Future Prospects

Although silicon has a lot of promise for sequestering carbon, there are a number of obstacles to overcome. The need for additional study to completely comprehend the processes by which silicon improves soil carbon storage is one of the primary challenges. To determine the ideal circumstances for adding silicon to soils and to measure its long-term effects on carbon sequestration, more research is required. Additionally, the broad use of silicon-based farming methods will necessitate investments in the creation of more effective and economical

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silicon fertilizers and amendments, as well as farmer education and outreach. Nonetheless, silicon appears to have a promising future in agriculture. Silicon may be essential to strengthening carbon sequestration efforts and fostering climate resilience in light of the increased interest in sustainable farming methods and the pressing need for efficient climate change mitigation solutions.

Conclusion

Climate change is one of the most pressing issues in recent time, and silicon provides a novel and environmentally friendly solution. Silicon offers an efficient and sustainable method of absorbing atmospheric carbon and lessening the effects of global warming by boosting plant productivity, improving soil health, and directly assisting in carbon sequestration. Its function in agriculture may grow increasingly more significant as research into the connection between silicon and carbon sequestration develops, changing our understanding of crop production, soil management, and climate change mitigation. We can take a big step toward creating a more resilient and sustainable agriculture system that not only feeds the globe but also helps shield it from the effects of climate change by embracing silicon's potential.

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