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DIATOMITE AS A SILICON FERTILISER AND THE ROLE OF SILICON IN MODERN AGRICULTURE

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ABSTRACT

Silicon (Si) can enhance crop resilience, but agronomic responses depend on chemical form and availability. This review evaluates diatomite as a slow-release Si source and porous mineral amendment, integrating the soil–plant Si cycle, H_4SiO_4 uptake, stress responses, foliar formulations and experimental evidence. Diatomite may gradually supply Si, improve the root-zone environment and serve as a carrier for other inputs; effectiveness varies with mineralogy, particle size, soil properties, plant species and stress conditions. Standardised methods for plant-available Si, explicit separation of nutritional and physical effects, and direct validation in horticultural crops are required.

INTRODUCTION

Modern agriculture requires inputs that sustain production and resilience to drought, salinity, temperature extremes and soil degradation. Si is not universally essential, but it can stabilise plant performance through structural and physiological effects, particularly in Si-accumulating grasses and under stress (Epstein 1999; Guntzer et al. 2012; Ma & Yamaji 2015; Coskun et al. 2016; Debona et al. 2017).

Diatomite (diatomaceous earth, DE) is a biogenic rock rich in amorphous silica and characterised by high porosity. Its agronomic interest derives from a combined role as a gradual Si source, a physical root-zone amendment and a carrier matrix for other inputs. This review critically evaluates these functions, emphasising H_4SiO_4, horticultural applications and criteria for agronomic recommendations (Savvas & Ntatsi 2015; Sandhya et al. 2018; Nascimento et al. 2021; Głąb & Gondek 2025).

This review treats diatomite as a multifunctional material, separating gradual H_4SiO_4 supply, physical root-zone modification and carrier/particle-film effects, and assessing their transferability to horticultural crops.

MATERIAL AND METHODS

This structured narrative review searched Web of Science Core Collection, Scopus and CAB Abstracts, supplemented by publisher platforms, DOI/metadata checks and citation tracking. The corpus was compiled in August–September 2026 and updated on 29 September 2026; 2010–2026 studies were prioritised, while earlier fundamental papers were retained. Searches combined “diatomite”/“diatomaceous

earth" with agriculture, horticulture, soil, fertiliser, silicon, mineralogy, porosity, dissolution, slow release, carrier or particle film, and Si/H_4SiO_4 with horticultural crops, uptake and stress.

Records were screened for material identity, application route, Si availability and agronomic/horticultural endpoints. Peer-reviewed DE studies were prioritised; quantitative characterisation studies and mechanistic reviews were retained where relevant. Non-DE Si studies were used only as horticultural comparators. Promotional, poorly traceable or merely incidental DE sources were excluded. Extraction distinguished total, amorphous/reactive, extractable/dissolved and plant-available Si. The synthesis is qualitative, not a meta-analysis or PRISMA systematic review.

RESULTS AND DISCUSSIONS

The Si cycle, diatomite and agronomic availability

In soil, Si occurs in minerals, amorphous silica, phytoliths and dissolved H_4SiO_4. For plant Si nutrition, H_4SiO_4 in soil solution and the capacity of reactive pools to replenish it are more relevant than total Si. After uptake, Si is deposited as hydrated amorphous silica and returns to soil in plant residues; biomass removal therefore reduces recycling. Diatomite contributes as a slow-release Si source, with release governed by amorphous character, pH, particle size and contact time (Keller et al. 2012; Schaller et al. 2021; Guntzer et al. 2012).

The agronomic value of a Si source therefore depends on its H_4SiO_4 replenishment rate and synchronisation with plant demand.

Diatomite and the main agronomic Si sources

Diatomite consists mainly of hydrated amorphous silica, but mineralogy and crystalline phases vary among deposits and processing histories (Reka et al. 2014; Lutyński et al. 2019). At 70–90 % SiO_2, elemental Si is ~32.7–42.1 %, yet plant-available Si depends on the amorphous/reactive fraction, surface area, particle size, pH and dissolution conditions rather than total SiO_2 (Haynes 2014). Its porosity can modify water retention/aeration and support carrier functions (Aksakal et al. 2012, 2013; Głąb & Gondek 2025). Powdered products should also be characterised for respirable crystalline silica as part of occupational-exposure control (Lutyński et al. 2019; NIOSH 2002).

The principal agronomic Si sources are summarised in Table 1.

Table 1

Comparison of the main silicon sources with potential agronomic use.

Source / Si	Release / availability behaviour	Agronomic role / limitations	References
Natural diatomite; 32.7–42.1% Si	Gradual, dissolution-controlled; source/pH/soil dependent	Soil/substrate; water retention/carrier; variable mineralogy/dust	Reka et al. 2014; Sandhya et al. 2018; Nascimento et al. 2021; Aksakal et al. 2012

Source / Si	Release / availability behaviour	Agronomic role / limitations	References
Processed/calcined diatomite; variable	Processing-dependent; phase characterisation required	Reactivity/crystallinity may change; respirable crystalline silica control	Reka et al. 2014; Lutyński et al. 2019; NIOSH 2002
Wollastonite / Ca silicates / slags	Weathering-controlled; pH, grinding and composition dependent	Si + Ca/Mg; source-specific reactivity	Haynes et al. 2013; Haynes 2014; Tayade et al. 2022
K/Na silicates; soluble	Rapid, water-soluble	Foliar/fertigation; K co-supply or Na load; alkaline	Laane 2018; Artyszak & Gozdowski 2021; Tayade et al. 2022
Stabilised H_4SiO_4	Rapid, monomeric/stabilised dissolved Si	Foliar/fertigation; cost/stability constraints	Laane 2018; Savvas & Ntatsi 2015
Nanosilica; ≤46.74 % Si	Size-, aggregation- and dissolution-dependent	Advanced formulations; dose/safety require specific assessment	Mandlik et al. 2020; Tayade et al. 2022; Thakral et al. 2024
Biogenic silica/phytoliths	Recycling- and dissolution-controlled	Si recycling; heterogeneous reactivity	Guntzer et al. 2012; Keller et al. 2012; Schaller et al. 2021

For Table 1, Si contents are expressed as elemental Si where data permit and release descriptors indicate dominant behaviour, not universal availability classes. Study-specific rates include natural DE at 0–600 kg ha^{-1} in rice (Sandhya et al. 2018), a 23 % Si DE fertiliser at 0–300 kg Si ha^{-1} in maize/sugarcane (Nascimento et al. 2021), stabilised H_4SiO_4 at 0–20 mg Si L^{-1} in olive (Nascimento-Silva et al. 2022) and nano-SiO_2 at 50–100 mg L^{-1} in strawberry (Avestan et al. 2019); these rates are not directly comparable or general recommendations.

Solid sources are dissolution/weathering-controlled, soluble silicates and stabilised H_4SiO_4 act more rapidly, and nanosilica behaviour depends on size, aggregation, dissolution and dose (Haynes et al. 2013; Laane 2018; Tayade et al. 2022; Thakral et al. 2024).

Si uptake and horticulturally relevant functional responses

Plants take up Si predominantly as monosilicic acid (H_4SiO_4). In high-Si-accumulating species, Lsi1 and Lsi2 coordinate radial uptake and transport towards the xylem, whereas many dicotyledonous horticultural crops and woody perennials accumulate less Si and may respond differently to source, dose and application route (Ma & Yamaji 2015; Nascimento-Silva et al. 2022). After uptake, Si is transported through the xylem and deposited mainly as hydrated amorphous silica in epidermal and cell-wall regions. Internal Si deposition must be distinguished from an external particle film: foliar diatomite or other siliceous particles may modify reflectance, leaf temperature and surface microclimate without requiring rapid Si uptake.

For horticultural crops, reported Si benefits can be grouped into five functional domains: (i) improved water relations and tolerance to drought and salinity, while

external particulate films may additionally reduce radiative heat load; (ii) reinforcement of epidermal/cuticular tissues and complementary defence responses that can reduce pathogen penetration or disease severity; (iii) produce-quality responses, including firmness, cuticle characteristics and post-harvest behaviour in specific crop systems; (iv) root development and nutrient relations, including soil- and source-dependent interactions with P and other nutrients; and (v) mitigation of salinity and selected toxic elements/metalloids. Direct horticultural experiments have documented responses in vegetables, strawberry and woody crops, but magnitude depends strongly on crop, Si source, dose and environment (Pozo et al. 2015; Jayawardana et al. 2014; Avestan et al. 2019; Al Murad et al. 2020; Nascimento-Silva et al. 2022; Simko et al. 2026). These responses establish horticultural sensitivity to Si, not quantitative equivalence with DE. Separately, DE can act as a physical insecticide through cuticle disruption and desiccation (Rojht et al. 2010).

Foliar formulations and horticultural applications

Stabilised H_4SiO_4 and soluble silicates provide rapidly available Si, whereas particulate sources differ in dissolution and surface behaviour. Responses depend on source, dose, application route and crop and cannot be transferred automatically to DE; nanosilica is size/aggregation dependent, while foliar DE may also function as a particle film or carrier (Pozo et al. 2015; Avestan et al. 2019; Nascimento-Silva et al. 2022; Simko et al. 2026). Table 2 summarises the principal foliar Si formulations and siliceous-material systems discussed in this context.

Table 2

Foliar Si formulations and systems based on siliceous materials.

Formulation / form	Advantages / limitations	References
Stabilised H_4SiO_4	Rapid; young olive 0–20 mg Si L^{-1} showed dose/time-dependent Si accumulation	Laane 2018; Nascimento-Silva et al. 2022
K/Na silicates	Rapid; soluble source. Capsicum 75 mg L^{-1} K silicate improved firmness/cuticle and reduced anthracnose	Jayawardana et al. 2014; Artyszak & Gozdowski 2021
Nanosilica	High surface area; strawberry 50–100 mg L^{-1} under salinity; size/aggregation/dose dependent	Avestan et al. 2019; Thakral et al. 2024
Foliar SiO_2 ± Ca	Lettuce: 3.66 mM SiO_2 ± 2.50 mM Ca; quality/disease benefits; no significant field-yield increase	Simko et al. 2026
Natural siliceous materials + foliar fertiliser	Particle film/carrier; study-specific combined systems; slow Si release	Moale et al. 2021; Sîrbu et al. 2023

In Moale et al. (2021), DE and natural zeolites used with foliar fertilisers in apricot/peach reduced leaf temperature by up to 4.5 °C, increased WUE by up to 30 % and increased yield by up to 8.1 % versus foliar fertiliser alone. In apple, combined particle-film materials + foliar fertilisers reduced pigment degradation by 25–30 % and added 11.56–12.38 % yield in the dry year, with much smaller effects in the exceptionally hot year (Sîrbu et al. 2023). These are study-specific outcomes of combined technologies, not general DE or Si effect sizes.

Horticultural relevance and limits of transferability

Direct horticultural DE evidence remains limited: ornamentals responded to 20–80 g top-dressed or 50–200 g incorporated DE (Mills-Ibibofori et al. 2019), onion field responses varied with salinity (Venâncio et al. 2022), and potato responses depended on soil and drought regime (Madegwa et al. 2025). Thus, dose, soil/substrate, water regime and crop physiology constrain transferability.

Non-DE studies in vegetables, capsicum, strawberry, young olive and lettuce support biological plausibility, not equivalent DE efficacy (Pozo et al. 2015; Jayawardana et al. 2014; Avestan et al. 2019; Nascimento-Silva et al. 2022; Simko et al. 2026), with responses dependent on salinity, species and Si form (Al Murad et al. 2020). Apricot/peach and apple results derive from combined particle-film + foliar-fertiliser technologies, so physical, carrier and nutritional contributions remain inseparable.

Agronomic evidence for diatomite and research priorities

Diatomite has three principal agronomic functions: a gradual Si source, a physical soil/substrate amendment and a carrier matrix for other inputs. Assessing effectiveness therefore requires mineralogical characterisation, measurement of amorphous/reactive Si and extractable/dissolved Si, application-rate information and simultaneous evaluation of plant and physical responses. Table 3 separates direct DE evidence from non-DE horticultural Si comparators; the latter are included only to define biological plausibility and transferability boundaries, not to attribute their effects to diatomite.

Table 3

Selected experimental evidence for diatomite and horticultural Si comparators: application rates, quantitative responses and limits of transferability.

System / dose	Quantitative / main response	Interpretation / limit	References
Rice + maize/sugarcane; DE 0–600 kg ha^{-1} or DE fertiliser 0–300 kg Si ha^{-1}	Plant Si/biomass/yield responses were dose-, soil- and water-dependent	Direct DE evidence; gramineous systems, limited transfer to horticulture	Sandhya et al. 2018; Nascimento et al. 2021
Physical amendment; DE 10–30 % v/v or 0.5–4 %	30 % DE: aggregate stability 28.04→45.70 %; FC up to ~0.083 cm^3 cm^{-3} at 4% in sandy soil	Physical response strongly rate- and texture-dependent	Aksakal et al. 2012; Głąb & Gondek 2025
Dahlia, Rudbeckia, Gerbera; 20–80 g top-dress or 50–200 g incorporated	Growth/nutrients/transpiration affected; transpiration maintained under water stress	Direct horticultural DE; pot/substrate, species/dose dependent	Mills-Ibibofori et al. 2019
Onion; DE-based Si 0–166.4 kg ha^{-1}; EC 0.65–4.1 dS m^{-1}	Yield/quality improved; attenuation to 2.8 dS m^{-1}; estimated optimum 78.5 kg Si ha^{-1}	Direct horticultural field evidence; study-specific	Venâncio et al. 2022
Potato; 2 temperate soils × 2 drought levels; DE/ASi/control; 15 t Si ha^{-1}	Soil moisture/P and yield responses depended on soil/drought; N_2O ↓ ~31% on average	Temperate field evidence; high Si input	Madegwa et al. 2025

System / dose	Quantitative / main response	Interpretation / limit	References
Apricot/peach + apple; siliceous particle materials + foliar fertiliser	Leaf T ↓ ≤4.5 °C; WUE ↑ ≤30 %; yield ↑ ≤8.1 %; apple yield +11.56–12.38 % in dry year	Combined technology; DE/Si contribution not isolated	Moale et al. 2021; Sîrbu et al. 2023
Capsicum; K silicate 75 mg L^{-1}; root/foliar	Lesion area −67 %/−39 %; symptoms delayed 2 d; firmness/cuticle thickness ↑	Non-DE soluble-Si comparator; tropical system	Jayawardana et al. 2014
Young olive; stabilised H_4SiO_4 0–20 mg Si L^{-1}; foliar/irrigation	Leaf-Si differences after 60 d; 20 mg L^{-1} most effective; root > leaf > shoot	Non-DE comparator in low-Si woody perennial	Nascimento-Silva et al. 2022
Lettuce; foliar SiO_2 3.66 mM ± Ca 2.50 mM; pots + field	Quality/disease/postharvest traits improved; no significant field-yield gain	Non-DE comparator; strongest responses partly combined with Ca	Simko et al. 2026

Table 3 shows that DE responses are context-dependent. Direct studies in gramineous and horticultural crops vary with species, application rate, soil/substrate and water regime (Sandhya et al. 2018; Mills-Ibibofori et al. 2019; Nascimento et al. 2021; Venâncio et al. 2022; Madegwa et al. 2025). Physical effects are also rate- and texture-dependent (Aksakal et al. 2012; Głąb & Gondek 2025), while fruit-tree studies used combined particle-film + foliar-fertiliser technologies and cannot isolate DE/Si effects (Moale et al. 2021; Sîrbu et al. 2023).

Mechanistic trials should separate Si supply from physical amendment effects using untreated, soluble-Si and, where feasible, physically comparable Si-inert controls. Across contrasting horticultural soils/substrates, dose–response studies should jointly measure dissolved Si, plant Si and biomass/yield to distinguish reactive-Si dissolution, H_4SiO_4 supply and plant uptake (Haynes 2014; Ma & Yamaji 2015; Nascimento et al. 2021).

Plant-available Si assessment also requires standardisation: DE mineralogy, particle size and amorphous/reactive Si should be linked to time-resolved H_4SiO_4 release under defined conditions (Haynes 2014; Lutyński et al. 2019; Schaller et al. 2021). The analytical chain should distinguish total Si → amorphous/reactive Si → extractable/dissolved Si → plant-available Si and relate these fractions to plant and agronomic responses; multi-year horticultural validation remains necessary.

CONCLUSIONS

Si can support crop resilience, but source value depends on H_4SiO_4 supply and crop uptake. Horticultural studies with soluble and nano-enabled Si do not prove equivalent DE efficacy. DE releases Si gradually and may modify soil/substrate physical properties; responses therefore require direct crop-specific validation.

Diatomite is a multifunctional biogenic material—a slow-release Si source, physical amendment and carrier. Recommendations require reactive-Si characterisation, H_4SiO_4 release kinetics and multi-year field validation.

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