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REVIEW ARTICLE

Silica fertilization to enhance carbon sequestration in crops: A review

M Amal Krishnan[1], R Rajeswari [1]*, S Maragatham[1], Pon Sathya Moorthy [2] & S K Rajkishore[3]

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India
[2]Department of Basic Engineering and Applied Sciences, Agricultural Engineering College and Research Institute, Kumulur,Tiruchirappalli 621 712, Tamil Nadu, India
[3]Department of Renewable Energy Engineering, Tamil Nadu Agricultural University, Coimbatore 641 003, Tamil Nadu, India

*Correspondence email - rrajeswaritnau@gmail.com

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Abstract

Carbon sequestration is a key strategy to mitigate climate change by capturing and storing atmospheric CO_2, with the aim of achieving net-zero emissions by 2050. It is categorized into geological, biological and soil-based methods. Geological sequestration stores CO_2 in deep formations such as saline aquifers and depleted reservoirs, with supercritical CO_2 injection optimizing storage. Biological methods utilize microorganisms such as algae and fungi, while soil-based approaches focus on practices like silica fertilization to enhance carbon storage. Silicon (Si) fertilization promotes phytolith formation, silica structures in plants that trap organic carbon (Phyt OC). Phytoliths persist in soils for centuries, contributing to long-term sequestration and indirectly supporting carbon capture and storage (CCS) technologies. Silicon also enhances plant resilience, photosynthesis and stress tolerance, thereby boosting biomass production and soil carbon stocks. Innovative techniques such as the sol-gel process transform silica-rich industrial wastes into fertilizers, promoting sustainable agriculture and reducing environmental impacts. These fertilizers improve carbon sequestration by enhancing phytolith production, particularly in crops like wheat. An integrated approach that combines silica fertilization, regenerative farming and advanced technologies optimizes the carbon sink capacity of agricultural soils. Additionally, phytoliths aid paleo ecological research by preserving historical vegetation data. However, balanced silica application is crucial to maintain soil health. This integrated strategy offers a sustainable solution to mitigate excessive carbon emissions, enhance soil carbon storage and support global climate goals.

Keywords: carbon sequestration; phytolith; silica; silica fertilization

Introduction

One important strategy in the fight against climate change is carbon sequestration, which is the process of capturing and storing atmospheric CO_2. Like other pollutants, CO_2 can be either reduced or repurposed to eliminate it from the atmosphere. Progress is being made in both reduction and repurposing. By 2050, industries aim to achieve net-zero emissions to help limit the global temperature increase to below 1.5 °C (1).

Reducing the emission of CO_2 is one of the best methods to reduce global warming. Using Carbon Capture, Utilization and Storage (CCUS) technology, implementing Best Available Techniques (BAT) for industrial retrofitting and increasing energy and material efficiency are all effective ways to reduce CO_2 emissions (2). These measures are particularly valuable in developing nations, where the adoption of efficient technologies can significantly reduce emissions (3). Additionally, the use of machine learning in emission monitoring offers a more accurate and efficient alternative to traditional methods (4). The advancement of fuel cell systems is also vital for CO_2 reduction, highlighting the importance of further development in both fuel cell and carbon capture technologies to enhance their emission-mitigating potential (5). Together, these strategies offer a comprehensive approach to addressing climate change and promoting sustainable practices. In the modern world, net-zero emissions are becoming a significant topic.

When assessing soil management techniques for raising soil organic carbon (SOC) in agricultural top soils, the phrases "carbon sequestration" and "carbon storage" are often used interchangeably, though they refer to related but distinct processes (6). Carbon sequestration is the process by which atmospheric CO_2 is transferred into the soil through plant biomass and residues, which are then stored as organic matter in the soil or it is the process of removing and storing CO_2 from the atmosphere in order to lower its concentration and lessen its impact on global warming (7). Capturing and storing atmospheric CO_2 is a key tactic in the fight against climate change.

Soil, as a significant carbon reservoir, can enhance sequestration through sustainable agricultural practices. The potential of silica fertilization to improve carbon sequestration in crops is reviewed in this paper, with a focus on the creation of phytolith-occluded carbon (Phyt OC), which can linger in soils and sediments for centuries. By enhancing mechanical protection, triggering antioxidant enzymes and establishing an environment that is unfavourable to pathogens, silica treatment can enhance carbon sequestration. Organic carbon and CO_2 are occluded within phytolith structures because of plants absorbing silica, creating extremely stable phyto carbon molecules that can linger in soil for decades. A sustainable source of silicon that is available to plants is provided by new methods for creating silica fertilizers from industrial waste streams. For plants, Si offers advantages such as increased resistance to pests, diseases and drought stress. Si fertilization can enhance carbon sequestration by encouraging the formation of phytoliths and boosting Si accumulation in crops. The usage of silicate fertilizers, like nano silica, is associated with increased formation of phytoliths, which are effective carbon sequesters. Silicate fertilizer has the potential to increase carbon sequestration rates from 0.94 million to 2.17 million tons CO_2 annually (8).

The process of capturing CO_2 through phytoliths is inherently slow, involving the growth and eventual decay of plants that absorb CO_2 through photosynthesis and convert it into organic matter. Once the plant material decomposes, phytoliths remain in the soil, providing a long-term storage solution for carbon and helping to stabilize CO_2 levels over extended periods. Plants are among the highest utilizers of CO_2, making them an excellent option for carbon capture, as they convert atmospheric CO_2 into biomass stored in various forms, including phytoliths. Additionally, the presence of phytoliths in the soil can enhance soil fertility and structure, promoting healthier ecosystems that further contribute to carbon sequestration. Utilizing plants for carbon capture is a natural and sustainable method that relies on existing biological processes rather than artificial technologies. Encouraging the growth of diverse plant species not only aids in carbon capture but also supports biodiversity, which is crucial for ecosystem resilience. The process of encapsulating CO_2 through phytoliths is slow, its effectiveness is significant. The plant kingdom's unparalleled ability to utilize CO_2 offers a promising avenue for carbon capture and by harnessing these natural processes, we can develop sustainable strategies to mitigate climate change and promote a healthier planet. As research continues to explore the potential of phytoliths and other plant-based methods, it is essential to recognize their role in the broader context of carbon sequestration efforts.

Carbon sequestration

From an early study conducted by Freund and Ormerod (1997) identified several options available for storing CO_2 including, "Underground storage in depleted oil and gas reservoirs or deep saline aquifers, ocean storage by injecting CO_2 into deep ocean waters and terrestrial storage through afforestation and reforestation".They also noted that while CO_2 capture is expensive, storage costs are comparatively lower (9). Subsequent research has expanded significantly on the fundamentals of carbon sequestration. According to Follett (2001), "If the amount of carbon entering the soil exceeds that lost to the atmosphere through oxidation, soil organic carbon (SOC) increases (10). Such an increase can result from practices that include, 1) improved tillage management and cropping systems, 2) management practices that increase land cover and 3) efficient use of production inputs such as nutrients and water" (10). CO_2 capture across various regions is illustrated in Fig. 1.

Types of carbon sequestration

Carbon sequestration is generally categorized into three main types geological, biological and technological (Fig. 2).

Geological carbon sequestration (GCS): Geological carbon sequestration involves capturing and storing anthropogenic CO_2 in deep, permeable geologic formations (11). This approach involves the capture of CO_2 from various sources,

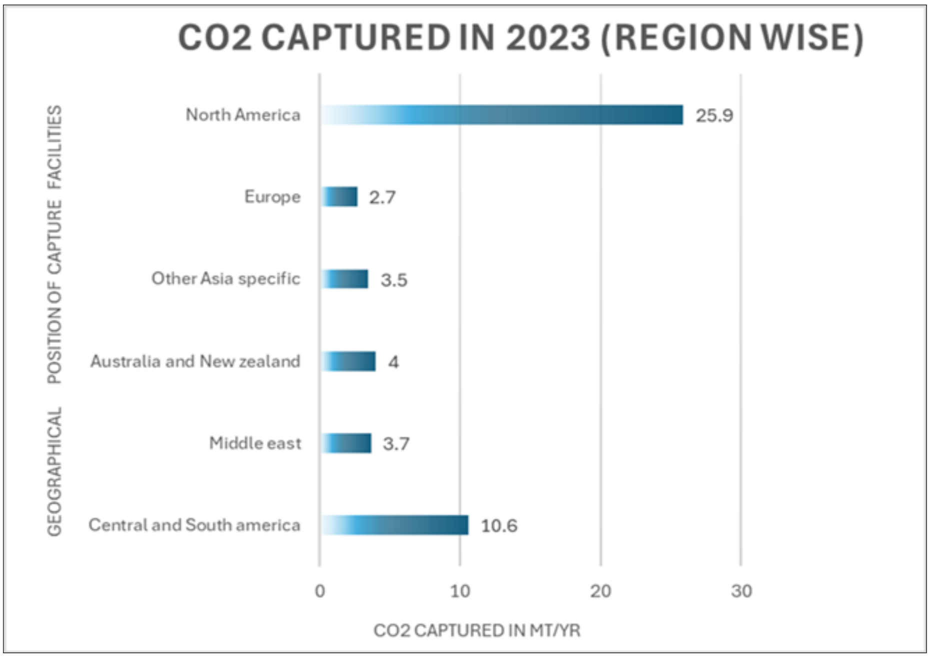

Fig. 1. CO_2 captured in different geographical areas.

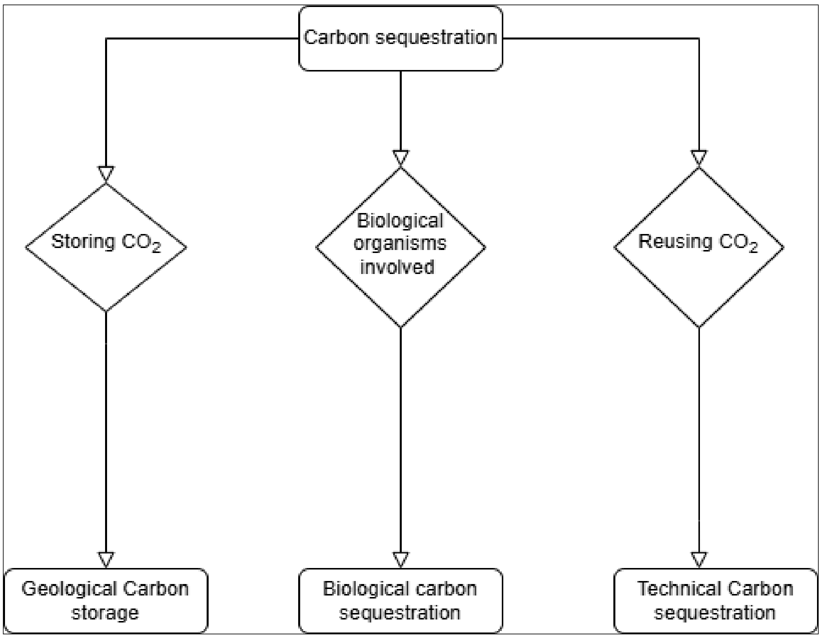

Fig. 2. Types of carbon sequestration.

followed by its transportation and storage in geological sinks such as deep saline aquifers, depleted oil and gas reservoirs and coal seams (12). The storage capacity differs among geological structures, with deep saline aquifers and depleted oil and gas reservoirs offering significant potential. Depending on how CO_2 is captured, there are four trapping mechanisms: structural and stratigraphic, residual, solubility and mineral. The method of trapping CO_2 varies depending on the mechanism. It is essential to comprehend how CO_2 is captured in order to maximize storage effectiveness and reduce leakage hazards (13). It focuses on injecting CO_2 into porous and permeable rock formations at depths of 800 meters or deeper. At these depths, the pressure and temperature conditions convert CO_2 into a supercritical state, where it behaves like a liquid, characterized by low viscosity, low water solubility and high density (14). Due to their high surface area and pore volume, materials such as activated carbon, porous silica, zeolites, hollow fibers and alumina are commonly employed in carbon capture technologies (15).

Technological carbon sequestration: The captured CO_2can be used for manufacturing industrially important products such as formic acid, petro chemicals etc.Formic acid can be manufactured sustainably through homogeneous catalysis with hydrogen and electrochemical reduction (ER) of CO_2, processes that use 0.83–0.96 kg of CO_2 per kg produced. Despite challenges such as energy-intensive purification and dependence on renewable energy, these methods significantly lower greenhouse gas emissions, reduce reliance on fossil fuels and support renewable energy integration, promoting sustainability in the chemical sector (16). Whereas in the oil industry, CO_2 injection into reservoirs enhances production by reducing oil viscosity and increasing reservoir pressure, potentially improving output by up to 15 % while enabling CO_2 reuse through reinjection (17). Similarly, converting CO_2 into valuable petrochemicals such as acrylic acid, furoic acid, ethylene and 2,5- dicarboxylic acid contributes to sustainability by integrating CO_2 reuse into existing facilities, fostering a circular economy, lowering emissions and adding value to CO_2 waste streams (18).

In agriculture, sustainable urea fertilizer production relies on renewable CO_2 sources like controlled biomass burning, biogas upgrading and direct air capture (DAC), requiring 0.735-0.75 tons of CO_2 per ton of urea produced, thereby reducing the environmental impact of fertilizer manufacturing (19). CO_2 is also utilized in carbonated beverage production as an acidic agent, taste stabilizer and antibacterial ingredient, with 9.52 kg of CO_2 needed per 1000 liters of carbonated water. Its high purity (99 %) ensures product quality while maintaining sustainability (20). In Europe, the production of up to 12.5 million tons of hydrogen annually from sustainable biomass such as agricultural residues and waste, has the potential to offset 133 million tons of CO_2 yearly when combined with bioenergy and carbon capture storage (BECCS), making it particularly useful for hard-to-electrify sectors like cement and steel (21).

CO_2 captured from industrial flue gases can be transformed into synthetic natural gas (SNG) using renewable hydrogen. Although this approach faces economic challenges compared to fossil natural gas, it shows promise in leveraging existing infrastructure and balancing the energy grid (22).

Biological carbon sequestration: Biological carbon sequestration involves the use of microorganisms like bacteria, algae, fungi and yeast to capture and convert atmospheric CO_2 into organic compounds (23). Arbuscular mycorrhizal fungi (AMF) and goethite together enhanced carbon sequestration in soil by promoting rhizodeposit stabilization in macroaggregates and organo-mineral complexes (24). Microalgae can be used for carbon sequestration and wastewater treatment. Since microalgae can efficiently capture CO_2 through photosynthesis and remove nutrients from wastewater. The key factors affecting their growth including strain selection, cultivation conditions, nutrient availability and CO_2 concentration (25). Agricultural methods can also help in carbon sequestration. A variety of farming methods and technologies allow more carbon from crop residues and other biomass to be retained and stored in soils as SOC (26). Silicate fertilizers can significantly contribute to carbon sequestration by enhancing Phyt OC accumulation in plants (27).

Silica

Silica is an essential element in many industries due to its unique properties. It holds significant economic value and has substantial potential in healthcare also. Silica nanoparticles (SiNPs) are especially useful in medical imaging as they act as contrast agents and fluorescent markers, facilitating precise diagnosis and tracking of diseases. In the realm of regenerative medicine, these nanoparticles excel in applications like wound healing and bone regeneration because they can be incorporated into biomaterials that allow for controlled drug release (28). In the construction industry, industrial silica sand has emerged as a viable alternative to conventional fine aggregate in concrete. Research revealed that a mix of 80 % coarse silica sand and 20 % river sand not only improved the compressive strength to 34.5 MPa but also outperformed traditional concrete (29). Moreover, using silica sand as a 20-30 % substitute offers several advantages like compressive strength and other strength parameters (29).

Silica-based materials play a crucial role in food industry applications through their diverse synthesis methods and versatile properties. These materials, produced through gaseous, liquid or mechanical routes, serve three essential functions: they act as enzyme immobilization hosts to enhance stability and reduce costs; function as hybrid fillers in food packaging to improve mechanical properties and extend shelf life and enable the development of sensitive detection systems for food contaminants (30).

Silicon (Si) is considered a "quasi-essential" element for plants, providing benefits such as increased resistance against pathogens, pests and drought stress. Plants absorb Si from the soil as ortho silicic acid, which is then transported via the transpiration stream and deposited in various plant parts such as cell walls and leaves (31). Fertilization with Si compounds can significantly increase Si accumulation in crops such as wheat. A study found that sodium silicate was the most efficient Si fertilizer for enhancing wheat Si content, followed by silica gel and pyrolytic silica particles. This was correlated with the ease of formation of plant-available ortho silicic acid from these compounds in the soil (31). The silica can improve the carbon sequestration by forming phytolith by accumulating around the cell. A study indicated that silica phytolith accumulation in wheat cultivars can increase significant carbon sequestration potential (32). Excess silica intake in can lead to accumulation. This accumulation is different for different species (Table 1). The accumulation of silica in plants can have significant agronomic benefits such as improving nutrient-use efficiency, enhancing resistance to pests and diseases and reducing the need for pesticides and fungicides (33).

Table 1. Si accumulation in plant species

Plant species	Si Accumulation	References
Rice (*Oryza sativa*)	High Si accumulator; stores Si as amorphous silica	(79)
Liverwortshorsetails, clubmosses, mosses	Varying Si concentration	(69)
Sedges and wetland grasses	Also significant Si accumulators	(80)
Oat (*Avena sativa*)	Distribution of Si in different oat plant parts	(81)

Beneficial effect

Silicon (Si) plays a significant role in enhancing resistance to various biotic stresses from pathogens and pests by contributing to strengthening mechanical protection as well as inducing the synthesis of antioxidant enzymes and defence-related hormones that help resist herbivory through direct and indirect modes of resistance (34). Si might also create an unfavourable environment for pathogens in the plant apoplast and interfere with host recognition by the pathogen, leading to an incompatible interaction (35). Moreover, Si is known to alleviate abiotic stress tolerance in plants, especially metal toxicity. A previous study demonstrated that Si ameliorates aluminium toxicity through Si-binding aluminium in the apoplasm (36). Si also mitigates toxicity from other metals and metalloids through co-deposition in the apoplast in addition to other mechanisms occurring inside the plant, although gaps remain to be fully elucidated (37). It also protects against pathogens such as fungi, bacteria, viruses and herbivores including insects, mammals and molluscs (35). The deposition of silica bodies (phytoliths) in plant tissues confers physical strength and rigidity, thereby acting as a barrier to pathogen penetration and herbivory (38).

In addition to alleviating stress, Si beneficially affects unstressed plants by improving photosynthetic efficiency, modulating oxidative stress via antioxidant enzymes, altering mineral nutrition and delaying senescence (39-43). Interestingly, Si interacts with major phytohormone signalling pathways such as Si can interacts in jasmonic acid pathway (44), salicylic acid (45) indicating its potential role in primary metabolism. Despite this vast array of beneficial effects, the fundamental mechanisms underlying the effects of Si on plant biology remain poorly understood.

Transportation of silica in plant

The researchers identified Lsi1 as a gene that encodes an aquaporin-like transmembrane protein that is permeable to silicic acid (46). The study found that suppressing Lsi1 in a rice cultivar reduced biogenic silica deposition in shoots over 12 hrs, whereas the expression of Lsi1 in Xenopus oocytes enhanced silicon content compared to water-injected oocytes over 30 min. Studies revealed that silicon enters the rice roots and oocyte cytoplasm as silicic acid (47). The Si uptake system was further defined by investigating the impact of the three transporter inhibitors on Si uptake in both wild-type rice and a mutant (GR1). GR1 is a mutant in which the silicic acid absorption pathway is interrupted (48).

Water channels in plants that carry silicic acid are transporters of silicon and are specific for silicic acid. However, some argue that the word "transporter" is misleading because, according to biochemical definitions, a transporter is a protein that attaches to the solute being carried (49, 50) and there is currently no proof that silicic acid binds to any water channel (51).

Silica fertilization

Silica can be applied to the plant in different ways such as silicate minerals, silicic acid, silicate fertilizers, etc (Fig. 3). Silicate rock powder having many essential nutrients can

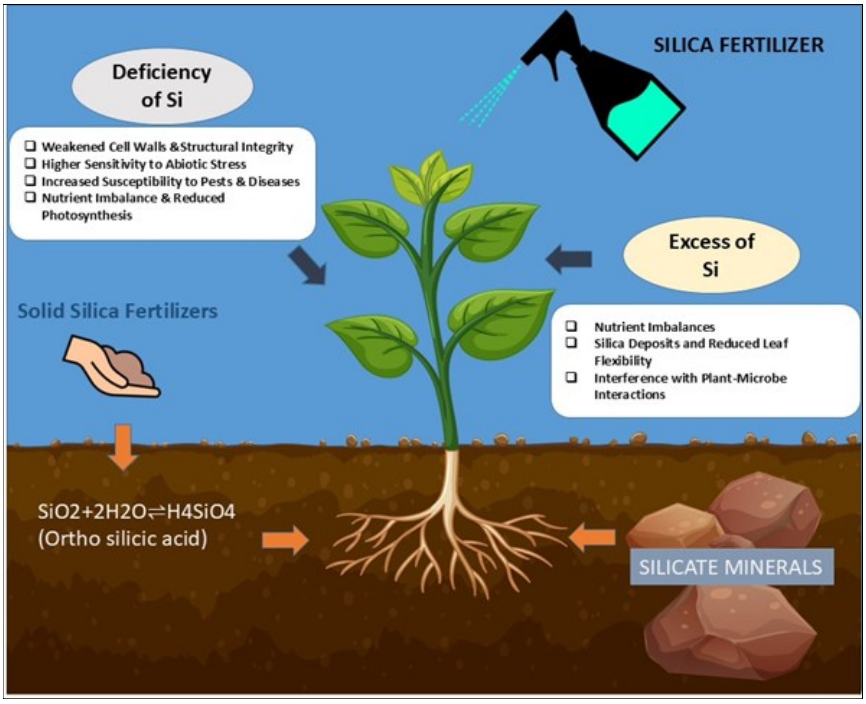

Fig. 3. Types of silicate fertilizations.

improve soil health, reduce reliance on synthetic fertilizers and increase carbon sequestration (52). However, commercial silica fertilizers are not widely available, particularly in developing countries. This has prompted research into utilizing abundant industrial waste streams such as fly ash and bottom ash from coal combustion, as alternative sources of plant-available silica. These waste materials contain significant quantities of silica; however, conventional extraction methods may not be released in a bioavailable form of crops.

The primary mineral phase of granulated slag consists of a dicalcium silicate structure formed through rapid cooling with remote cooling. If they react with other chemicals the $[SiO_4]^{4+}$ ions are easily released, allowing hydroxide ions (OH^-) to react and produce ortho silicic acid (53). Electrical Arc Furnace slag, a steel production by-product also can improve soil nutrient levels including Fe, Mg, N, P and K while increasing soil pH and electrical conductivity. It was applied as a soil enhancer for common beans (*Phaseolus vulgaris* L.) in a greenhouse setting and resulted in increased plant growth including greater height, dry weight of leaves and seeds and the number of husks, especially at a 1 % application rate (54).

Application of silicon-calcium fertilizer and foliar silicon spraying can reduce cadmium (Cd) uptake in rice grown in mildly Cd-polluted soils in Hengyang County, Hunan Province, China (55). Ortho silicic acid, which is absorbed by plants is subsequently deposited in different plant sections. Long-term carbon storage in soils is facilitated by the silicon that rice plants acquire as phytoliths, which obstruct organic carbon (56). A study in Rwagitima, Gatsibo district, Rwanda, during two wet seasons in 2019 evaluated the effects of stabilized ortho silicic acid (OSA) granules on rice (*Oryza sativa* L.) growth and yield. Silixol OSA granules can act as a sustainable approach to enhance rice productivity while reducing fertilizer inputs (57). Silicic acid can also be an effective nutritional strategy to boost soybean productivity, particularly under varying environmental conditions. A study conducted in the University of Agricultural Sciences, Bengaluru using soybean varieties (MAUS-2 and KBS-23) across two distinct rainfall years (2016 and 2017) proves that it significantly improved seed, haulm and husk yields along with oil content and protein content (58).

Application of nano fertilizer (N > 1.2 %; P_2O_5> 0.001 %; K_2O > 0.0001 %) particularly in combination with conventional fertilizers, significantly enhanced various agronomic parameters such as plant height, chlorophyll content and grain yield (59). Research has demonstrated that nanosilica can enhance rice tillering and yield with tests showing a 100 % increase in tiller counts when compared to traditional fertilizers (60). Nano-silica use boosted grain yield by 28 % and 32 % over two years and improved water use efficiency under low irrigation in Iran. Nano-fertilizers particularly nano-silica, enhanced plant growth, water retention and cell membrane stability, mitigating drought stress and supporting sustainable farming in water-scarce areas (61). In a study conducted in Ajowan (*Trachyspermum ammi*), a spice species in Iran found that significant variations in essential oil yield and composition, with thymol being the predominant compound when treated with nano silica (62).

The weathering of silicate minerals, particularly those found in basaltic rocks, releases essential nutrients like silica, potassium and magnesium, which are vital for plant growth. Thus alternative sources of crop nutrients such as nepheline and basaltic rocks which can provide sustainable options for farmers, especially in regions where conventional fertilizers are too expensive (63).

The increased Si deposition in wheat plants fertilized with Si compounds leads to structural reinforcement effects. Higher Si levels strengthen the epidermal cell walls of the leaves (31). Additionally, there was greater formation of silica bodies (phytoliths) on leaf surfaces, especially on the abaxial (lower) side of the wheat (64). Although the silica bodies had a consistent chemical composition regardless of the fertilizer used, the Si content in the epidermal cell walls varied based on the Si source (31). The deposited Si was present as amorphous silica in young plants, but gradually crystallized to α-quartz as the plant matured (31).

Silica and phytolith occluded carbon content

Silica plays a crucial role in the formation of Phyt OC in plants. When plants take up monomeric silicic acid (H_4SiO_4) from the soil, it polymerizes into silica gel nanoparticles and is deposited in plant tissues as phytoliths (65). These phytoliths act as a mechanical barrier against environmental stresses such as evaporation rates, CO_2 level and contribute to the improvement of light capture by strengthening cell membrane integrity and leaf blades, thereby enhancing the photosynthetic assimilation of CO_2 and the accumulation of biomass carbon (66). The silica deposition in plant tissues not only provides structural support but also influences the chemistry and isotopic composition of phytoliths, affecting the occlusion of organic carbon compounds during their formation process (67). This process of silica deposition and phytolith formation is essential for sequestering carbon in plant tissues and preserving it over prolonged periods in soils or sediments (68).

Furthermore, the interaction between silica and carbon components in plant tissues demonstrates a trade-off strategy under suboptimal conditions where, silica partly substitutes carbon-based components to provide mechanical structural support. This trade-off highlights the interconnectedness between silicon and carbon cycling in plants, highlighting the importance of silica in enhancing plant biomass through physical and biochemical processes (69). The positive correlation between Phyt OC and Si content indicates that Si-promoted phytolith production enhances carbon encapsulation, despite changes in carbon and silicon content within the phytoliths. Overall silica will help plant tissues become more resilient to environmental challenges and aid in the sequestration of carbon through the development of phytoliths. This highlights the detailed interaction between carbon and silicon dynamics in plant ecosystems.

Phytolith

Phytoliths are microscopic rigid particles. They are produced by many plants, especially grasses, sedges and some dicotyledonous angiosperms, as an outcome of silica biomineralization and are deposited in the cell walls, intracellular and extracellular spaces of plants (70). Phytolith are composed of hydrated silica ($SiO_2 \cdot nH_2O$) that are formed within plant cells, particularly in the epidermal and mesophyll tissues of leaves, stems and roots. They are an important component of plant anatomy and play a significant role in plant growth, development and defense against various biotic and abiotic stresses (71). This property allows researchers to identify plant species and study past vegetation. Their ability to retain the shape of the cells and tissue in which they are formed, makes them taxonomically significant for identifying plant species (72). Phytoliths are released into the soil as plants decompose and are highly resistant to decomposition owing to their inorganic composition. Consequently, they can persist in soil and sedimentary deposits for millions of years, providing a useful proxy for reconstructing past vegetation and environmental conditions (Fig. 4) (73).

Phytoliths, which are microscopic silica structures formed within plant tissues, have become valuable tools in archaeological and paleo-ecological research. Phytoliths can be used for finding historical human activities and vegetation dynamics mostly in regions where pollen grains are prone to decay, such as the Amazon. They help distinguish between cultivated and untouched landscapes by analyzing the accumulated amount of phytolith (74). Phytolith analysis has been used to study pre-Columbian land use and patterns of forest enrichment with palms in Amazonia, but its application has been limited (75). In Argentina's Pampean Plain, silica phytoliths play a key role in soil fertility and quality, influencing sustainable agriculture (76). By analysing phytoliths preserved in sediments, researchers can reconstruct ancient plant communities, identify crop cultivation and track environmental changes over time. Recent studies have highlighted the potential of phytolith radiocarbon dating to provide accurate chronological information, further enhancing

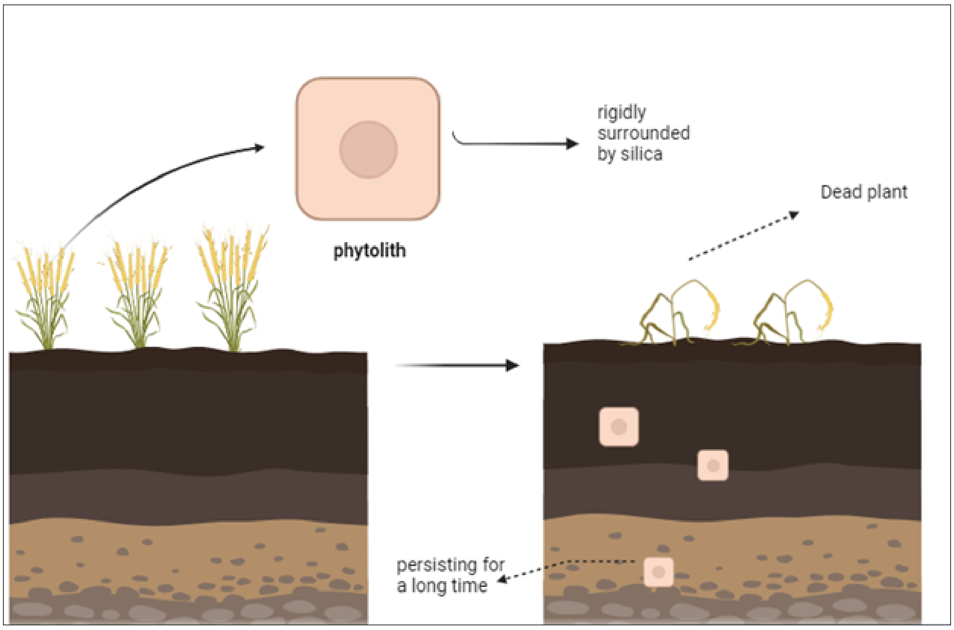

Fig. 4. Phytolith persistence in soil.

Table 2. Phytolith shape in different plant species

Plant	Phytolith shape	Reference
Panicum amarum	Dumbbell spool	(82)
Indo sasasinica	Rondel, saddle, irregular, elongate, bilobalt, flat	(83)
Dalbergiella nyasae	Tabular trapezoid	(84)
Adiantum abscissum	Elliptical shape, tapered ends and undulatesides	(85)

our ability to unravel the complexities of past landscapes and human activities. The morphology of the phytolith is quite interesting; it varies according to plant families. Some examples are listed in Table 2.

Phytolith occluded carbon

Phytolith occluded carbon (Phyt OC) refers to the organic carbon trapped and encapsulated within phytoliths during phytolith formation in plants. As described by Parr and Sullivan (2005), during the biomineralization of phytoliths, some organic carbon from the plant biomolecules also becomes encapsulated within the phytolith structure (70). This Phyt OC is effectively removed from the terrestrial biogeochemical cycle because it is highly resistant to degradation due to the protective phytolith casing around it. This occluded Phyt OC can remain stable for hundreds to thousands of years after plant residues have decomposed, making phytoliths an important long-term sink for sequestering carbon in the soil. The amount of Phyt OC varies among plant species, tissue types and environmental conditions but can range from 0.2-5.8 % of the phytolith mass (32).

Phytoliths play a crucial role in the long-term carbon sequestration in terrestrial ecosystems. As plants take up silica from the soil, a fraction of the organic carbon present in their cells becomes occluded and encapsulated within the phytolith structure, forming phytolith-occluded carbon (70). Phyt OC is remarkably resistant to decomposition and can persist in soils for hundreds to thousands of years after plant residues have decayed (77). Through a "relative accumulation" mechanism, the labile organic carbon fractions are lost over time, but the recalcitrant Phyt OC accumulates, accounting for up to 82 % of the total soil organic carbon pool in some soils (70). Certain plants, such as grasses and bamboos are highly efficient at producing phytoliths and their cultivation can significantly enhance the long-term terrestrial carbon sink capacity by increasing Phyt OC production and sequestration (78).

Conclusion

With the appropriate application of silica fertilization, plants can achieve enhanced disease resistance and structural stability, along with increased silica accumulation. However, this accumulation can have both negative and positive impacts depending on the quantity of silica deposited. The accumulated silica leads to the formation of phytolith, which in turn promote carbon sequestration. The integration of regenerative farming methods and strategic silicon/silica applications could significantly enhance the terrestrial carbon sink capacity of agricultural soils. This approach not only contributes to mitigating climate change but also provides a sustainable solution for agricultural practices, aligning with the goal of achieving net-zero emissions by 2050. Advanced technologies in the field of phytolith analysis due to the growth in archaeology will support this method of increasing carbon sequestration. Even though there are so many advantages, a high amount of phytoliths is not good for soil health.

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Authors' contributions

MAK collected the relevant literature on the topic, wrote the article based on the collected literature and critically evaluated it. RR, SM, PSM and SKR supervised the process and edited the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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