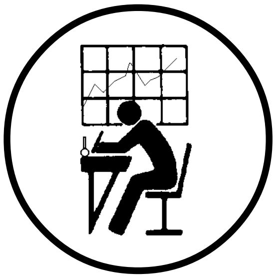
Silicon: The Universal Contaminent



Research Report

In acidic soils high in aluminum and iron, silicon counteracts toxicities, responsible for reduced root growth, by complexing in solution and preventing plant uptake.

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Bentgrasses on golf courses throughout the United States are challenged with environmental (heat, traffic, etc.) and biological (insects, diseases, etc.) stresses. As a result of intensive management practices, not to mention high quality expectations, bentgrasses are exposed to serious levels of stress. Survival under stress often reduces stand vigor and provides opportunity for attacking fungal pathogens.

Root and crown rot, as well as post emergence damping-off, induced by *Pythium aphanidermatum*, are diseases that affect both seedling and mature stands of creeping bentgrass. Given the proper conditions of high relative humidity and temperature and the sufficient inoculum density, *P. aphanidermatum* can be devastating. Demanding quality expectations in the shortest amount of time combined with the potential virulence of the pathogen, leaves the golf course superintendent reliant on preventative applications of synthetic fungicides as the primary disease management tool. Public concern for ground and surface water quality has prompted research into other avenues of control less dependent on synthetic fungicides.

Visualizing the disease triangle, we see that a disease is the result of three factors occurring simultaneously: a susceptible host, a pathogen capable of infection, and favorable environmental conditions. A fundamental approach to disease management requires a vigorous stand of turf that will be better able to tolerate stress and resist disease. Therefore, it is important to develop an understanding of plant health that results in a high quality turf. Knowledge of site conditions, soil properties (obtained by laboratory analysis) and well adapted species or cultivar selections, seeded at the proper rate, are vital first steps. Integration of cultural practices such as mowing height and irrigation methods along with refinement of nutrient applications has been shown to improve plant health. Furthermore, the source, concentration, and timing of essential mineral nutrients has been proven to influence overall plant health and disease susceptibility.

Silicon Dynamics

While research into the mineral nutrition of higher plants recognizes 14 essential macro and micro elements for plant growth, the essentiality of silicon (Si) is controversial. The necessity of this element has been difficult to prove as it is hard to work in an Si free environment. The pioneer of plant nutrition, Dr. Emanuel Epstein refers to Si as a "ubiquitous contaminant"; in fact, leaf tissue dry weights of plants not amended with Si can contain upwards of 400 mg Kg^{-1} .

Approximately 90% of the earth's crust is comprised of silicon, occurring in nature, not as Si, but as silicon dioxide (SiO_2) or silicates. Si is rendered accessible from two sources, weathering minerals and the more readily available opal phytoliths from decomposing plant material. In the soil solution, Si exists as monosilicic acid ($Si(OH)_4$) with concentrations about equal to those of the macronutrients potassium (K) and calcium (Ca). Si concentration in solution is indirectly proportional to pH, iron (Fe), and aluminum (Al) concentrations. Si availability in soil solution decreases at increased pH or with increased amounts of Fe and Al. Nutritionally, Si can modify or counteract adverse soil conditions. Manganese (Mn) rich soils often result in reduced plant shoot growth. Si has been shown to affect the microdistribution of Mn in the leaves leading to an increase in plant tolerance of the element. In acidic soils high in Al and Fe, Si counteracts toxicities, responsible for reduced root growth, by complexing in solution and preventing plant uptake.

Plants are classified as either Si accumulators or non-accumulators. Rice, sugar cane, and equisetum are accumulators, in that uptake of Si can exceed the rate of transpiration. Si uptake in the grasses occurs at a similar rate as transpiration, whereas dicots can exclude Si at the root. Plant uptake of Si is considered passive, and translocation via the xylem is in the form of monosilicic acid. There is no known downward movement of Si in the plant phloem.

Table 1. Silicon nutrient concentration (mg Kg^{-1}) analysis of creeping bentgrass roots, crown, and leaves.

Treatment	Root	Crown	Leaves	Total
1. Fungicide, nutrient solution + K	1672	750	1521	3943
2. Nutrient solution - K + Si (100 mgL^{-1})	1146	854	521	2521
3. Nutrient solution - K + Si (50 mgL^{-1})	1185	702	1060	2947
4. Nutient solution + K	1577	773	1601	3951
5. Nutrient solution - K	1535	607	1399	3541

Structural and Physiological Role of Silicon

Silicon is deposited in the plants as silica gel in areas where it complexes with other molecules and/or areas of Si saturation. In the roots it is deposited in the tracheids, vessels, and endodermis. The nodes and internodes contain Si around vascular bundles, epidermal cells, and stomates. The leaf sheath and leaf blade have Si in epidermal cells, guard cells, and serrated hook cells located along the margin of the blade. Silicon is also found in the spikelet and lemma of the inflorescence. Once deposited the Si is immobile for the life of the plant, with mature plants having more Si than young plants.

The role of Si in plants is varied. Epidermal cells impregnated with Si on the abaxial surface of the leaf blade increases the erect posture of the leaves for light interception. This enhanced light interception could result in increased photosynthetic activity leading to increased growth and plant health. Si is known to counteract high applications of nitrogen (N) which decreases leaf erectness as result of tissue succulence. Structurally Si is considered analogous to lignin by increasing cell wall rigidity and preventing lodging.

Physiologically, Si is involved in plant water relations, reducing water loss by acting as a physical barrier. Deposits of Si in epidermal and hook cells act as barriers to surface feeding herbivores. With regard to disease severity, research has shown nutrient solutions amended with soluble Si and applied to cucumbers, roses, and grapevines had reduced incidence of powdery mildew. In addition, hydroponically grown cucumbers in nutrient solutions amended with soluble Si had less severity of *Pythium* sp. and greater yield.

Experiment

A study was initiated to investigate the effects of soluble silicon on plant growth and disease severity caused by *Pythium aphanidermatum* in creeping bentgrass establishment. Research was conducted for seven months in controlled environmental chambers at Cornell. Five treatments were imposed on the creeping bentgrass "Penncross," grown in a slightly acidic greens sand (pH 6.8) and supplied with one of four basic nutrient solutions supplemented with 0 mg L^{-1} Si, 50mg L^{-1} Si, 100 mg L^{-1} Si, or 0 mg L^{-1} K. The source of silicon was potassium silicate ($K_2O{\cdot}SiO_2$). Plants were grown for three weeks at 20˚C under 14 hours of light and on the 21st day either inoculated with *P. aphanidermatum* and rated for five days or harvested, weighed, and analyzed for nutrient content. Metalaxyl was applied to Treatment 1 plants prior to inoculation to serve as a standard. Over the seven month time period this experiment was repeated five times and data was collected on dry weight yield, nutrient content, and disease severity.

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Table 2. Nutrient content of creeping bentgrass leaves as influenced by silicon and potassium applications.

Treatment	N	P	K	Ca	Mg	Si	Mn	Fe	Al	Zn
	g Kg^{-1}					mg Kg^{-1}				
1. Fungicide, nutrient solution + K	15.1	4.8	26.5	9.1	2.5	1300	430	2200	650	50
2. Nutrient solution - K + Si (100mgL^{-1})	23.2	4.5	22.4	8.9	2.2	480	360	1700	460	40
3. Nutrient solution - K + Si (50 mgL^{-1})	19.2	5.0	18.5	10.4	2.6	1200	370	2300	490	40
4. Nutrient solution + K	19.7	4.0	21.1	7.6	2.1	1500	410	3100	810	40
5. Nutrient solution - K	24.8	5.0	8.3	13.5	3.7	1300	450	3900	770	50
Sufficiency range	27-35	3-5.5	10-25	5-12.5	2-6	n/a	25-150	35-100	n/a	20-55

Results and Discussion

Growth, as measured by dry weight yield, three weeks after seeding was significantly influenced by the treatments. Total dry weight of the bentgrass plants receiving soluble Si was significantly greater than the bentgrass not supplied with additional Si or lacking K (see Chart 1). Interestingly, Si content in the leaf tissue was consistently low for plants receiving Si (see Table 1). In addition, the Si amended plants had less Fe, Al, Mn, and Cu in leaf tissue (see Table 2).

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Silicon

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A clear separation between treatments for disease incidence was evident on days 4 and 5 (see Chart 2). Disease severity was greatest on the plants supplied with the high rate of Si as compared to plants treated with the low rate of Si and plants lacking K. The interactive response of growth and disease was exhibited at the low rate of soluble Si that consistently resulted in higher yield and less disease.

Conclusion

In acidic soil conditions, Al, Mn, and Fe toxicities can be detrimental to plant growth. This study indicates that perhaps Si indirectly enhanced the growth of the plants by suppressing Al and Fe uptake and increasing the plant's tolerance to Mn. Plants supplied with the highest rate of soluble Si had less actual Si in the leaf tissue and greater disease damage. Studies have shown that plant succulence, increased population density from high seeding rates, and a uniform age of the stand enhance disease development; all three factors were evident.

Seeding is best suited to spring or fall with the goal of a dense stand of turf, able to establish an area and resist stresses. These findings suggest the possible benefit of Si amendments during establishment by increasing plant health and vigor without increasing disease severity caused by *P. aphanidermatum*. Further research of this "ubiquitous contaminant" in acid soils involving alternate cool season pathogens may increase our understanding of Si, and a possible optimum level, to be of benefit as an amendment during establishment.

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Figure 1. Total Dry Wt.

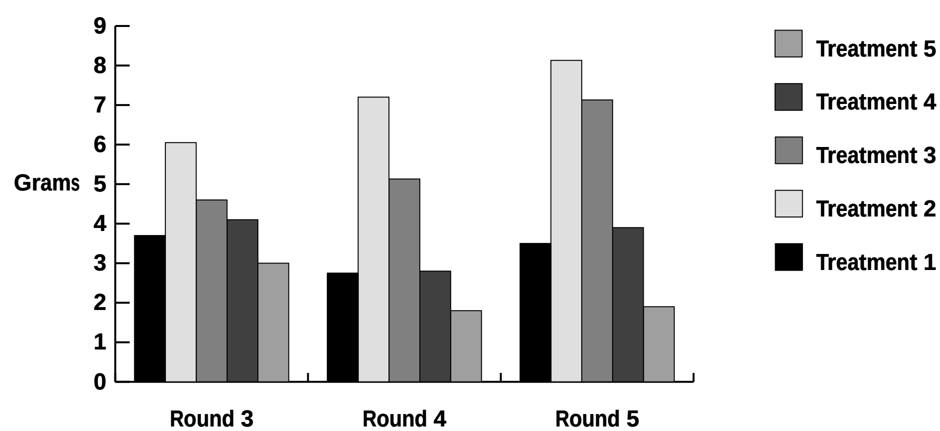

Figure 2. Mean Disease Rating By Day