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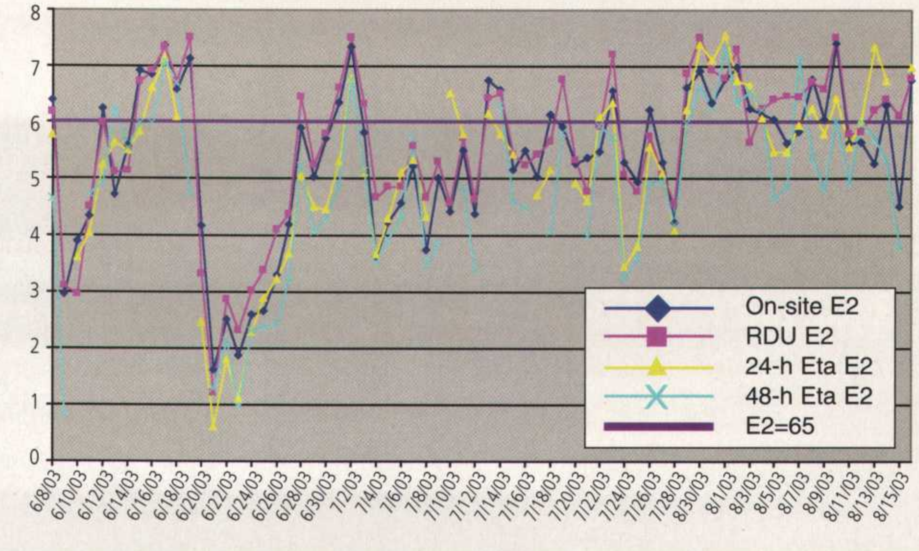
FIGURE 3

E2 values derived from meteorological data collected on-site, from Raleigh Durham (RDU) airport, and 24-hour and 48-hour forecasts according to the Eta weather model. The E2=6 line indicates the threshold for brown patch development according to the Fidanza Model. 24-h Eta forecasts were not available on June 9 and 19; July 9, 12,16 and and 19; and Aug. 15. 48-hour Eta forecasts were not available on June 10 and 20, July 10, 13, 17, and 20, and Aug.16.



Continued from page 60

On-site weather data was collected by a Campbell Scientific weather station situated directly on the research green. Forecasted weather data (24-hour and 48-hour forecasts) were compiled from the National Weather Service Eta model. The E2 value was calculated from these three sources of weather data and compared to the E2 values from airport weather data discussed above.

The airport and on-site weather data differed in their prediction of disease development on nine days during 2003 (Figure 2). On-site data correctly predicted whether or not brown patch activity was observed on five of the nine days, whereas the airport data correctly predicted disease development on the remaining four days. Therefore, the use of on-site weather data improved the accuracy of disease forecasts by only one out of 70 days. This slight improvement in accuracy probably does not justify the expense of purchasing and maintaining an on-site weather station, although additional research will be needed to complete a cost-benefit analysis.

In general, forecasted weather data tended to underpredict the E2 value when compared to airport weather data (Figure 2). There was, however, a relatively consistent relationship between observed and forecasted E2 values. As expected, 24-hour forecasts appeared to be significantly more accurate than 48-hour forecasts. Forecasts longer than 48 hours are not likely to be sufficiently accurate for prediction of turfgrass disease development.

The future of turfgrass disease prediction

By optimizing the timing of fungicide applications, disease forecasting has the potential to reduce the number of applications needed to maintain high-quality turf.

However, there is much work to be done before this technology can be used by turfgrass managers. Our research indicates that off-site weather data, collected from airport weather stations or other sources, can be used to predict disease development nearly as accurately as data from on-site weather stations. This result has major implications to our efforts to develop an Internet-based system for disease forecasting.

By using off-site weather data, it will be possible to produce disease outlooks for turfgrass managers, whether or not they have an on-site weather station. There also appears to be potential in the use of forecasted weather data to predict disease development up to 48 hours into the future. At this point, the primary limitation to the use of disease forecasting is the accuracy of the disease prediction models themselves, rather than the meteorological data. Continued research is needed to develop models that are accurate on a regional scale. ■

Tredway is a pathologist in the Department of Plant Pathology at North Carolina State University in Raleigh. Palmieri, Lackmann and Niyogi are in the Department of Marine, Earth, and Atmospheric Sciences at the school.

ADVERTISEMENT

The Andersons: Snow Mold Control Products

The Andersons offers a wide variety of snow mold protection products in both granular and sprayable formulations. These products have been and continue to be in university snow mold testing each year with additional work being done on new and improved formulations. These products have many years of solid performance at golf courses around the country in preventing both pink and gray snow molds.

When deciding on the best snow mold program approach to take, it should be based on historic levels of disease pressure at your golf course, along with prior history of infestations and the amount and times of snow fall cover. Timing of applications prior to snow events can be tricky in many northern areas, especially high altitude mountain regions. The fungicide treatment program you choose needs to attack both types of snow mold—pink snow mold (*Microdochium nivale*) and gray snow mold (*Typhula incarnata* and *Typhula ishikariensis*). Pink snow mold is the most common form of snow mold. It can be present with or without snow cover. It occurs under conditions of cool wet weather, high humidity, high nitrogen levels, soil pH above 6.5, and excess thatch. Gray snow mold occurs primarily in heavy snowfall areas. In addition to extensive snow cover, excess thatch and high nitrogen levels can promote disease activity.

Managing a golf course that is under snow for periods in excess of 120 days can be quite challenging for any snow mold control program. Here are a few cultural techniques to help prevent snow mold damage:

The snow mold free strips were treated with the Andersons FFII 14-3-3. Winter 2001 and 2002 Pullman, WA

- Mowing heights should be maintained going into fall.
- Green surfaces should be maintained with little to no leaf litter or needle debris.
- Look at the impact of tree shade in winter, especially on north-facing locations. Try to reduce risk by increasing winter sun.
- Thatch control is key. Active ingredients become tied up in excess thatch.
- Review your fertility program. Apply less N and more K going into fall.
- Surface and subsurface drainage is the key. Consider deep tine aeration in the fall to improve poor drainage.
- Sulfur applications can help. A soil pH above 6.5 favors pink snow mold.
- Reduce the amount of inoculant by early application of contact and systemic fungicides in the fall.
- Map areas that are prone to snow mold, implement additional preventative measures.

When it's time to plan your snow mold protection program, give the Andersons products a good look. You will see very solid performers in our product line as noted in the table below. The active ingredients in our product line continually deliver great control. Michigan State studies report, "18 of 19 best performing treatments in turf trials all included PCNB or chlorthalonil." Never before has it been easier and safer to apply products for snow mold control. Several of our granular fungicides now utilize our new DG Pro carrier that makes granular applications precise and easy to apply. The use of granular fungicides in fall and winter makes good sense. They allow for ease of application during freezing temperatures and lighter traffic on greens vs. spraying.

Article contributed by Ed Price, Territory Manager of The Andersons.

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Product	Product Code	Form	A.I.	Disease
FFII/14-3-3	AGC8566	Granular	PCNB	Pink and Gray Snow Mold
10-0-14 + 15% PCNB	ATT10PC4.1	Granular	PCNB	Pink and Gray Snow Mold
23-3-5 + Fungicide VIII	AGC8569	Granular	Thiophanate-methyl + iprodione	Pink Snow Mold
Bayleton 1%	ATTBY13	Granular	triademefon	Pink and Gray Snow Mold
Fungicide V on DG Pro	AGC87135	Granular	chloroneb	Gray Snow Mold
Fungicide IX on DG Pro	AGC8549	Granular	Thiophanate-methyl +chloroneb	Pink and Gray Snow Mold
Fungicide X	AGC8510-1	Granular	Iprodione	Pink and Gray Snow Mold
Systemic Fungicide on DG Pro	AGC8539	Granular	thiophanate-methyl	Pink Snow Mold
Sulfur	AGC8870	Granular	Elemental Sulfur	Pink and Gray Snow Mold
Penstar Flo	AGC85005	Sprayable	PCNB	Pink and Gray Snow Mold
Fluid Fungicide	AGC833861	Sprayable	Thiophanate-methyl + iprodione	Pink and Gray Snow Mold
Fungo Flo	AGC85225	Sprayable	thiophanate-methyl	Pink Snow Mold
Fungo 50 WSB	AGC85050	Sprayable	thiophanate-methyl	Pink Snow Mold

Bt Bacteria Might Form Basis for Future Biological Insecticide

By Tracy Ellis, Greg Bradfisch and Joel Coats

Will U.S. turf markets ever see the benefit of a *Bacillus thuringiensis (Bt)*-based biological insecticide for white grub control? Insecticides based on *Bt* may have advantages over current biologicals by having easier application parameters than nematode bioinsecticides or faster action than milky spore (Bacillus popilliae) disease. But the environmental benefit of *Bt*-based insecticides may never outweigh the spectrum and other advantages offered by some current chemical insecticides such as Merit and Mach 2 for grub control.

Hundreds of diverse crystalline proteins are known to be produced by *Bt* and many of these have insecticidal activity against a variety of pests. The name of the subspecies often has its origin with the discoverers or geographic regions of discovery such as *Bt tolworthi, kumamotoensis and japonensis*. Gene and amino acid sequencing often determine that a subspecies harbors genes for several insecticidal proteins. Also, members of different subspecies may have identical genes and express identical proteins.

Key knowledge of the gene sequence and the resulting expressed proteins are already known for many *Bt*. For more information on *Bt* toxin diversity and nomenclature please visit N. Crickmore, D.R. Zeigler, E. Schnepf, J. Van Rie, D. Lereclus, J. Baum, A. Bravo and D.H. Dean's "Bacillus thuringiensis toxin nomenclature" (2004) *http://www.biols.susx.ac.uk/Home/Neil_Crickmore/Bt/index.html.*

Specific details on the mode of action differ with each insect and *Bt* toxin interaction, but a general model for *Bt* mode of action is widely accepted by scientists (for mode of action information please visit Dr. D.J. Ellar's Web site at *http://www.bioc.cam.ac.uk/UTOs/Ellar.html#anchor736270*).

After being eaten, the *Bt* protein in the insect midgut is dissolved and enzymatically digested to render a solubilized and truncated protein toxin. The toxin then must bind to specific receptors in the gut where it causes pore formation and membrane disruption. The insect dies by septicemia and/or starvation. The efficiency of protein solubilization, truncation and toxin attachment for each insect and toxin combination accounts for the specificity and lethality of certain *Bt* proteins against different insect pests.

If any one of the steps in the mode of action fails to occur, the protein will not show toxicity against the insect. For example, the *Bt* protein will not be toxic if the insect gut has a high pH and the protein dissolves only at low pH, or if the insect digestive enzymes do not cleave to expose the active site, or the insect lacks specific gut receptors to bind the truncated toxin. One researcher (Sharpe) observed *Bt* toxicity differed between fall-collected grubs preparing for winter diapause and actively feeding spring-collected grubs. Presumably, the midgut biochemical pH of spring-collected grubs was more suitable for solubilizing *Bt* inclusions, the first step in *Bt* mode of action.

The physiological age of the pest may be an important consideration the optimal timing of *Bt* product application, adding to possible use complications of a *Bt* product.

Other subspecies of *Bt* which express proteins known to have toxicity against one or more U.S. white grub pests: *Bt tolworthi* that expresses proteins of lengths 61, 68 and 75 kilo dalton (kDa — a unit used to measure the molecular weight of the protein); *Bt kumamotoensis* that expresses doublets at 130 kDa; and *Bt japonensis* at 131 kDa as measured by polyacrylamide gel electrophoresis.

Bt tolworthi and other subspecies of *Bt* express proteins classified as $Cry3Ba_1$, $Cry3Bb_2$ (formerly CryIIIB & CryIIIB3). Laboratory and turf plug tests reported in 1992 and 1993 by Ecogen, cooperating with Chemlawn Research and Development, showed $Cry3Bb_2$ toxin to cause mortality of two main U.S. grub pests, Japanese beetle and northern masked chafer *Cyclocephala borealis.* Tests by Mycogen Corp. (currently

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TABLE 1

Host range spectra of Bt subspecies against U.S. grub pests[1]: (+) indicates susceptibility, (-) indicates no observed effect, (x) not reported.

	Oriental Beetle	Black Turfgrass Ataenius	Green Fruit Beetle	Northern, Southern & Pasadena Masked Chafer	May/June Beetles	Japanese Beetle
Bt subspecies						
kumamotoensis	X	-	+	-	-	-
tolworthi	-	-	-	+	-	+
japonensis	+	-	+	+	-	+

[1]results compiled from Michaels et al. 1993, 1996, MacIntosh et al.1990, Grossman 1992, Suzuki et al. 1992, & Robert el al. 1994.

No *Bt* candidate has yet made the long trek into commercialization as an option for white grub control.

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Dow AgroSciences LLC) confirmed *Bt tolworthi* to cause mortality of Japanese beetle and Northern masked chafers and concluded *Bt tolworthi* was also toxic to Southern masked chafer *C. lurida*, and Pasadena masked chafer (*C. pasadenae*).

Bt tolworthi had no toxicity against other U.S. pests Oriental beetle *Anomala orientalis*, Black turfgrass ataenius (*Ataenius sp.*), green fruit beetle (*Cotinis sp.*), nor June beetle (*Phyllophaga sp.*).

Mycogen reported in 1993 that *Bt kumamotoensis*, which expresses a protein classified as $Cry8Ba_1$ (formerly CryIIIE), was toxic to green fruit beetle grub (*Cotinis sp.*) *Bt kumamotoensis* was not toxic to black turfgrass ataenius, masked chafers, June beetles nor Japanese beetles.

By 1992, Ohba discovered subspecies *japonensis* (*Btj*) which expresses toxin Cry8C (formerly CryIIIF) to be toxic to white grub Cupreus chafer (*Anomala cuprea*), hence the nickname "buibui" after the insect. The host range of *Btj* buibui was well-defined for several insect pests of economic importance in Japan by Suzuki et. al., and shown to be highly toxic to genera in the subfamily Rutelinae, which includes pests also of U.S. economic significance, such as Japanese beetle and Oriental beetle. Mycogen later reported high levels of toxicity of *Btj* against the native U.S. grubs green fruit beetle and the Southern, Northern and Pasadena masked chafers.

There was a brief effort in the United States to develop a *Btj*-based product by Mycogen and Kubota Corp. in the mid-1990s. However, the limited activity against black turfgrass ataenius and May/June beetles discouraged further investment. *Btj* is now owned by Sumitomo Chemical Co. which, in late 2003, acquired Kubota's biological pesticide business and is the basis of registered flowable and granular product Buihunter in Japan intended for use against chafers in sweet potatoes.

Sumitomo Chemical has the intention to expand the Buihunter label to turf. However, at this writing, the plan on whether to develop *Btj* in the United States by subsidiary Valent BioSciences is unclear.

No *Bt* candidate has yet successfully made the long trek into commercialization to be available as an option for white grub control in turf despite candidates like *Btj*, which have activity against main U.S. grub pests of Japanese beetle, Oriental beetle and masked chafers.

One weight against the usefulness of *Bt* subspecies active against grubs may be apparent lack of toxicity by known *Bt* candidates against grubs in the subfamilies Melolonthinae and Aphodinae that include May or June beetles, European chafer, Asiatic garden beetle, black turfgrass ataenius and *Aphodius* sp., while some chemical insecticides have a broader spectrum. However, industrial players holding ownership and knowledge of the *Bt* strains may decide to further develop some of these biological candidates and discover new ones.

In the future, market forces may turn to give *Bt* products a place in the biological product line-up for grub control.

Ellis, a turfgrass pest consultant, performed Bt grub research with guidance from Bradfisch while at Mycogen (now DowAgroSciences LLC in Indianapolis) as well as at Iowa State University with direction from Coats, a professor and chair at its Department of Entomology in Ames.

Ultradwarf Bermudagrasses Exhibit Easy Mutation Tendencies

PART 1:
Off-type mutations may occur naturally.

By Patrick McCullough, Bert McCarty, Vance Baird, Haibo Liu and Ted Whitwell

Bermudagrass (*Cynodon* spp. L. C. Rich) is the most widely used turfgrass in the southern United States(Emmons, 2000). Native to eastern Africa, bermudagrass has aggressive stolons and rhizomes that form vigorous turf with high shoot densities and rapid growth capabilities (Beard, 1973). Bermudagrass has excellent wear, drought and salt tolerances, but needs high nitrogen fertility, full sunlight and routine cultivation (McCarty and Miller, 2002). In all, it is a good choice for golf courses.

Genetics and history

Turf-type bermudagrasses are classified into four groups according to their heredity and chromosome number:

- common bermudagrass, a tetraploid with a total of 36 chromosomes;
- African bermudagrass, a diploid variety with 18 chromosomes;
- hybrid Magennis bermudagrass, a naturally occurring triploid with 27 somatic chromosomes; and
- Bradley bermudagrass, an aneuploid with 18 somatic chromosomes (McCarty et al., 2001).

Selections used for golf greens are sterile triploids, the result of an interspecific hybrid with 27 chromosomes (Burton, 1991).

In the 1950s and 1960s, Glen W. Burton of the U.S. Department of Agriculture in Tifton, Ga., released several bermudagrass hybrids, including Tiflawn, Tifway, Tifgreen and Tifdwarf. Hybrid bermudagrass (*Cynodon dactylon* Pers. x *C. transvaalensis* Burtt-Davy) is the warm-season turfgrass used most commonly on putting greens (Beard, 2002).

After its release in 1956, Tifgreen, also noted by its experimental notation 328, quickly became the most popular bermudagrass golf green in the world, as common bermudagrass and sand greens were used prior to its release (McCarty et al., 2001).

Bermudagrass putting-green quality has traditionally been considered inferior to finer textured creeping bentgrass because cultivars such as Tifgreen and Tifdwarf have trouble withstanding routine mowing heights lower than .189 inches (Beard, 1973). In contrast, recently introduced dwarf-type bermudagrass varieties tolerate long-term mowing heights of .126 inches or closer (McCarty and Miller, 2002).

Dwarf bermudagrass exhibits finer leaf textures, higher per-area shoot densities and low growth habits that allow for lower mowing heights and produce conditions similar to creeping bentgrasses (McCarty and Miller, 2002; Beard, 2002). Dwarf bermudagrass varieties available currently include: TifEagle, Champion, Mini Verde, Classic Dwarf, FloraDwarf, Florida Dwarf, Reesegrass and MS Supreme. Although many Southern golf courses have converted to these improved grasses, traditional bermudagrass management practices appear inadequate for the long-term success of the new varieties. Superintendents face new challenges, including different fertility requirements, disease management, mitigating shade intolerances, managing thatch/mat development and promoting root growth.

Bermudagrass mutations

Concerns exist over the potential of genetic instabilities of traditional hybrid bermudagrass putting greens. Off-type patches of different color and texture grasses are major contamination problems of Tifdwarf and Tifgreen bermudagrasses, causing putting greens to become mosaic and difficult to play (McCarty and Miller, 2002; Beard, 2002).

Tifdwarf bermudagrass, for example, is believed to be a chance mutation in previously planted Tifgreen bermudagrass. However, most somatic mutations and genetic instability of triploid hybrid bermudagrass lead to undesirable off-type contamination.

Contaminations of off-type bermudagrasses may develop over several years and are believed to have arisen from the chance occurrence of mutations in parent material or possibly contamination through mechanical means.

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Mutations are abrupt, inheritable changes brought by alterations in a gene, a chromosome or by a change in chromosome number. The rate of mutation can be increased artificially, but results cannot be controlled. Usually recessive, mutations may remain unexpressed for generations.

Mutations are produced by internal disorders, such as inaccurate gene duplication, and by natural external forces, such as severe temperature changes or sunlight radiation. Natural mutations appear rarely, whereas artificial ones can be produced more frequently and occur more quickly.

Tifway II, Tifgreen II and TifEagle are induced mutations of original grasses by exposing original plant material to artificially high levels of radiation. Tifdwarf, FloraDwarf, and Pee Dee 102 bermudagrasses are believed to be natural mutants from Tifgreen bermudagrass, which is a first-generation hybrid and is a completely sterile triploid. Thus, it must be propagated vegetatively.

The mottled appearance of this green reveals off-type contamination from mutations.

Because Tifdwarf is probably a vegetative mutant from Tifgreen, the possibility exists that an original planting of Tifdwarf can undergo another mutation to produce a different grass. Although mutations offer new ways of introducing genetic variability into breeding lines, they also may cause instability into existing materials. Therefore, mutations may produce undesirable off-types over several years (McCarty et al., 2001).

Recently, geneticists have used DNA-amplification fingerprinting — a marker-assisted procedure that helps turf breeders secure turfgrass cultivar proprietary rights and planting stock certification, and evaluate off-type relationships — to specify the genetic relationships among bermudagrass cultivars. Using these techniques, Caetano-Anollés et al. (1997) found Tifway to be genetically stable despite the enormous gene pools of African and common bermudagrasses. The researchers observed off-type bermudagrasses found in Tifway stands were genetically distant to to the variety and represented a heterogeneous group of bermudagrass probably of interspecific hybrid origin. The authors concluded these off-types probably resulted from sod contamination and not mutations.

In later studies, Caetano-Anollés (1998) investigated Tifdwarf and Tifgreen bermudagrass, cultivars traditionally used as putting green turf. Through this research, Caetano-Anollés confirmed genetic instabilities of Tifdwarf and Tifgreen bermudagrass.

Phenetic analyses showed almost all cultivar accessions and one-half of the off-types studied were genetically distinct, but very similar. The researcher concluded this genetic variation was probably a result of somatic mutations and Tifgreen accessions represented a genetically diverse bermudagrass group of interspecific hybrid origin. These discoveries provide the first conclusive evidence that off-type patches in bermudagrass greens are a direct consequence of genetic instabilities of Tifgreen and Tifdwarf. As expected, additional concerns exist with the new ultradwarf bermudagrass cultivars.

Many of these cultivars, like Champion, are selections from previously planted Tifdwarf or Tifgreen stands and potentially have the ability to mutate somatically into off-type contamination. In the next article, we discuss how herbicides that disrupt genetic replication and damage DNA sequences may induce bermudagrass mutations and the importance this may have for long-term ultradwarf bermudagrass management.

McCullough is a graduate assistant; McCarty, Baird, and Whitwell are professors; and Liu is an associate professor in the Department of Horticulture at Clemson (S.C) University.

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Scientists Start to Recognize Silicon's Beneficial Effects

By Richard J. Hull

In the first articles of this series on beneficial elements (Hull, 2004), we discussed the general distinctions between essential and beneficial nutrients. The beneficial element under consideration here, silicon (Si), could justify being applied to turf. In fact, there are more published reports on the beneficial effects of applying Si to turf than there are for most essential micronutrient elements.

In his review article on Si, Emanuel Epstein concluded that Si is unquestionably an important requirement for the normal growth of many plants, and it should be viewed as "quasi-essential" (Epstein, 1999).

Si in soils and soil solutions

Silicon is the second-most abundant element in the earth's crust at 31 percent. Only oxygen is more plentiful at 49 percent.

Many of our most common minerals are various combinations of aluminum and iron silicates. These minerals are highly insoluble, so while the mineral matter of most soils is literally made of Si, its concentration in the soil solution is relatively low. As Si minerals weather, some of the Si slowly hydrates and solubilizes as orthosilicic acid (H_4SiO_4).

Because the Bordwell acidity measurement (pK_a) of silicic acid is 9.82 at 77 degrees Fahrenheit, it loses none of its positive hydrogen ions (H^+) at the pH of most soils and remains in the soil solution as uncharged silicic acid. The pK_{a1} is that solution pH at which an acid will lose to the solution 50 percent of its least tightly held H^+ such that half of the acid molecules are then present as a monovalent anion.

Salicic acid is weakly soluble; a saturated solution being about 2 millimoles (mM), which is equivalent to 56 milligrams (mg) Si/liter (Si/l). Therefore, soil solutions generally have a Si concentration of .1 mM to .6 mM (3-17 mg Si/l), which is low but still is 100 times greater than soil solution phosphate. Because there are so many silicate minerals in most soils, this low silicic acid concentration is well-maintained at the .1 mM to .6 mM level. This is the form and concentration of Si available to plant roots.

Si absorption and transport

Plants differ in their ability to absorb Si from the soil solution. Marschner (1995) identifies three types of plants based on their capacity for Si absorption: Si accumulators, Si nonaccumulators and Si excluders.

Silicon accumulators include several primitive plants including the horsetails (*Equisetum* spp.) and wetland grasses such as paddy rice that contain Si at 4.6 percent to 7 percent of their leaf dry weight. These plants contain much more Si than is carried to the surface of the roots as the plant loses water through transpiration. The roots of these plants must deplete the silicic acid from the soil water adjacent to their root surfaces allowing additional silicic acid to diffuse toward the roots. This requires active Si uptake by the roots. Si nonaccumulators contain .5 percent to 1.5 percent Si in their dry leaf tissues and include most dry land grasses including sugarcane, cereals and turfgrasses. These plants absorb as much Si as is transported to their roots by the mass flow of transpirational water.

The Si excluders contain less than .23 percent Si in their dry leaf tissues. These plants contain less Si than transpirational water would deliver to their roots. Here, water is absorbed more rapidly than the silicic acid it contains, indicating that Si is in some way excluded from entering the roots. It might be good to realize that even at .25 percent to .1 percent of dry tissues, Si is present at levels comparable to the macronutrients sulfur (S), phosphorus (P) and magnesium (Mg).

Since accumulator plants and nonaccumulators growing in low silicic acid concentrations can concentrate Si to levels greater than that of the growing medium, it is assumed that an active transporter is involved.

Studies reported by Tamai and Ma (2003) show that rice can accumulate silicic acid through the action of a membrane transporter that has a low affinity for silicic acid, is inhibited by a number of metabolic toxins and is only

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weakly in competition with the uptake of other nutrients. A rice mutant defective in this specific transporter protein couldn't concentrate silicic acid to the levels observed in wild-type rice.

These findings support the conclusion that silicic acid is absorbed by an active process that uses metabolic energy through a specific transport protein that loads silicic acid into root epidermal cells or from root cells into xylem elements.

Silicon is transported in plants from roots to leaves mainly through the xylem, which can contain silicic acid levels many times that of the soil or nutrient solution. There is little evidence of silicic acid being translocated by the phloem to sites of carbohydrate storage.

Silicon and cell wall structure

Within plants, Si transport is marked by the presence of abundant silicic acid polymers incorporated in cell walls. These occur as amorphous silica deposits known as "opal" or as more crystalline-shaped opal phytoliths (Marschner, 1995). Such deposits are most abundant in the outer epidermal cell walls, and hairs of leaves and stems — the sites of greatest transpirational water loss.

These impregnated Si layers within cell walls are most developed in older leaves and present a barrier to cuticular transpiration and fungal penetration of leaves. The strengthening effect of silica polymers in cell walls can prevent xylem vessels from collapsing during times of maximum water stress.

The interaction of Si with lignin biosynthesis and structure, mostly in vascular cells, has been studied, and several theories of silicic acid binding with phenolic groups have been proposed. That such reactions can occur is unquestioned, but their role in determining lignin structure and physical properties is less certain.

Silicic acid can form ester-like linkages between phenolic groups of lignin, and it is likely that such structures will stabilize and strengthen the cell walls. It is also likely that the action of other nutrients, e.g. boron, will be increased when Si is present. At present, however, there is no evidence that Si is essential for cell wall biosynthesis and its involvement with cell wall structure plays no part in Si excluding species.

It has frequently been observed that the presence of Si reduces the toxicity of some heavy metals in plants. The mechanism of such protection is incompletely understood, but it appears to depend on Si binding with metals and preventing their concentration to toxic levels at localized sites. Iron, manganese and aluminum are the metals most often found to be less toxic in the presence of Si. In Si-accumulator plants, iron and manganese are immobilized within the roots before they can be transported to shoots (Ma and Takahashi, 1990). This is enhanced in wetland plants because Si increases the rigidity and volume of aerenchyma (air-filled spaces in roots and shoots) that favors the transport of oxygen into the roots, oxidizing iron and manganese to their less toxic form.

In nonaccumulator plants, Si can suppress the transport of metals to shoots by forming complexes with the metals and binding them in root cell walls. Some nutrient elements like calcium can also be immobilized in this way.

Wear tolerance

The Si content of turfgrasses places them squarely in the ranks of nonaccumulator grasses. Leaf blades of tall fescue, Kentucky bluegrass and bermudagrass contained 23.9 grams (g), 36.6 g and 24 g silica/kilogram (kg) dry tissue, respectively (Street et al. 1981). When the Si supply was increased, the tissue silica concentrations increased to 41.4 g, 61 g and 38.5 g/kg dry weight, respectively. Clearly, these turfgrasses are not Si excluders.

Applications of Si did not alter turf growth, but water usage was reduced 10.2 percent and 17.5 percent by the low and high silica rates, respectively. Other plants have been observed to become more water efficient when supplemental silica was added. Apparently, the greater silica barrier deposited within the outer cell walls of leaf epidermal cells markedly diminishes cuticular transpiration. Stomatal transpiration is not significantly affected, so any net increase in water-use efficiency would be small.

Because Si promotes greater stem strength by stabilizing cell wall polysaccharide and lignin polymers, its impact on wear tolerance in turf has been studied (Trenholm et al. 2001). Spraying potassium silicate at 1.1 kg and 2.2 kg Si/hectare or applying a soil drench at 22.4 kg Si/hectare to two greens-quality ecotypes of seashore paspalum reduced wear injury by about 20 percent. However, potassium alone or together with Si produced the same effect. There was little evidence that Si alone enhanced the wear tolerance of turf.

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