Sustainable Management of Salt and Sodic Affected Fairways

CrossOver G Turf represents combination of a highly refined, calcium and magnesium silicate amendment and gypsum in granular form. Application of CrossOver G Turf results in the effective release of silicate and sulfate anions -- two highly active and versatile mineral constituents that offer professional turfgrass managers complimentary sets of biogeochemical solutions that are well suited for use on fine textured salt and sodic affected fairways that are prone to seasonal abiotic stresses.

Treating Salt-Affected Fine Textured Soils

When compared to calcium, gypsum and limestone products, CrossOver G Turf's mineral constituents offer a significantly better and more comprehensive set of geochemical solutions to correct chemical imbalances, nutrient deficiencies, structural instability (deflocculation) and ion toxicity issues associated with low pH, salt-affected and high pH sodic soils.

Silicate anions and calcium cations released into the soil profile following CrossOver applications are particularly effective in treating soils exhibiting poor structure and stability – establishing soil surface complexes that improve flocculation and agglomeration of dispersed clay particles and formation of unique soil binders that lead to increased particle aggregation, structural strength and long term stability.

Soil structure modification

Application of CrossOver G Turf initiates the release of monosilicic acid in the soil solution. As concentrations of monosilicic acid increase, polymerization reactions result in unique silicon-rich inner-sphere complexes being adsorbed at soil surfaces. These silicate-based soil surface complexes that improve flocculation and agglomeration of dispersed clay particles.

Long-Term Strength and Stability

Long term soil stabilization occurs in soils when calcium ions chemically react with soluble silica (monosilicic acid) and alumina to form calcium-silicate-hydrates (CSH) and calcium-alumino-hydrate (CAH) polymer gels that function as "binders" between soil particle surfaces.

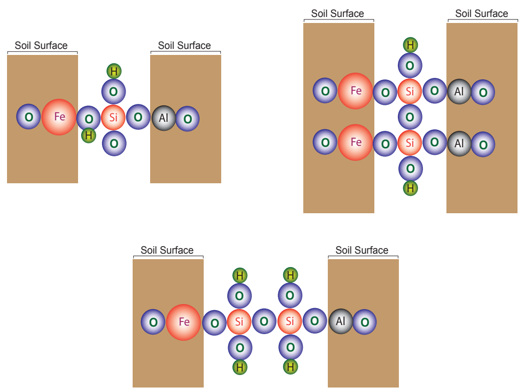
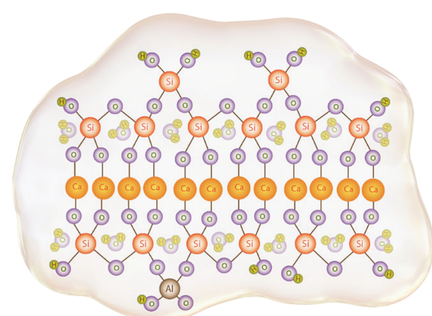


Illustration of strong inner-sphere silicate ligand complexes at exchange sites on surface of soil particle. Soil modification by flocculation and aggregation is significantly improved over calcium bonds and are less susceptible to desorption.

These reactions are called "pozzolanic reactions." Of the two, calcium silicate hydrates produce the strongest mechanical strength.

$$Ca(OH)_2 + H_4SiO_4 \rightarrow Ca^{2+} + H_2SiO_4^{2-} + 2\,H_2O \rightarrow CaH_2SiO_4 \cdot 2\,H_2O$$



Depiction of calcium-silicate-hydrate. C-S-H gels can be approximately viewed as layered structures, in which calcium oxide sheets are ribbed on either side with silicate chains, and free calcium ions and water molecules are present in the interlayer space.

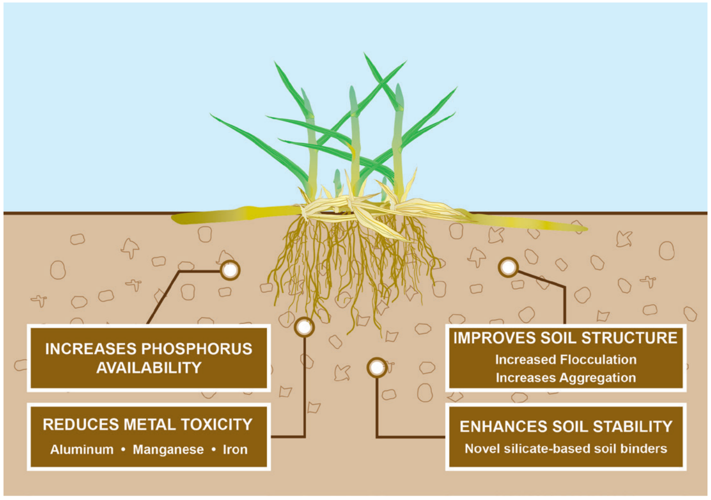
Beyond Soil Structure and Stability

The uniqueness of silicon's inner-sphere adsorption characteristics also contribute benefits to soil profiles beyond the reclamation of sodic soils.

Phosphorus Fixation and Metal Toxicity

Improved phosphorus availability and immobilization of toxic metal contaminants in the soil are two very important processes associated with the activity of silicate ligand exchange adsorption processes.

These are addressed in separate CrossOver Information Bulletins.



Soil benefits realized from the application of CrossOver G Turf are primarily associated with the release of soluble silicon species into the bulk soil solution that result in a multifunctional menu of geochemical reactions proven to be highly efficient and effective at managing and correcting a number of problems associated with soil structure and stability, sodic soils, phosphorus fixation and metal toxicity.

Sustainable Turfgrass Management

It is understandable that under most sustainable turfgrass guidelines, considerable attention has been given to strategies designed to promote replacement or reduction of chemical pesticides in favor of "organic solutions"

Recent studies have confirmed that environmental stresses (abiotic stresses) significantly impact world agriculture and turf. These studies clearly show that abiotic stresses cause much higher yield losses and poor quality turf than biotic stresses.

A key focal point for successful turf management programs in the future will certainly include the need to incorporate strategies that address issues of abiotic stress.

Dealing With Environmental Stresses

Silicon and Abiotic Stress

Silicon is not inert. It has been found to be a biologically active element, participating in highly complex interactions with key components of the plant's defense response system.

The role of silicon in conferring tolerance in plants against abiotic stresses is fully utilized with CrossOver G Turf. Plant available silicon, released by CrossOver G Turf, plays a key role in activating processes that enhance and improve the efficiency and effectiveness of defense response systems under abiotic stress conditions.

It is well documented and recognized that silicon can play an important role in increasing plants' tolerance to environmental (abiotic) stress.

Silicon is known to effectively mitigate various abiotic stress factors such as salinity, drought, heat, chilling and freezing stresses and manganese, aluminum and other metal toxicities.

Many plants, especially turfgrasses, have also developed a predisposition for the uptake and use of silicon in conferring tolerance to abiotic stresses. **Improved plant tolerance to abiotic stress with silicon is often manifested as a quicker and more efficient defense response at the onset of abiotic stresses and enhanced recovery once these stresses have abated.**

Silicon Mediation of Abiotic Stress Factors

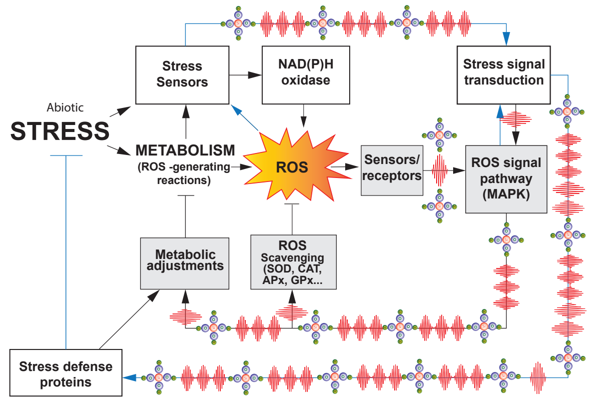
The key mechanisms of Si-mediated alleviation of abiotic stresses in vascular plants include:

- altering the activity of enzymatic and non-enzymatic antioxidants
- immobilization of toxic metal ions in soil
- complexation or co-precipitation of toxic metal ions with Si in or *ex planta*

Altering the activity of enzymatic and non-enzymatic antioxidants

Enzymes, proteins and hormones are major constituents of relay mechanisms, signaling pathways and cascades that drive defense response mechanisms in plants.

Silicon's biochemical properties enable it to interact with a host of enzymes, proteins and hormones and act as a modulator influencing the amplitude, timing and duration of stress transmission signals and protein activated plant defense response pathways.



Illustraton of signal pathways being modulated by the presence of silicon, acting as a potentiator of plant defense responses or as an activator of strategic signaling proteins.

Through its ability to interact with several key components of plant stress signaling systems silicon increases the production of important enzymatic and non-enzymatic antioxidants in plants (i.e., SOD, POD, CAT, GPX, APX, MDHAR, GR, AsA, and GSH).

It is generally accepted that this over production of ROS scavenging antioxidants (via upregulation of many ROS-scavenging genes) by silicon improves plant tolerance and resistance to various abiotic stresses.

Silicon-mediated alleviation of metals in soils

Monosilicic acid (H_4SiO_4) released following application of CrossOver G Turf is particularly effective in establishing silicate processes that reduce toxic metals from being absorbed by plants.

Complexing in soil solution. Monosilicic acids complex with metal species in the soil solution to form less toxic compounds that are removed from the rootzone as precipitates. This is similar to what happens *in planta* when silicon complexes with metals in the apoplast.

$$2H_4SiO_4 + 2Al^{3+} \leftrightarrow Al_2Si_2O_5 + 2H^+ + 3H_2O$$

$$2Al^{3+} + 2H_4SiO_4 + H_2O \leftrightarrow Al_2Si_2O_5(OH)_4 + 6H^+$$

Adsorption of metals onto polymerized silicates on exchange sites. The negative sites on soil surfaces are important exchange sites for cations. Fe, Al and Mn oxides embedded in the soil surface are known to strongly retain heavy metals.

Under low pH conditions, heavy metals can be released from these oxides sites where they may become solubilized and therefore become bioavailable (and toxic) to plants.

Monosilicic acid interacts with Fe, Al, and Mn oxide surface OH^- groups through ligand exchange to form silicate innersphere complexes.

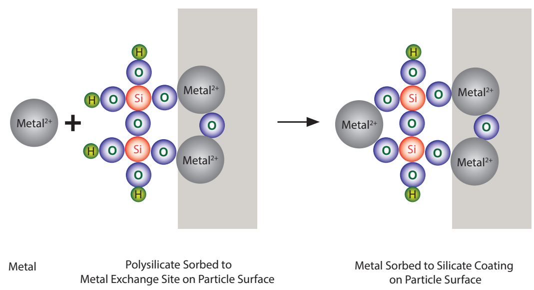
This is highly significant because the silicate complexes formed serve two purposes. They neutralize the metal oxides on the particle surface and also establish stable adsorption sites for heavy metals that are less susceptible to desorption via pH or decomposition.

Silicon-mediated alleviation of metals *in planta*

Silicon-mediated alleviation of metal toxicity in the soil and *in planta* is widely known.

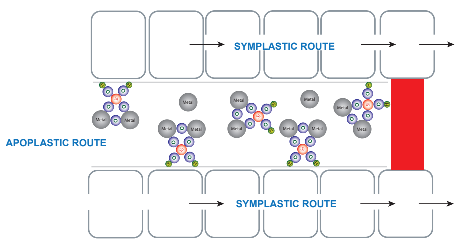
Metals often move from the soil solution into the plant and can accumulate in apoplastic intercellular spaces throughout the plant. Free metals such as manganese and aluminum that are absorbed and move to the apoplast of plant tissues often serve as feedstock for Fenton reactions resulting in the production of harmful hydroxyl radicals.

Under stress conditions, plants often increase their absorption of silicon (monosilicic acid) molecules. As the monosilicic molecules come in contact with free metals, they form complexes with metals.



Graphic showing initial formation of silicate coating on metal oxide exchange site and subsequent of ligand-like adsorption of metal to silicate coating.

When monosilicic acid forms complexes with metal molecules, the metal silicate complex attaches to the extracellular walls of the apoplast or deposits as a precipitate.



In either case, these complexed metals are rendered inert, and therefore do not engage in chemical reactions that could otherwise result in ROS production.

Fenton Reaction

$$Metal^{2+} + H_2O_2 \rightarrow Metal^{3+} + OH^- + \cdot OH$$

This co-deposition process effectively prevents "free" metal ions from entering the Fenton equation.

Silicon therefore indirectly contributes to a decrease in •OH ion production by decreasing the availability of many free cationic metals – preventing the Fenton reaction from acquiring required metal catalysts.

Sulfur and Abiotic Stress

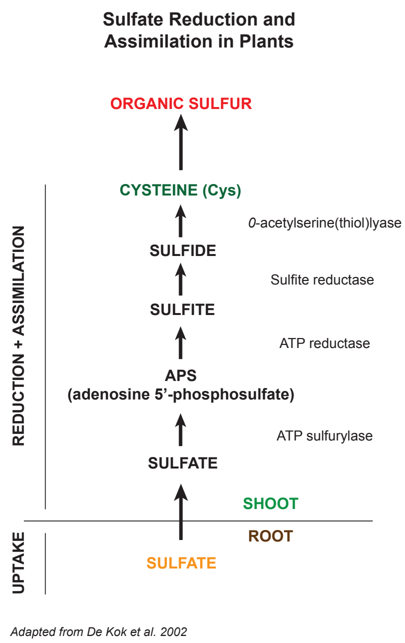
Silicon's interaction with enzymes, proteins and hormones to modulate the amplitude, timing and duration of stress transmission signals and protein activated response pathways is without question, a critical component of the turfgrass plant's ability to resist or tolerate abiotic stresses. Indeed, the viability of the plant's abiotic response system is dependent upon effective control of multiple informational transmissions, which interconnect in a network of metabolic physiological responses.

But another element (albeit often overlooked) also plays a critical role in the abiotic response process – Sulfur.

Why is Sulfur So Important?

Sulfur is an essential plant nutrient. It is a component of protein, lipids, carbohydrates, and many other cellular constituents and intermediate metabolites (Leustek, 2000). Along with nitrogen, phosphorus and potassium, **sulfur is recognized as a crucial element affecting plant growth, plant performance, yield and <u>plant response/defense against abiotic stress</u>**.

Inorganic sulfate (SO_4^{2-}) taken up by the roots is the major sulfur source for growth and abiotic defense response – although it has to be reduced to sulfide before it is further metabolized. The reduction of sulfate to sulfide and its subsequent incorporation into the amino acids, cysteine (Cys) and methionine (Met), takes place predominantly in the shoot in the chloroplast. **Cysteine is the precursor or reduced sulfur donor of most other organic sulfur compounds in plants**.



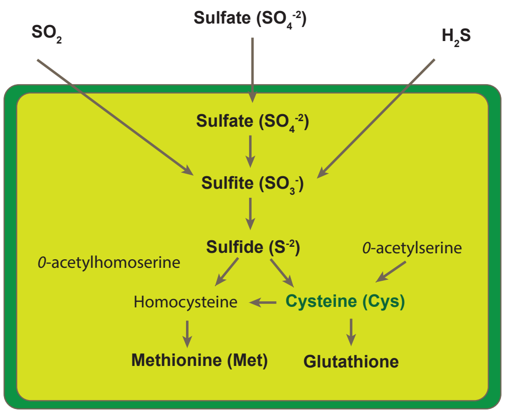
An overview of sulfate reduction and assimilation in plants.

The predominant proportion of the organic sulfur is present in proteins. Cysteine and methionine play significant roles in the structure, conformation and function of proteins. But their contribution goes beyond just proteins. **Plants contain a large variety of other organic sulfur compounds, as thiols (glutathione), sulfolipids and secondary sulfur compounds (alliins, glucosinolates, phytochelatins), which play an important role in physiology and protection against environmental stress and pests (De Kok et al., 2002a).**

Sulfur Metabolism

Platform for Abiotic Stress Response Mechanisms

Sulfur-containing defense compounds are crucial for the survival of plants under biotic and abiotic stress. **The reduction and oxidation (redox) properties of sulfur in proteins, and of sulfur-containing metabolites, are particularly important in the interaction between the reductive assimilation processes of photosynthesis and reactive oxygen species that arise as by-products of electron transport chains.**



Sulfur containing precursor compounds produced in chloroplasts

Cysteine (Cys)

- In plants, cysteine is the only metabolic sulfide donor for the generation of methionine, glutathione, phytochelatins, iron-sulfur clusters, vitamin cofactors, and multiple secondary metabolites.
- In addition to its structural role in proteins, cysteine functions as a precursor for essential biomolecules, such as vitamins and co-factors (Droux, 2004; Wirtz & Droux, 2005), antioxidants, such as glutathione (Meyer & Hell, 2005; Mullineaux & Rausch, 2005), and many defense compounds, such as glucosinolates, thionins or phytoalexins (Rausch & Wachter, 2005).

Glutathione (GSH)

Glutathione fulfils various roles in plant functioning. It is the major transport form of reduced sulfur in plants. Roots likely largely depend for their reduced sulfur supply on shoot/root transfer of glutathione via the phloem.

- Glutathione plays a highly significant role in the protection of plants against oxidative and environmental stress and it depresses/scavenges the formation of toxic reactive oxygen species, e.g. superoxide, H_2O_2 and lipid hydroperoxides.
- Glutathione serves as a thiol buffer in the protection of proteins via direct reaction with reactive oxygen species or by the formation of mixed disulfides.
- It is the most abundant sulfur-containing low-molecular weight compound found in plants

Methionine (Met)

- Plays a crucial role in protein structure and in metabolic function
- Involved in biosynthetic pathways and iron-chelating substances in roots.
- Provides a significant amount of one-carbon groups for use in plant metabolism
- A precursor in the synthesis of plant hormone ethylene
- Implicated with plant-growth hormones such as cytokinins and auxin

Factors Affecting Availability

As important as sulfur is to plant health and abiotic stress defense, it is often not present at levels needed by turfgrass under stress due in part to:

- Lack of sufficient organic matter in sandy soil conditions as well as irrigation practices that can leach S out of the rootzone. Moreover, the mobility of sulfate (SO_4^{2-}) under most conditions makes it very difficult to use soil tests as predictive tools for S fertilization requirements.
- Emissions of sulfur air pollutants in acid rain are being diminished due to regulatory restrictions. Most of the S is now been removed from natural gas and catalytic converters in automobiles remove most of the S that was previously returned to the atmosphere.
- Sulfur is not present in sufficient quantities to meet growth and stress defense demands in many of today's higher-analysis fertilizers.
- Availability of sulfur is intimately dependent on demand-driven sulfate uptake and assimilation.

Sulfur is the Perfect Companion to Silicon in Promoting Plant Defense Response to Abiotic Stress

CrossOver G Turf has specifically been formulated as a rich source of both silicon and sulfur to improve plant health and combat abiotic stresses in turf.

Certainly the role of silicon and sulfur in plant defense responses to abiotic stress is complicated and require continued investigation. But a growing body of research and field observations support the need for both elements in developing solutions to abiotic stress.

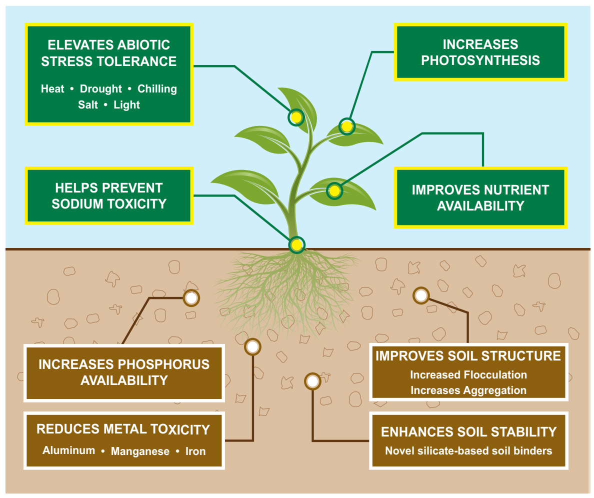
Silicon is often compared to a dimmer light switch that controls light output. It upregulates the plant defense response signals during stress that results in the increased production of proteins, enzymes and hormones needed mount abiotic defense response mechanisms.

However, the plant also needs to have suitable sulfate reserves available in the soil during stress as upregulated sulfate absorption is needed in the synthesis of many of the enzymatic and non-enzymatic antioxidants as well as sulfur containing amino acids and proteins that drive many stress relieving metabolic adjustments by the plant.

CrossOver G Turf provides the silicon that the plant uses to increase the demand for antioxidant production. The demand for antioxidant production subsequently creates the demand for assimilation and reduction of sulfate that is provided by the CrossOver G Turf gypsum constituent. Both the demand and supply sides of key abiotic stress response solutions are provided with CrossOver G Turf.

Purchase Information for Crossover
is available at:

HARSCO
www.crossover-silicon.com
email: CrossOver@harsco.com



Minimum Guaranteed Analysis
CrossOver G Turf
Calcium(Ca)........25.0%
Magnesium(Mg)....3.0%
Sulfur(S)..............10.0%
Monosilic Acid.......1.4%

Directions For Use:
Apply at 5-10 lbs. per 1000 sq. ft. per month during a 3-month treatment period to build sufficient calcium and silicon reserves in the soil. ***CrossOver G Turf*** can also be applied as a single treatment at 25-30 lbs.per 1000 sq. ft