The science behind Potsil

Is silicon an important plant nutrient?

Plant scientists do not classify silicon (Si) as an *essential* plant nutrient. This is because you can grow a plant without the presence of silicon. However, any plant grown without any silicon would be extremely weak, photosynthesise slowly, be highly susceptible to many pests and diseases and have a vastly reduced yield. As such, while not being essential, silicon is very *important*, if you wish to grow healthy crops.

Some crops are considered silicon hyper-accumulators. This is particularly common amongst the monocot plants; especially cereal crops, bamboos, and grasses. For dicots, the highest shoot silicon concentrations have been recorded in species of the Cucurbitaceae (e.g., cucumber), Fabaceae (e.g., pea), Rosales (e.g., elm), and Asteraceae (e.g., sunflower) plant families (Guntzer et al. 2012).

Monocot plants can accumulate extremely high concentrations in their tissues. For example, the bamboo *Sasa veitchii* (figure 1) in which an astonishing 41% of the dry weight is silica (SiO_2). As the absorption of silicon into plants is an active controlled process (not passive diffusion), the plant would not absorb and deposit such massive levels of silicon unless it was performing major beneficial functions.

Figure 1: the bamboo *Sasa veitchii*; 41% SiO_2 by dry weight.

Even in crops that are not considered hyper-accumulators silicon has numerous beneficial effects, which are observed once applications of soluble silicon are made to them in controlled experiments and field trials. This is especially the case when these plants are exposed to stress.

How does silicon improve plant growth and health?

Simply put, silicon 'Makes plants stronger'! Deposits of silicon in plants provide structural rigidity which is a major advantage when facing multiple stresses in a crop's growing environment.

Silicon is naturally absorbed by plant roots in the form of uncharged silicic acid and transported to the shoot through the transpiration stream (Bybordi, 2012). At the end-points of the transpiration stream, the concentration of silicic acid rises due to the loss of water. As a result of this, the silicon polymerizes in these areas into amorphous silica ($SiO_2 \cdot nH_2O$). Amorphous silica is chiefly deposited in cell walls, lumens, and in the intercellular voids, especially around stomata where water transpiration takes place. The silicon bodies so formed can range in size from 100 nm to 200 mm (figure 2). The largest of these silicon deposits are termed 'phytoliths' (that is Greek for plant rocks!).

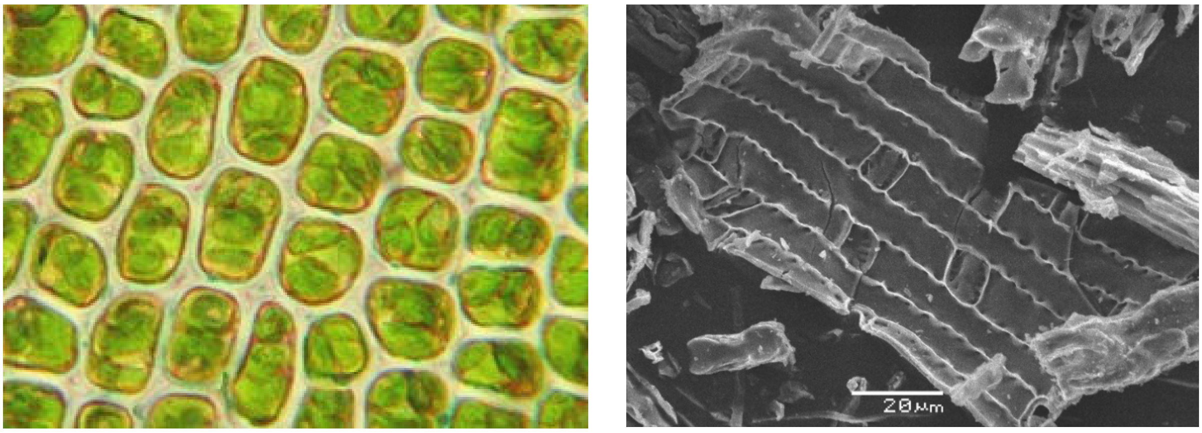

Figure 2: Left; light microscope image of leaf epidermal cells. The clear cell walls have silicon reinforcing their cellulose matrix. Right: electron microscope image of phytoliths present amongst the leaf cells of elephant grass, Benjamin Gadet, 2013.

During the process of amorphous silica forming it has been found that it can bind metals and other elements, particularly Al, Ti, Mn, Cu, N, and C. As amorphous silica is not readily soluble, these elements are then inaccessible to the plant cells. This is particularly useful for plants growing in soils polluted with heavy metals as the bound toxins cannot harm metabolic processes.

Silicon can also prevent damage by heavy metals before they reach the foliage. It has been found that under stress conditions silicon helps maintain the structural integrity of the plasma membrane in the root cells. This allows the plant to exclude toxic elements, even when there is a strong concentration gradient from the surrounding soil. Once in the plant, silicon has also been found to bind toxic aluminium into hydroxyaluminumsilicates in the apoplast of the root apex, thus detoxifying Al; a particular problem in acidic soils. Silicon has also been found to limit the translocation of toxic elements travelling to the foliage. This is true for toxic heavy metals, and also sodium when plants are exposed to salt stress. Once toxic elements have reached the plant cell, it has been found that the damage caused to the ultrastructure of chloroplasts is minimised by supplying adequate silicon, with it protecting the double membranes and maintaining the integrity of the granae.

Silicon can also help alleviate the harmful effects of excessive nutrient levels on a cellular and physiological level, with it providing protection in soils with excessive levels of zinc and manganese.

The silica that is deposited in the walls of the cells in the foliage and stems contribute significantly to their mechanical strength and rigidity and supplying supplemental silicon in the fertigation stream has been shown in multiple independent studies to enhances the strength and rigidity of cell walls. Stronger cell walls are important as they contribute to resisting lodging in cereal crops in windy conditions (figure 3). In addition, enhanced leaf thickness, erectness, and rigidity improves the exposure of leaves to light; an effect that has been shown to increase in relation to the amount of silicon delivered.

Figure 3: A wheat crop that has lodged following heavy rain and wind. The mechanical strength provided by adequate silicon nutrition can help prevent such losses of crops.

As well as the direct mechanical effects of large silicon deposits in the foliage, some researchers also have evidence to suggest that silicon has a role in directly modulating physiological functions and metabolic processes. This includes altering the activity of some enzymes, antioxidant capacity, plant water relations, photosynthesis, uptake of nutrient and non-nutrient anions, mobility of ions inside the plant tissues, hormone balance, and gene expression (See Guntzer et al., 2012).

Of the enzymes that silicon has been shown to modify, it is the enhancement of the activity of antioxidative enzymes that has been most widely observed and studied. These enzymes contributing to the scavenging of ‘reactive oxygen species’ (ROS) that cause major damage to plant tissues and processes when the plant is exposed to abiotic stress conditions. The main antioxidative enzymes that have been reported to increase their activity, when plants treated with extra silicon are exposed to abiotic stress are superoxide dismutase (SOD), catalase (CAT), guaiacol peroxidase (GPX), glutathione reductase (GR), ascorbate peroxidase (APX), and dehydroascorbate reductase (DHAR).

Silicon has also been found to modify the level of various biochemicals that contribute to antioxidant activity under abiotic stress. This includes glutathione (GSH), polyamins, some phenolic compounds (particularly chlorogenic and caffeic acids), and proline. Proline is an amino acid that acts as both an antioxidant and osmo-protectant under drought or salinity stress. As a result, silicon application has been found to significantly reduce the level of ROS generated under abiotic stress conditions.

Various other beneficial effects of silicon on plants exposed to abiotic stresses have been reported, such as excessive radiation and temperature, UV radiation, freezing and waterlogging (summarized in table 1).

Biotic stresses

Amorphous silica in plants, present as either phytoliths or deposited in cell walls, reduces the palatability of the foliage to herbivores due to its abrasive properties. Silicon addition has also been found to induce resistance to a range of microbial pathogens. A non-exhaustive list of pests and diseases where silicon has been reported to improve resistance of the crop to attack include;

Fungal pathogens

- *Magnaporthe grisea* - rice blast
- *Rhizoctonia solani* – rice sheath blight
- Powdery mildew on grapes, melons, cucumbers, squashes, wheat, barley,
- *Leptosphaeria sacchari* - ring spot in sugar cane
- *Uromyces vignae* – cowpea rust
- *Fusarium oxysporium* f. sp. Cubense - Panama wilt in banana

Oomycete pathogens

- *Pythium* in cucumber

Bacterial pathogens

- *Xanthomonas oryzae* pv. Oryza – blight in rice
- *Pseudomonas syringae* – bacterial leaf spot in melon

Viral pathogens

- Tobacco ringspot virus
- Cucumber mosaic virus

Insect pests

- *Schistocerca gregaria* – locust
- *Bemisia tabaci* – whitefly
- *Diaphorina citri* - Asian citrus psyllid
- *Spodoptera frugiperda* – fall army worm moth
- *Scirpophaga incertulas* – rice yellow stem borer moth
- *Cnaphalocrocis medinalis* - rice leaf folder moth
- *Nilaparvata lugens* - brown planthopper
- *Dermolepida albohirtum* – greyback canegrub beetle
- *Chilo suppressalis* – Asiatic rice borer
- *Chlosyne lacinia saundersii* – sunflower caterpillar

Arachnid pests

- *Tetranychus urticae* – red spider mite

It should be noted that as silicon acts by physical means and pre-activating plant defence mechanisms it should be used primarily as a preventative means of pest and disease control rather than a curative method (it is not a pesticide). Use Potsil as part of your integrated pest management (IPM) program.

The man-made atmospheric increase in CO_2 concentration since the Industrial Revolution is thought to have reduced silicon content in the tissue of grasses and this could be an issue for plant protection in cereal crops and bamboos in the future as the concentration of CO_2 in the air is predicted to continue to rise for some time. As elevated CO_2 levels have been found to lower the proportion of tissue that is composed of silicon compounds, silicon hyper-accumulating crops like rice may become more susceptible to pests in future.
In addition to silicon, Potsil contains potassium, another nutrient known to be essential for optimal pest and disease resistance.

Table 1: A summary of the benefits of silicon on crop plants

Plant processes	**Stresses**	**Other**
Increased photosynthetic rates	Soil water deficits (drought)	Soil pH optimization
Thicker, more erect and rigid leaves improving light interception	Waterlogging	Increased shelf life of fresh produce
Delayed senescence	Salinity and sodicity	Reduced lodging
Water use efficiency / improved control over stomatal conductance	Heavy metal toxicity	
Improved wounding response	Aluminium toxicity	
	Tropospheric ozone	
	Insect and arachnid (mite) pests	
	Fungal and bacterial pathogens	
	UV radiation	
	High temperatures	
	Freezing	
	Nutrient imbalance	

What if my crop is not exposed to stress?

Even in non-stressed crops, Si may enhance plant growth by improving leaf erectness, thereby increasing light interception and concomitantly canopy photosynthesis (Savvas et al., 2007).

Silicon fertilizers have been found to increase photosynthetic rates and efficiency (quantum yield Fv/F0 and Fv/Fm) in a number of crops, including rice. The reason for this positive response of photosynthesis to silicon has been proposed to be either a protective role of silicon on chloroplast integrity or from a silicon-mediated enhancement in the concentrations of pigments related to light absorption, or from both.

Silicon is thought to be key to optimizing water use efficiency in crops. One of the symptoms reported for silicon deficiency is an excessive rate of transpiration. Silicon can affect transpiration via its effects on stomatal apertures. Silicon deposition modifies the structural composition of the guard cell walls in a manner that leads to a reduction in their turgor pressor, this in turn reduces stomatal conductance and water transpiration. However, in some stressful situations that limit water uptake (drought or salt stress), silicon has been found to increase stomatal conductance and hydraulic conductance by activating aquaporin channels in the roots.

Another beneficial effect of silicon on plants that has been described by many authors is the delay of the senescence process. Savvas et al. (2007) reported darker leaf colour and a slowing of the senescence process in older leaves of hydroponically cultivated roses treated with silicon through the nutrient solution. Similar observations have been reported in other crops. While the mode of action of delaying senescence is not yet fully understood, a protection structural integrity of the chloroplast (like occurs under heavy metal toxicity) is a likely hypothesis.

All of these processes combine to improve overall plant growth rates and crop yield with silicon fertilizer addition. This has been observed in many crop trials in numerous agricultural and horticultural crops, including rice, sugar cane, cucumber, zucchini squash, bean, tomato, roses, and many more.

Silicon is everywhere, why apply it to plants?

Silicon is the second most abundant element in the earth's crust and is in high concentrations in most soils. However, most of this silicon is present as insoluble oxides and silicates that form the sand, silt or clay fractions of the soil matrix. It is only the soluble silicon that is available to plants, and this is present in the soil water in concentrations that are below those required to produce optimum plant growth and health.

The soluble form of silicon found naturally in soil water is chiefly monomeric silicic acid (H_4SiO_4), which occurs at concentrations ranging from 0.01 to 2.0 mM (0.6-120 mg L^{-1}). Silicic acid does not dissociate at pH lower than 9 and thus plants take up Si in this non-ionic form, actively or passively, depending on the external silicon concentration and their inherent requirements. With 1.0 mM often considered the minimum effective concentration, many soils should be considered deficient in 'available' silicon.

Low silicon levels in the soil solution constitute a common problem in many areas of the world, especially in highly weathered Oxisols and Ultisols as well as in organic soils such as Histosols (Figure 4). For comparison, the silicon content of a Histosol is often 1%, compared to up to 45% in a fertile Podzol soil. In China for instance, silicon deficient soils account for more than 40% of the total agricultural land.

When you consider hydroponic crops or crops growing in organic growing media (peat, coir etc), then the plants will be receiving very small amounts of silicon due to the complete lack of weathered silica material in the growing media. As a result, hydroponic and containerized plants often respond dramatically to silicon fertilization with improved growth and health.

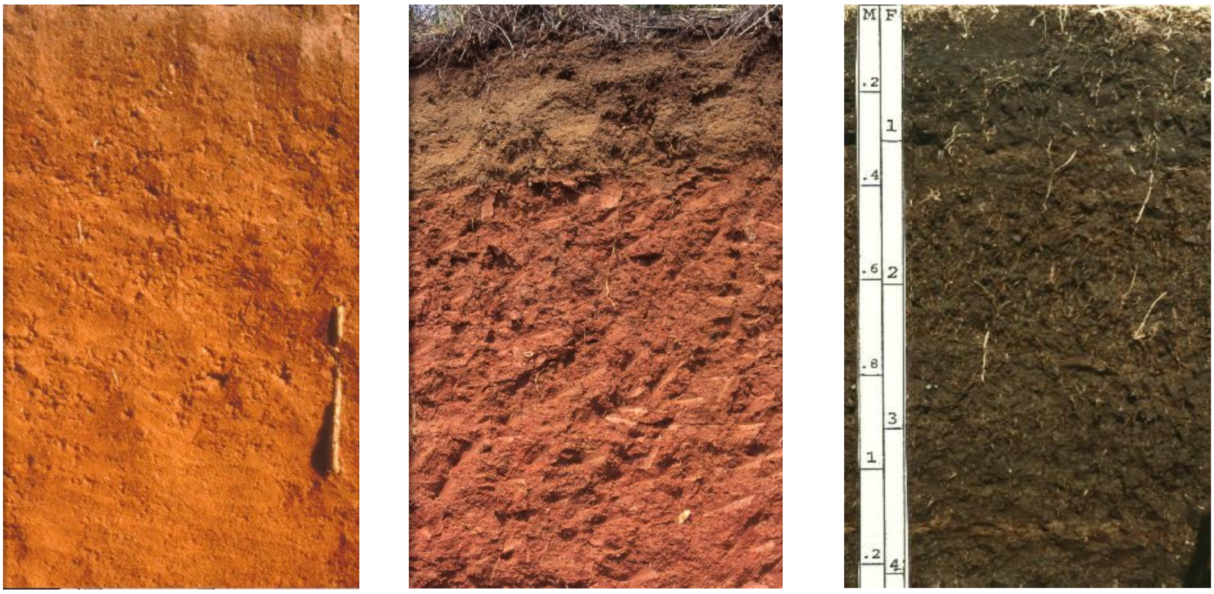

Figure 4: Soils routinely found to be deficient in silicon. Left = Oxisol, Middle = Ultisol, Right = Histosol

Problems due to a lack of silicon in soil can get worse over time, especially if cultivating silicon hyperaccumulating crops, such as cereals. The harvestable biomass removed will be taking away biologically available silicon, as will any crop residue removed after harvest (hay, straw, foliage etc). Unless replaced at the same rate by weathering or fertilizer addition, this loss of available silicon will eventually lead to crop losses. For this reason, silicon fertilization is now routine in rice and sugar cane crops, especially in soils with very low available silicon. These fertilizers are not used just to boost yield, they are now considered essential to avoid major crop losses.

What effect does the potassium in Potsil have on crops?

Potassium (K) is an essential plant nutrient that is needed in plants for, amongst other things, flower formation and fruit set. This could explain why bananas are such a good source of this nutrient for human nutrition! Therefore, symptoms of potassium deficiency are often observed when plants come into flower and fruit. On the foliage of plants potassium deficiency manifests itself as a scorching (browning) and rolling inwards of the leaf margin (edge), especially on older leaves (figure 5). Symptoms can also include necrotic lesions and the death of leaves and buds. Potassium deficient plants have also been found to be more susceptible to heat stress in hot weather. Unfortunately, for many plants a deficiency of potassium is often symptomless and farmers can suffer losses in yield due to potassium deficiency despite their plants looking perfectly healthy. As a result, potassium deficiency is often referred to as 'hidden hunger'.

Figure 5; Classic symptoms of potassium deficiency in tomato (left) and grape (right).

There are number of options for adding potassium to a crop, but each has an associated drawback;

- **Potassium nitrate** (KNO_3) – Readily soluble, and easily absorbed. However, excess nitrogen can lead to excessive vegetative growth. This excessive growth can be weak, prone to attack by pests and disease, and at the expense of fruiting and flowering.
- **Potassium sulphate** (K_2SO_4)- Supplies two key nutrients, but sulphates are prone to causing scorching if applied as a foliar spray.
- **Potassium chloride** (KCl) – Cheap and soluble, but chloride is directly toxic to plants in anything other than background levels.
- **Potassium phosphate** (K_2HPO_4/KH_2PO_4) – Useful for supplying two key nutrients and for pH buffering. Not useful in situations where there is already adequate levels of phosphorus.

Potsil has none of the above drawbacks.

As with nitrates, potassium's high solubility in water can mean it is leached from the soil when there is high rainfall or if you apply too much irrigation. As such, a foliar spray of Potsil lowers the amount of potassium that reaches the sub-soil.

Specification and analysis of Potsil

Potassium (as K_2O)	11% w/w, 13.30% w/v
Silicon (as SiO_2)	23% w/w, 30% w/v
Solids content	34%
pH	11.0
Specific gravity	1.3 g/cm^3
Viscosity	55 MPa·s (@ 20°C)
Solubility	Fully miscible with water
Colour	Green (naturally derived chlorophyll)
Odour	Odourless
Country of Manufacture	United Kingdom

Heavy metals analysis:

Cadmium (Cd)	<0.11 ppm
Mercury (Hg)	<0.11 ppm
Lead (Pb)	<0.10 ppm

Note: 1. "<": less than means the test result is lower than the Minimum Detection Limit.
Note: 2. Minimum Detection Limit: Value after the less than (<) sign.
Note: 3. Test Method: Acid Digestion and Quantitation by Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES)

Potsil quality control

Potsil Laboratories, Pentney, Norfolk, England.

Potsil is tested regularly in our own laboratories. Our in-house monitoring measures the specific gravity, potassium ion content and/or the alkali component by titration.

We also submit samples from each 5,000L batch for independent analysis of silica and potassium content by inductively coupled plasma mass spectrometry (ICP-MS).

Samples are also tested for heavy metals from each 5,000L batch.

Application protocols

General points to consider when applying Potsil

Foliar sprays of Potsil are preferred to soil drenches for field crops. This is because;

1) Silicon is transported around plants in xylem and will not travel in the phloem. As a result, only very small amounts of soil-applied silicon will reach phloem sinks. If you want silicon to exert its action on fruit, foliar applications are essential;

2) silicon can be locked up as insoluble silicon gel if applied directly to the soil. However, when growing in hydroponics silicon can be delivered to the roots with little risk of lock up.

Do not mix Potsil with other products before diluting. This risks the formation of insoluble silica gels. This is especially true of any acidic products (figure 6).

Conduct a bucket test to confirm tank mix compatibility before co-applying with other agrochemicals.

Conduct a test spray before full scale application. This is especially important when raising the dose rate or choosing the highest dose rate recommended.

Consider your overall potassium levels. Potsil contains significant levels of potassium and as such, this should be considered as part of your overall nutrient management program.

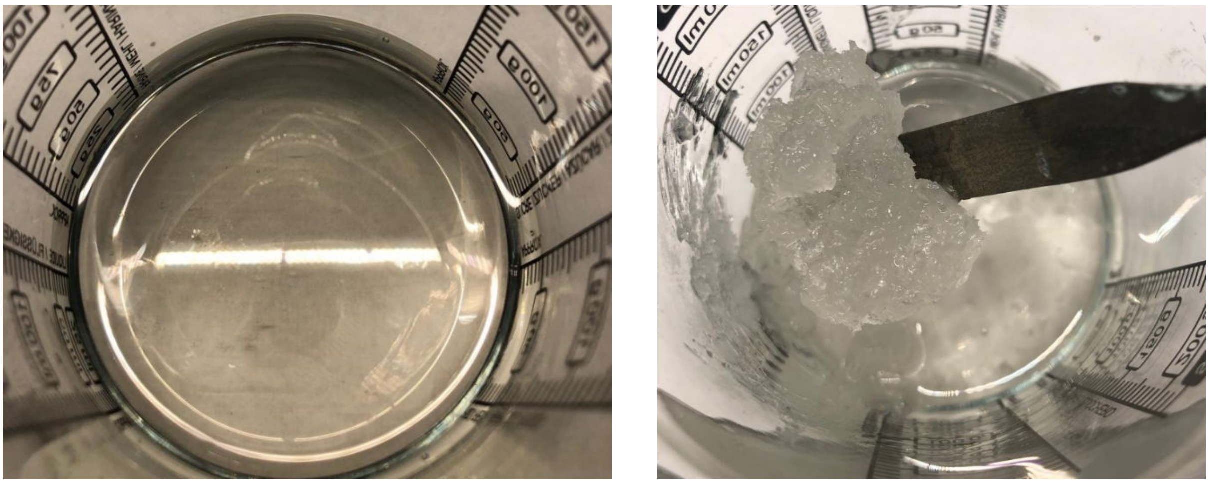

Figure 6: Left = Potsil's silicon component as a fully soluble liquid (minus multifunctional additives and natural pigment). Right = When phosphoric acid is added to the solution an insoluble gel has formed which will permanently lock up the silicon nutrient and can block filters, pipes and spray nozzles.

Apply 'little and often' for best results. Applying regularly helps maintain silicon levels in tissues as they grow. As silicon cannot be moved around the plant in the phloem a constant available supply is needed to promote growth and protect the crop from pests and disease. Applying little and often also helps prevent major sudden changes in foliar and soil pH. In hydroponics Potsil can be applied continuously throughout the growing cycle in the fertigation stream.

Field crops (cereals and vegetables)

Foliar sprays; For young plants apply at 10-150mL in 100L of water during establishment. Raise the dose rate to 50-300mL in 100L of water for mature plants. Apply until run off from the leaf. Start dose rates at the lower values and only raise them to the higher values once you have confirmed that your crop is not overly sensitive (scorching).

Apply to an equivalent of 2L per hectare.

Repeat applications every two weeks.

Soil drench; Apply 3L per hectare in 1000L of water directly to the soil. Avoid contact with the foliage.

Repeat applications every four weeks.

pH Adjustment of soil; Potsil can be applied after harvest to raise the soil pH. Use as a direct replacement for lime. Dose rate can be significantly higher than in-crop application rates as there is no risk of scorch at this time. Do not attempt to adjust your soil pH once a crop has been sown.

Ornamental nurseries, orchards, vineyards and plantation crops

Foliar sprays; For young plants apply at 50-150mL in 100L of water during establishment. Raise the dose rate to 50-300mL in 100L of water for mature plants. Apply until run off from the leaf. Start dose rates at the lower values and only raise them to the higher values once you have confirmed that your crop is not overly sensitive (scorching).

Do not spray high dose rates during flowering.

Apply to an equivalent of 3L per hectare.

Repeat applications every 2 to 4 weeks.

Turf grass

Apply 5-10L / ha in 200L of water using either a backpack or boom sprayer.

Do not apply in hot, dry weather or frosty conditions.

Note: grasses have been found to naturally increase their silica content of their tissues after defoliation in an induced defence response. As a result, turf that has been mowed regularly or grasses and bamboos that have been pruned hard or attacked by herbivores may need an extra amount of silicon to be added as fertiliser to maintain them in a healthy state. Removal of clippings will also remove silicon from the growing system.

Hydroponics

Manual addition; Add Potsil to your nutrient tank as a supplemental additive at 1.0-2.0ml per 10L of final solution. Then add your base fertilizer and adjust the pH to the optimum for your crop. Add extra Potsil as you add water back to the system to replace water lost through evapo-transpiration.

Automated systems; Apply Potsil at 1.0-2.0mL per litre using a dedicated Dosatron/Solanoid. Study the effect of Potsil's alkalinity on your fertigation stream and adjust your acid solenoid in accordance.

Figure 7: Autodosing Potsil into a hydroponic system.

Silicon is completely absent from a hydroponic system unless present in the 'inert' media (perlite may leak some silicon). There is no silicon in conventional two part (A and B) or three part fertilizers.

Consider the potassium levels of Potsil as part of your nutrient management program. Add a 'Cal-Mag' additive if using Potsil with a base nutrient package already high in potassium.

For guidance on safe transport, storage, use and disposal of **Potsil** refer to the Safety Data Sheet (SDS).

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Selected references

For ease of reading we have not included a full list of citations in this technical data sheet. However, please get in contact to know more or read the selected publications below from which a substantial amount of the information in this document was extracted;

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