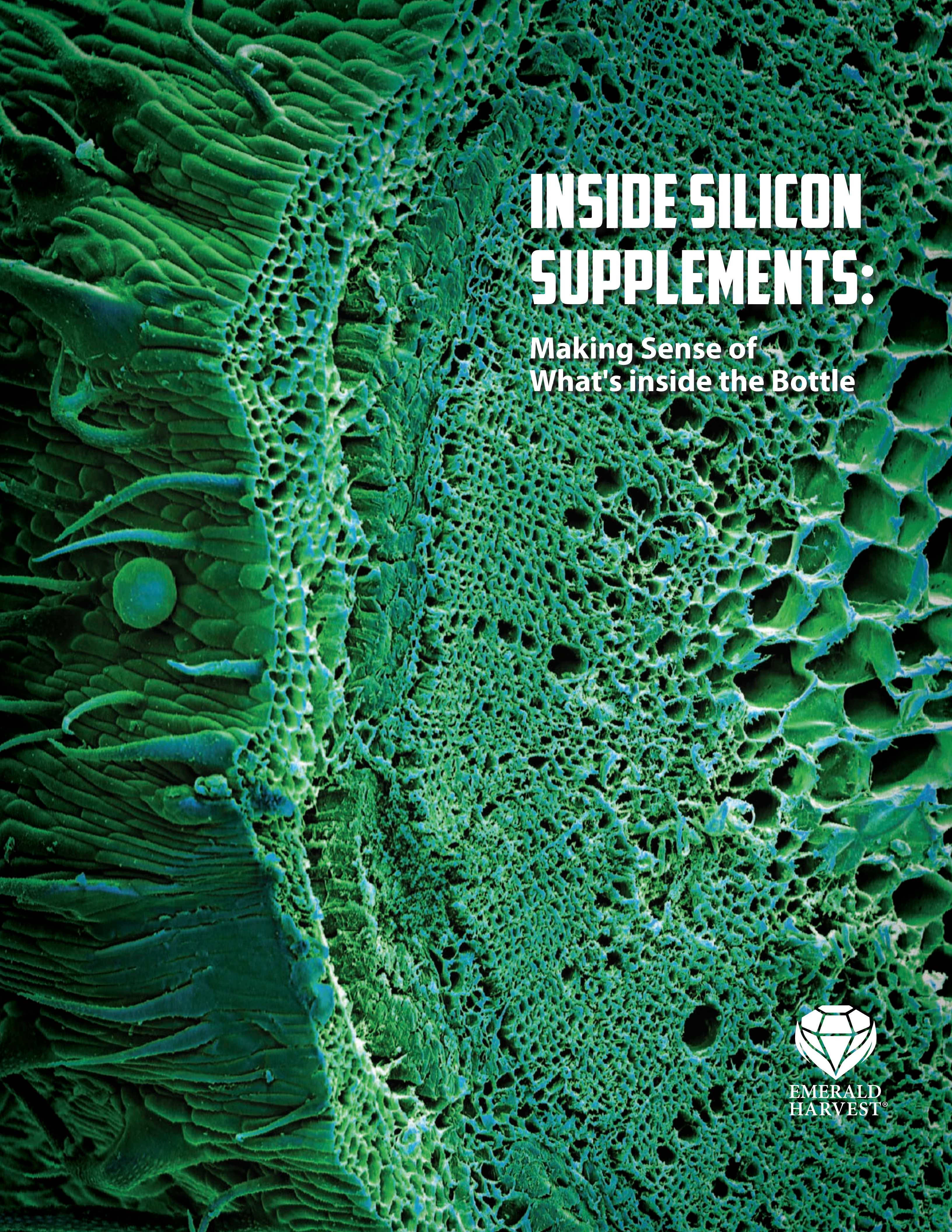
INSIDE SILICON SUPPLEMENTS:

Making Sense of What's inside the Bottle



EMERALD HARVEST®

Silicon can be a confusing and misunderstood element.

Silicon packs a powerful punch, increasing crop quality, strength and resilience. Yet the fertilizer market is flooded with misinformation about silicon supplements, including confusing labeling and misleading marketing claims with no basis in science. This poses a challenge for growers seeking to choose the best product.

With every nutrient company touting the superiority of its silicon-based product, it's no wonder growers get confused and struggle to make an informed choice. Even the terminology—silicon, silica, silicic acid, silicate—is often used interchangeably in the fertilizer industry, despite the fact that these terms mean different things. Growers are left wondering, "What am I buying?"

The trouble is that silicon itself cannot be absorbed by plants. Like most mineral elements, it needs to be provided in a form that the roots can take up. So what is the best silicon-based compound to feed plants? This is not at all clear to many commercial growers, who hear a lot of conflicting advice.

This white paper lays the confusion to rest. First, we examine silicon's pathway into the plant as it hitches a ride in a chain of different silicon-based compounds. We also look at the challenge posed by the immobility and inertness of silica, the most common silicon compound in nature. We then outline the benefits of silicon supplementation for crops and the ways in which industry marketing and inconsistent label requirements obscure what's actually in the bottle. Finally, we offer advice on how to select a powerful silicon supplement from among the many options out there.

SILICON IN NATURE

Silicon is everywhere, in one form or another. The second-most abundant element in the earth's crust, it bonds readily with oxygen to create some of the most common materials on the planet. It is the primary component of sand and clay, the basis for granite, amethyst and quartz and the key ingredient in glass, computer chips and fiber-optic cables. It's even found in toothpaste. It is particularly ubiquitous in the ocean: Plankton and sponges absorb silicon-based compounds and use them to form their microscopic skeletons and spicules.

Given how common silicon is, it may come as a surprise that plants growing in nature do not always have abundant levels of the element available to them. This is because the form in which silicon most often appears in nature, silica, is inert, insoluble and cannot be absorbed. Plants can only take up silicon in the form of silicic acid. (This serves as a catchall term for plant-available silicon, encompassing monosilicic acid, H_4SiO_4, also known as orthosilicic acid, as well as its oligomers, i.e., disilicic acid and even more complex forms.) Silicic acid is the only water-soluble form of silicon.

Essential vs Beneficial Elements

In addition to hydrogen, carbon and oxygen, which plants get naturally from air and water, 14 mineral elements are necessary for plant growth:

- Nitrogen
- Phosphorus
- Potassium
- Calcium
- Magnesium
- Sulfur
- Boron
- Chlorine
- Copper
- Iron
- Manganese
- Molybdenum
- Nickel
- Zinc

Five additional minerals are classified as beneficial. While they are not essential to plant growth, the advantages of applying them to crops should not be understated, and some may be essential for particular plant species:

- Aluminum
- Cobalt
- Selenium
- Silicon
- Sodium

Envision a white-sand beach: Thousands of years from now, sea levels will have changed drastically, and the driftwood that washes up on the shore today will have decomposed and reentered the earth's ecosystem as minerals and nutrients. But the white sand—silica—is built to withstand the crashing waves and the ebb and flow of the tide. It can't be broken down easily, and it will remain long after everything else on the beach has eroded away.[1]

That's precisely why plants benefit from silicon: It strengthens their cell walls, making them tougher and more resistant to damage and abiotic stressors like wind and rain. It helps plants keep water in their stalks and leaves and keep biotic invaders like viruses and fungi out. The strength of silicon-fortified leaves and stalks is a deterrent to herbivores, who are less likely to chew through a plant's tough exterior.[2] And if you've ever picnicked on the beach, you probably know what it's like to get silica in your food. Insects are put off by the gritty texture of silicon in plant leaves, just like you're probably unwilling to eat a sandy sandwich.

1 Global sand exploitation for applications such as concrete and electronics does pose a significant risk to the environment, and sand scarcity is a matter of growing concern worldwide. Some sand-mining processes also endanger animal species, threaten clean water supplies and make it easier for harmful bacteria to breed. Aurora Torres et al., "A Looming Tragedy of the Sand Commons," Science 357, no. 6355 (2017): 970–71, https://doi.org/10.1126/science.aao0503.

2 Showkat Hamid Mir et al., "Silicon Supplementation of Rescuegrass Reduces Herbivory by a Grasshopper," Frontiers in Plant Science 10, no. 671 (2019).

Why supplement nonessential elements?

Aluminum:

- Enhances herbivore defense
- Promotes phosphorus uptake

Cobalt:

- Supports rhizobacteria
- Enhances drought resistance
- Slows senescence (aging)

Selenium:

- Enhances pathogen and herbivore defense
- Prevents phosphorus toxicity

Sodium:

- Can replace potassium as an osmoregulator
- Facilitates nitrate uptake

Silicon:

- Strengthens cell walls and acts as a protective barrier
- Heightens resistance to biotic and abiotic stressors
- Controls metabolism of terpenes and phenolic compounds

THE SILICON CYCLE

To understand why silicic acid is the only silicon delivery system for plants, it's important to know how the element is taken up. Figure 1 provides a snapshot of the cycle of silicon deposition and absorption in nature. When silicon compounds meet hydrogen, usually in the form of water, silicic acid forms. Although silicic acid enters plant roots at relatively low concentrations, its concentration increases as it is distributed through the xylem, or vascular tissues, to other parts of the plant. The density of silicon transporters that absorb silicic acid in the roots ultimately determines the amount of silicon taken up by the plant.

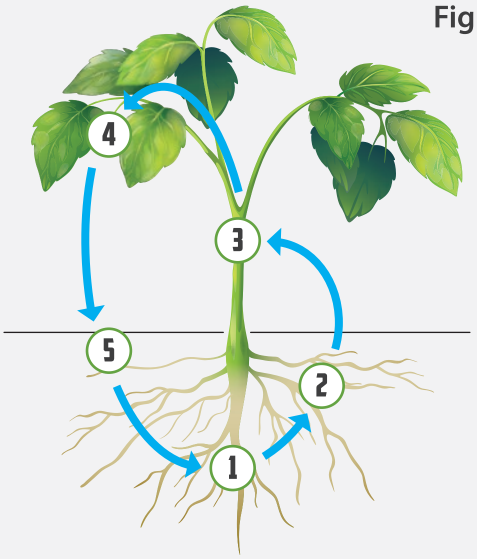


Figure 1. Overview of the silicon plant–soil cycle

1. Silicon compounds hydrolyze to produce $Si(OH)_4$
2. $Si(OH)_4$ is taken up by the roots
3. $Si(OH)_4$ is translocated through the xylem
4. SiO_2 is polymerized and deposited in plant tissues
5. Silicon compounds are deposited in the soil through organic decomposition and other sources

Eventually, silicic acid molecules polymerize into insoluble silica, which is deposited in plant tissues, first in the abaxial (lower) epidermis and then, as the plant grows, in the epidermis. It then condenses into particles of hard, polymerized silica gel, also known as phytoliths. It is this silica that imparts silicon's benefits to plants by strengthening plant tissues and structures.

So why not just feed plants silicic acid? Simply put, silicic acid is unstable and undergoes polymerization at high concentrations. Bottled in solution at more than 100 to 200 ppm, it will precipitate, meaning it will surrender its hydrogen atoms and revert to grainy silica. This process works beautifully when silica is deposited in plant tissues, but when it happens prematurely—for example, in a nutrient reservoir—the silicon cannot be taken up by plant roots. This creates a problem for fertilizer manufacturers, who need to supply their customers with a powerful silicon supplement that won't precipitate in the bottle or after mixing.

SILICATES: THE BEST OF BOTH WORLDS

To benefit crops, silicon must be delivered in a form that is both soluble and stable. Silicic acid is the only soluble form of silicon that a plant can take up, and an effective silicon supplement will deliver it in a stable form that remains in solution until the plant needs it.

For this reason, commercial silicon supplements take the form of silicates: complex silicon compounds composed of silicon bound to metal cations, such as sodium, potassium or calcium. Whereas silicic acid polymerizes into complex, increasingly less soluble

Glossary

Silicon (Si)
The 14th element in the periodic table and the seventh most abundant in the universe. Thanks to its tendency to bind to oxygen, silicon almost never appears in nature in its elemental state.

Silica (silicon dioxide, SiO_2)
Insoluble silicon bound to oxygen. The most recognizable form of silica is quartz. Silica sand—composed of quartz granules—is responsible for the white beaches of places like Florida's Siesta Keys and Australia's Whitehaven.

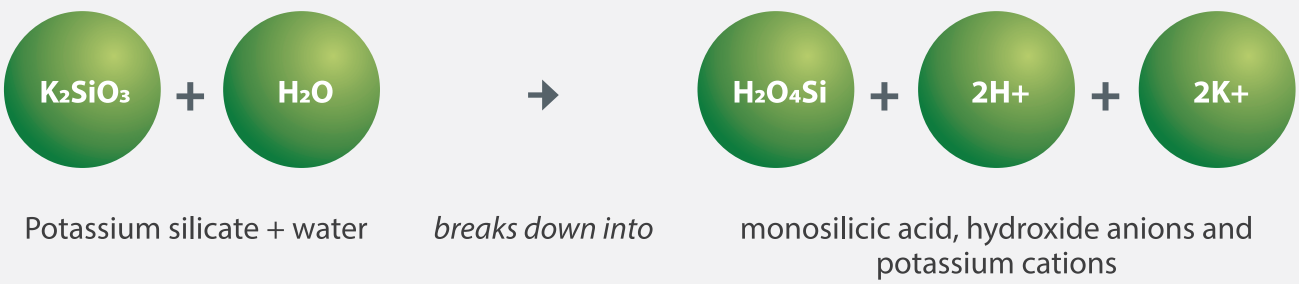
Silicic acid
Actually a group of closely related acids including monosilicic acid (H_4SiO_2), also called orthosilicic acid, as well as disilicic acid, trisilicic acid and other oligomers. Silicic acid is the only soluble form of silicon and the only form that can be absorbed by plants.

Silicate
Generally speaking, a silicate is any one of a number of compounds containing a silicon atom and an oxygen atom. Soluble silicates are formed with numerous other elements as well, such as potassium, sodium, calcium or magnesium, forming potassium silicate, sodium silicate and so on. Silicates range in solubility but are fairly stable and present all over the planet in mineralized forms.

compounds in highly concentrated nutrient solutions, silicates offer both solubility and stability: the best of both worlds for a bottled supplement.

However, silicates break down after application, so it's important to understand how an individual plant will react. The addition of a silicate, such as potassium silicate or calcium silicate, to water hydrolyzes its molecular structure into silicic acid and potassium or calcium, respectively (Figure 2).

Figure 2. Hydrolyzation of potassium silicate (an equivalent molecular breakdown occurs with all silicates)



Silicates, therefore, impart nutrients to plants in addition to silicon—some of which can be beneficial, and some of which may be harmful to crops under certain conditions or at high doses. A supplement's manufacturer should make the product's silicon source material and quantity clear on the label, so that growers don't expose their crops to harmful amounts of chlorides or even essential micronutrients such as boron or molybdenum that might be toxic to plants or to grazing animals at high levels.

DEMYSTIFYING SUPPLEMENTATION

Given that plants can survive without silicon, do the benefits of silicon supplementation outweigh the headache of selecting and applying the appropriate formulation to crops? According to the data, the answer is a resounding yes.

Silicon benefits plants in myriad ways, many of which are well-documented and some of which agricultural scientists are only beginning to discover and understand. Furthermore, the benefits of silicon supplementation differ by plant species; in some species, silicon may be considered an essential element, as opposed to merely a beneficial one (Figure 3).

Figure 3. The benefits of silicon supplementation by plant species

Concentration	Root dry weight (g)	Crown dry weight (g)	Leaf number	Fruit number	Fruit weight (g)
Without Si	3.5	24.3	10	0	0
0.1 mL/L of Si	6.7	46.2	19	4	168

* Table data source: G.H. Korndörfer and I. Lepsch, "Effect of silicon on plant growth and crop yield," Studies in Plant Science 8 (2001): 133-47, https://doi.org/10.1016/S0928-3420(01)80011-2.

Silicon fortifies stalks and stems, enabling them to support weighty CBD- and THC-rich fruits and flowers, and delays plant senescence, among other benefits:

- Increased resistance to biotic stresses, including harmful fungi, bacteria and herbivores.[3,4,5] Research indicates that both root and foliar silicon applications yield benefits.[6]
- Reduced oxidative damage due to enhanced activity of primary antioxidative enzymes.[7]

3 Pat Bowen, Jim Menzies and David Ehret, "Soluble Silicon Sprays Inhibit Powdery Mildew Development on Grape Leaves," Journal of the American Society for Horticultural Science 117, no. 6 (1992): 906–12, https://doi.org/10.21273/JASHS.117.6.906.

4 Flore Guntzer, Catherine Keller and Jean-Dominique Meunier, "Benefits of Plant Silicon for Crops: A Review," Agronomy for Sustainable Development 32, no. 1 (2011): 201-13.

5 Joseph Heckman, "Silicon: A Beneficial Substance," Better Crops 97, no. 4 (2013): 14–16.

6 Rupesh K. Deshmukh, Jian F. Ma and Richard R. Bélanger, "Editorial: Role of Silicon in Plants," Frontiers in Plant Science 8 (2017), https://doi.org/10.3389/fpls.2017.01858.

7 Dimitrios Savvas and Georgia Ntatsi, "Biostimulant Activity of Silicon in Horticulture," Scientia Horticulturae 196 (2015): 66–81.

- Improved photosynthesis due to improved transmission of light to photosynthetic tissue.[8] This is mainly due to heightened leaf rigidity, which helps keep leaves flat, providing a more even surface for light to strike.
- Greater availability of other essential and beneficial elements, including calcium, magnesium and zinc.[9] Notably, silicon can ameliorate the undesirable consequences of phosphorus deficiency or excess phosphorus.[10,11]
- Heightened plant metabolism resulting from greater production and activity of phytohormones.[12,13]

Even when the benefits of silicon aren't visible to the naked eye, consumers will notice a difference, and growers will enjoy bigger yields and greater biomass. Fortunately for growers, it's difficult to overfeed plants silicon, which rarely causes damage to plants even when applied in excess.

In recent years, commercial growers have shown increasing interest in silicon due to its numerous plant benefits. Silicic acid is particularly important in soilless hydroponic agriculture, where its natural supply is limited. However, despite the abundant benefits of supplementation, growers still struggle to select the right silicon supplement for their plants. Analysis of the most popular products on the market reveals several common pitfalls growers fall into. We outline the main challenges below.

Terminological Confusion

There is a lot of debate online about the uses and merits of silicon, silica and silicic acid. In fact, this debate is pure semantics: No matter what form of silicon a manufacturer lists on the bottle as the active ingredient, only silicic acid can be absorbed by plants. To boot, different states have different labeling requirements, making it hard for growers to understand what they're buying.

8 Ibid.

9 Maria Greger, Tommy Landberg and Marek Vaculík, "Silicon Influences Soil Availability and Accumulation of Mineral Nutrients in Various Plant Species," Plants 7, no. 41 (2018).

10 Jianfeng Ma and Eiichi Takahashi, "Effect of Silicon on the Growth and Phosphorus Uptake of Rice," Plant and Soil 126 (1990): 115–19.

11 Yi Zhang et al., "Silicon Compensates Phosphorus Deficit-Induced Growth Inhibition by Improving Photosynthetic Capacity, Antioxidant Potential, and Nutrient Homeostasis in Tomato," Agronomy 9, no. 733 (2019).

12 S. K. Lee et al., "Effect of Silicon on Growth and Salinity Stress of Soybean Plant Grown under Hydroponic System," Agroforestry Systems 80 (2010): 333–40.

13 Ibid.

Adding to the confusion, silicon and silicon compounds are designated "non-plant-food ingredients" on fertilizer labels. This term is applied to all non-essential elements and compounds in fertilizers. While the terminology may understate their importance, so-called "non-plant-food ingredients" occur in nature and can be enormously beneficial to plants.

REGULATORY INCONSISTENCY

If you compare silicon products, you'll notice that no two labels look alike. Even two bottles of the same product sold in different regions may have different information listed on their labels. Regulations and registration processes vary substantially from state to state, resulting in products with different label guarantees. Some states continue to require guarantees of silicon dioxide or silica rather than silicic acid.[14]

The Association for American Plant Food Control Officials (AAPFCO) provides a broad set of standards, requiring manufacturers to list five elements on all fertilizer labels: brand and grade, guaranteed analysis, directions for use, name and address of registrant and net weight.[15] However, the AAPFCO's guidelines are non-binding, and how this information is presented to consumers varies widely from product to product.

A new era for California labeling

Label consistency is coming to the state of California. Beginning in 2021, "soluble silicon" will be the only silicon guarantee allowed on supplement labels, and all current labels will have to be adapted by 2024. Growers will no longer see many different compounds on labels when shopping for supplements and will no longer be misled into thinking that these products offer more or less direct pathways for supplements into plants. It's a positive step forward for California, and with any hope, other states and countries will soon follow suit.

14 Notably, the state of California has acknowledged these inconsistencies and has taken action to eliminate the confusion. By 2024 and for all labels submitted in 2021 and onwards, "soluble silicon" will be the only "guarantee" permitted on supplements' guaranteed analyses. Alternative (and misleading) compounds (silica, silicon dioxide, monosilicic acid, etc.) will no longer appear on fertilizer labels.

15 "AAPFCO Product Label Guide," Association of American Plant Food Control Officials, 2019, https://www.aapfco.org/pdf/product_label_guide.pdf.

Note too that a derivation statement—the section on the back label that lists which actual silicon compound, or raw material, is in the bottle—is not required by these standards, often leaving growers in the dark about the source of the silicic acid they're feeding their plants.

Misleading Marketing

Many manufacturers promote their silicon supplements with misleading or erroneous claims about silicon absorption. This can make it challenging for growers to compare products and select the most potent formulation.

For example, one manufacturer claims to bottle silicon dioxide and assures growers that it will boost fruit growth. This oversimplification may lead growers to believe that silicon dioxide is a uniquely powerful form of silicon. Although silicon dioxide ultimately fortifies plant tissues, only silicates deliver shelf-stable formulations, and only silicic acid can be absorbed by plants.

Another label claims to offer "superior absorption" of "bioavailable silica," even though silica simply cannot be absorbed by plant roots. Yet another lists potassium silicate in its derivation statement but doesn't include a single silicon compound among its active ingredients; it lists only "soluble potash."

Not only are such claims confusing to growers, but they often betray misunderstanding on the part of nutrient manufacturers about how silicon is taken up into a plant and deposited in its tissues. This makes it challenging for growers to make an informed decision and select the best silicon supplement for their crops. Companies that neglect to include derivation statements on their labels further muddy the waters. As a result, growers waste time and money doing online research and risk applying substandard silicon supplements to their plants.

Choosing an Effective Silicon Supplement

Fortunately, armed with a few pieces of information, growers can easily select a silicon supplement that delivers solid results. Growers should begin by looking at a product's derivation statement, and any product lacking a derivation statement should set off alarm bells.

WHAT TO LOOK FOR

The silicon source material listed on the derivation statement should satisfy four requirements:

- **It must be sufficiently water-soluble.** An ideal silicon supplement will readily dissolve in the nutrient solution, so that plants receive as much silicic acid as possible. Silicon compounds range from extremely water-soluble, such as potassium silicate, to very insoluble, such as magnesium silicate.[16,17] In addition to the source material, solubility is also influenced by other nutrients in the nutrient solution, as well its temperature, pH and other factors. The supplement you choose should include clear directions for use; read them carefully.
- **It must yield sufficient silicic acid.** The amount of silicic acid matters far more than the total silicon in a supplement. The silicon source material must yield sufficient silicic acid after dissolution and not in forms that are unavailable to plants. More complex forms are not available to plants because they can't be carried by the transporters in cell membranes.
- **It must remain stable during both storage and application.** Silicates are water-soluble silicon compounds that are stable in solution at relatively high concentrations, unlike silicic acid, which is only stable at low concentrations.
- **It should not release any hazardous or environmentally persistent byproducts.** This goes without saying. However, not all products on the market are safe for your soil or crops.

As Figure 4 indicates, potassium silicate meets all four criteria. Other silicates, such as magnesium silicate or calcium silicate, are weakly soluble. Sodium silicate also meets all four criteria, but excess sodium not only impairs potassium uptake but also leads to sodium accumulation in plant cells, which can cause toxicity.[18] Application of potassium silicates won't result in salt buildup or cause toxicity in plants.

16 Guilherme Bossi Buck, Gaspar Henrique Korndörfer, and Lawrence Elliott Datnoff "Extractors for Estimating Plant Available Silicon from Potential Silicon Fertilizer Sources," Journal of Plant Nutrition 34 (2011): 272–282.

17 Dennis Sebastian et al., "A 5-Day Method for Determination of Soluble Silicon Concentrations in Nonliquid Fertilizer Materials Using a Sodium Carbonate-Ammonium Nitrate Extractant Followed by Visible Spectroscopy with Heteropoly Blue Analysis: Single-Laboratory Validation," Journal of AOAC International 96, no. 2 (2013): 251–59, https://doi.org/10.5740/jaoacint.12-243.

18 Jose M. Pardo and Francisco J. Quintero, "Plants and Sodium Ions: Keeping Company with the Enemy," Genome Biology 3, no. 7 (2002): 1017.1-1017.4.

Figure 4. Silicon sources and their characteristics with reference to all four criteria for efficacy

Silicon source	1. Sufficiently soluble	2. Yields silicic acid	3. Stable in solution
Calcium silicate		✓	✓
Potassium silicate	✓	✓	✓
Sodium silicate	✓	✓	✓
Silicic acid	✓	✓	

Potassium silicate, in particular, is known for its beneficial properties.[19] It preserves the growing environment through the slow, controlled release of potassium ions, and it is free from acidifying or salinating properties.[20] Because the compound remains stable despite changes in the nutrient solution or growing medium, it is compatible with both hydroponics and soil. Importantly, it supplies the plant with additional potassium: a bloom-boosting macronutrient. In fact, the effect of potassium on plant metabolism is so beneficial that growers who use potassium silicate supplements can't be always certain which aspect is bringing their crops greater benefits—the potassium or the silicon.

19 Sophia Kamenidou, Todd J. Cavins and Stephen Marek, "Evaluation of Silicon as a Nutritional Supplement for Greenhouse Zinnia Production," Scientia Horticulturae 119, no. 3 (2009): 297–301.

20 Y. Tokunaga, "Potassium Silicate: A Slow-Release Potassium Fertilizer," Fertilizer Research 30 (1991): 55–59.

The future of fertilizers?

Emerging research suggests that nanotechnology and stabilized silicic acid may improve soil quality, boost yields and minimize nutrient losses, among other benefits. These fertilizers can help to offset adverse effects caused by excessive fertilizer use and reduce the need for frequent fertilization.

Growers should keep an eye on these emerging technologies. However, research is ongoing. For example, at the time of writing, nano silicon fertilizers are primarily used as foliar sprays in controlled experiments. Not much data is currently available regarding root application.

These innovations show extraordinary promise but are still under scrutiny and require more research before becoming commercially available.

THE BOTTOM LINE

Don't let marketing and misinformation fool you. A stable, soluble silicon supplement, ideally derived from potassium silicate, will increase crop resilience, ameliorate biotic and abiotic stress and boost yields, among other benefits. No bells and whistles are required.

Selecting the right silicon supplement for your plants should be easy, yet so many fertilizer companies obscure the silicon source material in the bottle, misrepresent product benefits and mislead customers with marketing hype.

We believe that growers should have access to nutrient lines that are simple to use and reasonably priced, and should be able to discuss their needs with reliable, knowledgeable customer support. At Emerald Harvest, it's our mission to deliver simple, easy solutions, so you can focus on growing your business.

Contact Emerald Harvest for information about Sturdy Stalk, our potassium silicate supplement, and the rest of our premium product line. Emerald Harvest base nutrients and supplements help growers maximize the genetic potential of crops. To set up an appointment with a representative, call 1.866.325.8235 or email info@emeraldharvest.co.

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