A PRACTICAL RESEARCH DIGEST FOR TURF MANAGERS

# TurfGrass TRENDS

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## Surface Algae on Golf Course Putting Greens and Tees

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Algae occur in nearly all terrestrial environments on earth, even Antarctica, so it should not be surprising that they are part of the soil microflora on golf courses. A study conducted 20 years ago in the Houston area correlated algal populations and diversity with land usage. The largest populations of algae were associated with a golf course (disturbed/fertilized site) as compared to a woods or a disturbed/unfertilized site in the same area.

As with any naturally occurring group of organisms, algae have the potential to become problems, especially when environmental conditions favor growth of the algae over the turfgrass. Florida's normal rainfall of 60-65 inches, most during the summer, creates such an environment. However, algae is not limited to Florida, since human intervention can create a favorable environment in any climate. In this article, only surface algal problems will be discussed.

### Source of Algae

Terrestrial algae are the algae that live in soil and are often referred to as edaphic algae. In general, terrestrial algal species are different from aquatic

#### Algal Growth Requirements

Conditions that favor surface algal growth are:

1) excessive moisture,
2) soil surface exposure to sunlight,
3) adequate nutrients.

Excessive moisture can be due to rainfall or irrigation. It can also be related to shady areas where the surface remains excessively wet, even under normal rainfall or irrigation patterns. Shade combined with excessive moisture is probably the primary cause of surface algae. Shade does not have to be in the form of trees. A cloudy day results in the entire green being shaded.

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algal species. A study at Mississippi State University has helped to confirm that this is true for golf courses also. This means that the algal species causing your surface algal problems are not coming from your irrigation water source. As noted above, the algae are simply a natural part of the soil microflora. The algae cannot be eliminated, but their growth can be controlled.

A superintendent's concern about irrigation water and algae should be focused on nutrient and pesticide runoff from the golf course and how that effects irrigation water quality, which in turn effects turfgrass and algal growth on greens and tees.

## Types of Algae

Most terrestrial algae found on greens and tees can be divided into two groups, the green algae and the blue-green algae. The third group one might encounter are the diatoms and yellow-green algae.

The green and blue-green algae differ not only in color but in some very basic life characteristics. Blue-green algae are actually a type of pigmented bacteria (prokaryote). Green algae are eukaryotes, which means they are more similar to fungi than bacteria. Both algal types have photosynthetic capabilities, just like the turfgrass. Examples of green algae associated with greens and tees surfaces include *Chlamydomonas, Cosmarium*, and *Cylindrocystis*. Blue-green algae often found include *Lyngbya, Nostoc, Oscillatoria* and *Phormidium.*

Of the two groups of algae, the most likely group to be found on **surfaces** of greens and tees are the blue-green algae. Blue-green algae prefer neutral to alkaline conditions whereas green algae prefer acidic conditions. The soil pH does not determine the algal population on the surface; it is the surface soil pH or the soil pH in the thatch that will determine the algal population. If herbicides or fungicides are used on greens and tees, the algal population may shift to green algae. Insecticides do not seem to influence algal growth as extensively.

It is not uncommon to have multiple days, if not an entire week, when the weather pattern results in minimal sunshine and excessive rainfall. Those conditions lead to a weakened turfgrass stand that starts to thin, exposing the algae on the soil surface to light. If the grass was being cut below optimum height (and 1/8 inch is below optimum height for ANY turfgrass species), the grass was already in a stressed state.

Since the algal species are capable of photosynthesis, they do need sunlight. However, they do not need nearly as much sunlight, especially the blue-green algae, as turfgrass requires to thrive. A healthy crop of blue-green algae can be grown in the laboratory under a single fluorescent light bulb; a situation in which turfgrass would become thin and elongated. This means the shady, wet conditions that are detrimental to turfgrass growth are perfect for algal growth. Add in the readily available nutrients on greens and tees, and the algae are set to "bloom".

## Crusts and Toxins

A characteristic of blue-green algae that is greatly appreciated by agriculturists and soil conservationists is their ability to hold soil together. On golf course greens and tees, this characteristic develops into the unappreciated crusts and slime that often form. Blue-green algae also produce toxins. It is currently unknown if the crusts and slimes have any negative effect on turfgrass due to toxin production. The crusts and slimes do prevent the turfgrass from growing back into an area unless they are removed or broken up.

## Cultural Controls

Surface algal growth is a secondary problem. A superintendent must solve the original problem of shade and excessive moisture to prevent or cure the problem. If these conditions are not due to weather, then it is essential to initiate a program to correct these conditions. Remove or thin trees and shrubs. Reduce irrigation in problem areas. This may require hand watering non-affected areas until the algal-infested areas are dried out. Install fans to increase air circulation. If the conditions are due to weather, then a proactive approach, that may include the use of pesticides, must be initiated.

Cultural controls to help reduce surface algae include frequent sand topdressings. These should be heavy enough to cover-up the algal growth. This helps to absorb excess surface moisture and, more importantly, cuts the algae off from the sunlight. If algal crusts are present, aerify, spike, slice or verticut prior to sand topdressing. It is critical to physically break-up the crusts. Raising the height of cut is critical for relieving stress on closely mowed turfgrass. The turf will then be able to grow more vigorously and shade out the algae.

Fertilizer management to control algae is probably difficult to do on greens and tees. If possible, minimize the presence of phosphorus on the soil surface. Again, remember that the concern is not what is present IN the soil but what is present ON the soil surface. Nitrogen may also increase algal growth, especially of those algal species that do not fix nitrogen themselves.

Two fertilizers that are often mentioned for controlling algae are hydrated lime and ferrous sulfate. Both products must be used with extreme caution on closely cut fine turfgrass. Hydrated lime is only a temporary fix and may actually increase the surface algae. The lime initially acts as a dessicant and dries out the soil surface. However, it will instantly raise the surface soil pH which means the blue-green algae will thrive if weather conditions remain favorable for their growth. Also, if the turfgrass has thinned due to one of the root rot patch diseases (examples include take-all patch, summer patch, bermudagrass decline), these diseases may increase dramatically as the soilborne pathogens that cause these diseases also like alkaline soils.

Ferrous sulfate is an acidic fertilizer (due to the ferrous ion and not the sulfate ion) which will inhibit the blue-green algae, but perhaps not the green algae. Also, it will burn the turf if not applied properly or when applied at higher than 2 to 3 ounces per 1000 square feet. Test a small location first to determine if it would be effective on your golf course.

### Integrated Surface Algal Control

An integrated approach to surface algal control requires:

- An understanding of why the algae have become a problem.

Establishment of a tree removal or tree thinning program if excessive shade is responsible for algal growth.

- Increasing the height of cut to alleviate stress on the turfgrass and to shade the soil surface to prevent algal growth.
- Development of a cultural program that includes sand topdressing, less irrigation if necessary, and disruption of the algal crusts when present.
- Preventative use of fungicides only when weather conditions warrant their use. They should not be used if the algae develop for reasons that are not related to weather and which can be controlled by reducing shade or altering management practices such as irrigation.

## Chemical Controls

Copper sulfate has been reported to control surface algae, but superintendents often note that it burns greens and tees. One reason for this burning is they were using the fertilizer formulation of copper sulfate, $CuSO_4 . 5 H_2O$, which is hydrated copper sulfate (blue vitriol) and is very soluble in water. The fungicide formulation of copper sulfate, $CuSO_4 . 3 Cu(OH)_2$, is insoluble or only slightly soluble in water. It is often referred to as basic copper sulfate or tribasic copper. This latter material must be registered for golf course turfgrass use in your state to be legally used as it is a fungicide and not a fertilizer material.

The active ingredient in other fungicides that may be registered for control of algae in your state are mancozeb, chlorothalonil and quaternary ammonium salts. We have examined all three of these products in trials on the research green at the University of Florida's Fort Lauderdale Research and Education Center. The algae that develop on this site are blue-green algae. We provide an ideal environment by irrigating twice daily, whether it rains or not.

Mancozeb and chorothalonil fungicides were most effective when used preventatively, either prior to conducive weather patterns or shortly after they begin. Combined with the cultural controls, they can prevent the development of surface algae. We have not observed any control, preventatively or curatively, of surface blue-green algae using the quaternary ammonium salts. This product must be applied in the specified amount of water to prevent burning of the turf. Research in Texas indicates the material must be drenched to be effective.

The rate evaluated for mancozeb was 4.5 ounces active ingredient per 1000 square feet, the rate that has always been on the label for algal control. Since chlorothalonil had not been evaluated for algal control previously, the rates initially evaluated were 1.5, 3 and 6 ounces active ingredient per 1000 square feet. Applications were made at either 14 or 28 day intervals. The chlorothalonil was not effective at the lowest rate. Mancozeb and the higher chlorothalonil rates were effective in preventing or minimizing development of surface algae under the severe conditions used for evaluation. An application timing interval of 14 days was most effective under severe conditions, but 28 days would be adequate if environmental conditions were not as intense.

If heavy algal growth was already present (>50% surface algae per plot), at least two and usually three applications of these fungicides were required before any curative effect was observed. In other words, fungicides will be effective in preventing or minimizing algal development prior to or during the initial stages of conducive conditions for algal growth, but they will not be effective in eliminating the problem once it has developed.

It has been observed that some fungicides, primarily systemic DMI fungicides, may enhance surface algal development. This simply emphasizes the need to thoroughly understand why you are applying fungicides and what the positive or negative consequences may be of that application.

## Biological Controls

There are presently no biological controls available for controlling surface algal growth. Interestingly, plant pathologists are examining algae more closely for use as biological control of plant diseases. Also, pharmaceutical companies are finding previously unknown antibiotics produced by algae, especially blue-green algae.

*Dr. Monica L. Elliott is an Associate Professor of Plant Pathology at the University of Florida's Fort Lauderdale Research and Education Center. Dr. Elliott's research is focused on developing integrated disease management programs for golf course and landscape turf.*

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# Subsurface Algae in Turfgrass Soils: Both Friend and Foe

*By Dr. Eric B. Nelson*
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Even though many algae, including the cyanobacteria and green algae, require light for photosynthesis and growth, many of the terrestrial algae found in turfgrass soils can also be heterotrophic. This means that, in addition to photosynthesis, they can also get energy from the decomposition of other organic compounds. As a result, they are able to survive deep within the soil where no light can penetrate. However, growth rates and activities are greatly reduced as compared with those in the light and it is believed that algae found below the first few inches of soil are simply passive survivors and not contributing to the metabolic activities in the soil.

## Conditions Favoring Algae

Algae have been found in soils at populations ranging from about 10,000 cells per gram of soil (typical of most soils) to nearly 100,000,000 cells per gram of soil in an undisturbed grassland. More common populations on golf course turf are in the range of 30,000 to 60,000 cells per gram of soil. These populations represent some of the higher populations of terrestrial algae found on earth. The vast majority of this population occurs in the top inch of soil. Even though both aquatic and terrestrial algal species are widely distributed on golf course turf, there is a high degree site specificity of specific genera and species. Those occurring in soils are generally not the same as those occurring in ponds and streams.

The major abiotic factors affecting the distribution of algae in turfgrass soils is solar radiation, moisture, temperature, nutrients, and pH. Things such as organic matter content and soil texture are less important. Generally, the higher the soil moisture, soil temperature, and sunlight penetration to the soil surface, the greater the population and activities of algae. Increased levels of both organic and inorganic nutrients also enhance the growth and activity of terrestrial algae.

Soil pH also affects the activities of certain types of algae. For example, cyanobacteria thrive best in alkaline soils (pH 7.0 and above) whereas green algae do best in more acidic soils (pH 5.5 and below).

On golf course putting greens, moisture and nutrients are frequently not limiting. In fact, in many cases, moisture levels can be excessive, creating anaerobic conditions that favor the growth of some cyanobacterial species. On these types of sites, temperature appears to be the overriding factor influencing algal growth and activity. Generally the warmer the soil, the greater the growth of algae. Surprisingly, however, many of the same algae that are active at high temperatures can be

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somewhat active even in frozen soils. Many of these species are extremely resistant to freezing temperatures and in some areas, problems with algae are more commonly seen in mild wet winters than in the summer.

The turfgrass species can also affect the type of algae found in a given soil. For example, in a Mississippi State study in 1991, it was found that species of *Oscillatoria* were the predominant algae in bermudagrass greens whereas species of *Anacystis* were the dominant algae in bentgrass greens. This distribution can vary too according to the time of year and geographical location.

Pesticides are another factor affecting the distribution and activity of soil algae. In general, most herbicides, fungicides, and soil fumigants are toxic to algae whereas insecticides generally are not. Nearly all of our knowledge about pesticide toxicity to algae comes from either laboratory culture studies or from a limited number of field studies on agricultural crops. Much remains to be learned about the impact of turf management chemicals on soil algae.

## Algae's Roles in Soil Health

Subsurface algae play important roles in the formation and maintenance of a healthy soil. For example, algal growth is an important means by which organic carbon and nitrogen are added to the soil. Many species of cyanobacteria not only fix carbon in $CO_2$ through photosynthesis, but they can also fix atmospheric nitrogen. Both of these processes also play an important role in humus formation.

In natural soils, algae produce considerable amounts of polysaccharide that helps to aggregate soil colloids and improve soil structure while at the same time improving water infiltration and percolation.

Subsurface soil algae are also known to associate with plant roots, producing hormones that stimulate root growth and enhance the activities of other beneficial root-associated microorganisms. In fact, in many of the rice growing regions of the world, some cyanobacterial species are inoculated into soils to enhance rice yields by as much as 36%! However, the growth stimulating effect of cyanobacteria in turfgrass soils has not yet been documented.

Soil algae also commonly interact with other microorganisms in soil. Many soil algae excrete a variety of antimicrobial compounds that affect the activities of other microorganisms, including plant pathogens. In this case, a species of Nostoc was used for the biological control of a seedling disease of millet. Upon the death of nearly all algae, they serve as an important food source for many important bacteria and fungi in soils. While living, soil algae serve as food sources for protozoa, earthworms, nematodes, and microarthropods.

A number of associations of algae with other microorganisms in soil can result in enhanced algal growth resulting in detrimental effects on turfgrass growth and quality. This is particularly the case with a problem known as black layer discussed below.

## Algae-Related Turf Problems

Despite the beneficial properties of soil algae, occasionally, the excessive growth (or blooms) of algae can create problems in the management of turfgrasses. Of the problems associated with algae on golf course turf, surface slimes and black layer are perhaps the most troublesome. Usually the presence of these problems in turfgrasses indicates that some environmental parameter (usually moisture, temperature, or fertility) are somehow out of balance. In Dr. Elliot's article, the problems associated with surface algae are reviewed. Here, I will focus on problems associated with algae beneath the soil surface.

**Inhibition of Turfgrass Root Growth** - Little attention has been given to algae as potential inhibitors of turfgrass root growth and incitants of turfgrass decline. Even though algae are not typically infectious pathogens, a number of cyanobacteria species have been shown to inhibit root growth of a number of crop plants by producing antibiotic substances that also inhibit bacterial growth. It is well known in the floriculture industry that algal proliferation (usually cyanobac-

### Management Strategies for Control of Black Layer in Putting Greens

| *Control Approach* | *Treatment* |
|---|---|
| Suppress Cyanobacterial Blooms | Apply any of the following:<br>Chlorothalonil<br>Mancozeb<br>Quaternery Ammonium Salts (Algaen-X) |
| Maintain High Redox Potentials | Fertilize with $NO_3$ fertilizers<br>(frequent applications at light rates)<br>Reduce irrigation so soil surface can dry<br>Improve air flow to reduce relative humidity<br>and promote drying |
| Minimize Free Sulfur | Avoid the application of elemental sulfur and<br>sulfur-containing fertilizers |

teria) on subirrigation mats and on roots of potted plants in greenhouses can lead to reductions in plant growth and quality. Similarly, it is very common in the diagnosis of turfgrass problems to observe a number of different filamentous and unicellular algal species associated with the roots of turfgrasses in a state of decline. In the absence of recognizable pathogenic agents, algae are sometimes the only biotic agent associated with such general decline symptoms. This luxuriant algal growth is usually absent from healthy turf roots. Despite this apparent association, we currently do not know whether algae do indeed directly lead to declines in turfgrass health. This is another area of important research that will shed new light on the ecology of algae in turfgrass soils.

**Black Layer** - Black layer has been the most notable problem caused by subsurface algae in golf course turf. This is a problem primarily limited to golf course putting green constructed with a high sand content root zone mix. On the surface, turf takes on a bronze color before gradually thinning. Removing a cup-cutter plug generally reveals a prominent black layering approximately 1 to 4 inches below the soil surface. This layer often contain small black globular bodies that can be seen easily with a hand lens. The most notable characteristic is the noxious sewage odor associated with the black layer. This odor is due to reduced forms of sulfur such as hydrogen sulfide gas ($H_2S$) that is formed under anaerobic conditions as a by-product of the action of sulfur-reducing bacteria. This gas can further react with metal elements like iron to form black globules of iron sulfide which gives the layer a black color.

The black layer represents a zone where roots cannot penetrate and water movement is restricted. The lack of drainage through this layer gives rise to a perched waterlogged zone creating anaerobic conditions at that site. How then does this plugging occur? Black layered greens often show varying levels of cyanobacterial infestations, usually by species of *Nostoc* and *Oscillatoria*. These species are known to produce copious amounts of mucilages and organic matter, particularly in the calcareous sands commonly used in greens construction. Mucilage production is also enhanced in the presence of elemental sulfur, chelated iron, lime, and gypsum. These mucilages can bind together the sand particles and fill the pore spaces creating this impermeable layer where water and organic substances can accumulate. The resulting anaerobic conditions can then favor the activities of the sulfate-reducing bacteria and the generation of hydrogen sulfide.

It is believed that the hydrogen sulfide directly inhibits root growth since it is a well known inhibitor of root respiration in higher plants. Furthermore, research has shown that exposure of creeping bentgrass turf to 1000 ppm H2S resulted in death of the entire plant in as little as 7 days. The actual black layer, which is composed of metal sulfides, is not toxic and the presence of the layer should be an indication that anaerobic conditions are present in the root zone and that a turfgrass toxin is present.

## Control of Black Layer

The predisposing factor for black layer formation is the growth of cyanobacteria in the root zone profile. Without this growth, the general plugging of the profile does not occur, the anaerobic conditions to not arise and $H_2S$ is not formed. Therefore, controlling black layer formation can be approached from several different angles (Table 2). First, minimize surface growths of cyanobacteria on the putting green surface. This can be accomplished through the application of a number of different materials listed in Table 2. Research has shown correlations between surface proliferation of cyanobacteria and black layer formation. Second, maintain high redox potentials. In other words, maintain high oxygen levels in the root zone. This can be accomplished primarily through water and fertility management. Finally, avoid the use of sulfur-containing fertilizers. Under anaerobic conditions, $H_2S$ is formed from the action of sulfur-reducing bacteria only in the presence of sulfur-containing compounds.

*Dr. Eric B. Nelson is an Associate Professor of Plant Pathology at Cornell University. He has degrees in botany from Indiana University and plant pathology from Ohio State University. Dr. Nelson is active in research on the ecology and control of soil-borne pathogens, concentrating on biological control of plant diseases.*

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## Glossary

Anaerobic - growing or living in the absence of oxygen.

Aquatic - growing or living in water.

Chlorophyll - the green photosynthetic pigment in plants that converts light energy and carbon dioxide into carbon for the plant.

Heterotrophic - requiring complex carbon and nitrogen compounds for growth and activity.

Microarthropods - a group of microscopic insects.

Mucilage - slimy, gelatinous substances composed of polysaccharides and proteins.

Protists - a group of relatively primitive organisms classified within the Protoctista.

Protozoa - microscopic single-celled non-photosynthesizing Protists.

Redox Potential - the measure of the oxidative potential of a soil; redox potentials increase as oxygen levels increase; at high redox potentials, a greater amount of oxidation can occur.

Terrestrial - growing or living in the soil.

# Disease Prediction for Golf Courses

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How do you decide when to apply a fungicide? Experienced turf managers use their historical knowledge of diseases in the area, current symptoms and signs of disease problems, recent weather conditions, expected weather conditions in the next few days, along with the many other factors that can affect disease severity: compaction, mowing heights, fertilizer and pesticide applications, and other management practices.

Turf managers are under considerable pressure to justify and, preferably, reduce their pesticide applications. Calendar schedules for fungicide applications are not only difficult to justify environmentally, but they are also costly. In addition, as fungicides become more specific in their modes-of-action, a scheduled fungicide might not be effective for the particular disease that is developing. There are many reports of disease enhancement (increased disease severity) when a fungicide is applied that does not control the pathogen that is currently active. Thus, the wrong fungicide can not only be a waste of money, it can also exacerbate the existing problem. Finally, calendar-based sprays may actually give less than optimal control because disease pressure might be greatest right at the end of an application interval when little fungicide remains to fight the pathogen.

There are, of course, some possible advantages to calendar-based fungicide applications. Many of the available fungicides are broad-spectrum and are likely to control a number of important and common diseases. Calendar applications can be scheduled for days on which a golf course is closed to members or times that are otherwise convenient for the turf manager. Scheduled applications generally provide disease prevention and potentially reduce turf injury compared to curative applications.

Despite these potential advantages, most turf managers would agree that environmental conditions and disease problems vary quite a bit from year to year. They would probably also agree that for environmental and economic reasons, they would prefer to apply fungicides only when they are really needed— if they could also avoid some of the potential risk of waiting for disease-conducive conditions.

At this time, most fungicide applications involve educated guessing. Unlike weed and insect pests which can be counted, turf managers must use past experience and weather predictions to determine when diseases are likely to occur. Disease prediction systems offer a way to make more precise and timely applications that may improve disease control and, perhaps, even reduce the number of applications.

Fungicide applications may be reduced by using prediction systems in two ways. First, conducive weather conditions may approach, but not quite reach, the levels necessary for a disease outbreak. If these conditions are monitored more precisely, a turf manager could confidently skip an unnecessary application and still sleep at night. Fungicide applications might also be reduced by substituting biocontrol agents applied according to predictions. Many biocontrol agents are currently being studied. They are living organisms, and it is difficult to maintain high populations for long time periods. If they could be applied when disease pressure is greatest, their short-term activity might be very effective and reduce the need for fungicide applications.

There are two main approaches to disease predictions. Disease prediction may be made by monitoring environmental conditions that lead to disease outbreaks. Predictions may also be made by directly monitoring the activity of the pathogen that causes the disease through the use of immunoassays, or antibody tests, such as the commercial Alert® field diagnostic kits (Neogen Corporation). It may also be possible to combine these approaches.

## Disease Prediction Using Environmental Factors

The initial step in the study of any turf disease is to determine what environmental factors lead to disease development. It is well known that fungi that cause turf diseases are active over a wide range of temperatures. Different temperatures appear to be important for the various prediction systems. Systems may use minimum, maximum and mean air temperatures. Some prediction systems also include soil temperatures. Even though some fungi are more active at high temperatures and others at lower temperatures, there is still considerable overlap in the temperature range of activity. Clearly, temperature alone is not enough to predict most turf diseases.

The most important additional factor is water. This may be soil moisture, high relative humidity, actual water droplets on leaf blades, or some combination of these factors. Leaf wetness is technically difficult to measure accurately, yet it is critical in disease prediction because most fungal spores and mycelium require free water for germination and growth. Measures of high relative humidity are often used to estimate periods of leaf wetness.

In general, there are particular combinations of moisture and temperature that allow a fungus, the most common type of turfgrass pathogen, to invade a turfgrass plant. The combinations of factors which provide a pathogen with the opportunity to successfully infect a plant are called "infection periods." Infection periods can be used to predict disease outbreaks. Of course, other factors, such as nitrogen fertility, affect disease severity, but most existing prediction systems use only environmental factors at this time.

Two commercial computerized environmental monitoring stations are currently available to turf managers, the Envirocaster@ and the Metos@ Golf. Both of these instruments monitor environmental factors several times each hour, than average and store all of the hourly environmental data. Computer models then calculate turf disease predictions from these data. The use of computerized weather stations allows the models to reflect the biological complexities of the real world without overburdening a busy turf manager with time-consuming calculations.

**Infection period models.** For severe diseases such as Pythium blight and brown patch (Rhizoctonia blight), turf managers should be informed each time an infection period occurs. When environmental conditions are not favorable for disease, the message from the computer may simply state that an infection period has not occurred. Infection

### Pythium Foliar Blight Model

**Environmental Factors Monitored:**
(over 24 hour period)

*Hall Model*
Air Temperature:
>18 hrs at >70 degrees F with a minimum of 68 degrees F for high risk conditions.

*Nutter Model*
Air Temperature:
Max: >86 degrees F, Min: >68 degrees F
Relative Humidity >90% for 14 hours

**Field validation**
The Hall Model does not include a measure of moisture which may make it inaccurate in drier regions. The Nutter Model has been most widely field tested because it is available in commercial computerized weather stations.

**Comments**
Shane reports that the Nutter Model could miss outbreaks under Ohio conditions. He suggests reduction of the high relative humidity requirement from 18 hr to 9 hr and some slight changes in temperature requirements. He cautions that both models should be field tested where they are to be used.

The author's observations in western Massachusetts for the past 7 years suggest that the Nutter Model, as programmed in the Envirocaster®, predicts the rare Pythium outbreaks in that region. It is likely that many superintendents often apply fungicides unnecessarily in New England. On the other hand, golf courses with low lying turf areas and poor air movement might find that the model underpredicts in those disease-conducive conditions.

period models may also determine if a disease outbreak if likely to be severe, moderate, or light which may be helpful in making a fungicide application decision. Disease prediction systems may also include recommended cultural practices such as avoiding mowing or irrigation during a time when the risk of spreading active fungal mycelium is high.

The computer message may list the current limiting factors as conditions approach those needed for an infection period. For instance, if daily maximum temperature is the limiting factor for an infection period and the day is definitely going to become hotter, then an infection period will probably occur. Thus, environmental monitoring can be combined with weather predictions to determine the likelihood of disease outbreaks.

**Severity models.** Infection period models are most useful for diseases that develop quickly and can be very damaging. For less threatening diseases, fungicide applications are usually made only after disease potential reaches a certain level. Severity prediction models are more useful for such diseases as anthracnose, leaf spot, and red thread. Such a model has been created for anthracnose at Michigan State University. It accumulates "anthracnose severity units" based on leaf wetness and average air temperature. While the severity units themselves are actually based on infection periods (the potential for the fungus to successfully infect the turf), it predicts disease only after a series of infection periods, each of which accumulates points according to the Anthracnose Severity Index. A fungicide application is made only when a certain threshold number is reached. Severity prediction models have the added advantage allowing a turf manager to modify the threshold number to meet the local conditions of a particular turf site.

**Degree day models.** A third type of prediction model has been applied to other pest problems, but has few applications for turf diseases at this time. It is based on the concept of "degree days" which reflect an accumulation of "heat units" during a growing season. Degree days are a way to

## Rhizoctonia Brown Patch

**Environmental Factors Monitored**

*Fidanza Model* (perennial ryegrass)
Soil Temperature: $\geq$61 degrees F
Air Temperature: $\geq$61 degrees F
Relative Humidity: $\geq$95% for >8 hr, mean $\geq$75%
Precipitation: $\geq$0.47 inches (12 mm) or
Leaf Wetness: $\geq$6 hr
Equally effective: $E = -21.5 + 0.15RH + 1.4T - 0.033T2$ (RH= mean relative humidity and T = minimum daily air temperature. A warning is produced when $E \geq 6$)

*Schumann Model* (creeping bentgrass at putting green height)
Soil Temperature: Mean >70 degrees F; Minimum >64 degrees F
Air Temperature: Mean >68 degrees F Minimum >59 degrees F
Relative Humidity: >95% for at least 10 hr
Precipitation: 0.1 inches (0.254 cm)
Cancel prediction if Air Temperature <59 degrees F in the 24-48 hr post-warning.

**Field Validation**

Fidanza et al tested their model under Maryland conditions. Schumann et al tested their model in Massachusetts, New Jersey and Georgia. The model was not helpful under Georgia conditions which may reflect the long periods of conducive environmental conditions and/or different strains and species of the pathogen.

**Comments**

The similarity between the models developed independently in Massachusetts and Maryland is interesting. Disease predictions appear to be based on the effects of environmental conditions on fungal activity rather than the specific plant environment. Nearly all false predictions can be eliminated in the Schumann Model, if a cancellation policy is used based on minimum air temperature following a warning. Turf managers can consult weather predictions to determine if a fungicide is needed following a disease prediction. This is an important feature in regions that often cool off following the hot, humid weather that favor brown patch.

The author has observed severe brown patch outbreaks following very heavy rainfalls, but relatively cool weather, which could not be accommodated in the Massachusetts Model. Turf managers should be aware of this disease potential in very wet weather.

## Sclerotinia Dollar Spot

**Environmental Factors Monitored**

*Hall Model*
Air Temperature and Rain: mean >72 degrees F over two days with rain or >64 degrees F over three days with rain.

*Mills and Rothwell Model*
Air Temperature: maximum >77 degrees F
Relative Humidity: >90% any 3 days in 7

**Field validation**
Burpee and Goulty evaluated both models in the field over two seasons. They suggest that the Hall model underpredicts and the Mills and Rothwell model overpredicts.

**Comments**
The author has been making daily dollar spot observations for several seasons in Massachusetts in an attempt to correlate environmental factors with disease outbreaks without major progress. It may be that environmental factors are too variable for a simple environmental model to recommend fungicide timing for dollar spot.

measure what we intuitively sense when we notice that a year has an "early spring" or a "late spring." This concept has been applied to certain pest control measures that are timed according to the blooming of forsythia or other plant development stages. The development of all organisms is tied to the accumulation of degree day units. By doing experimental work on a specific pest, it is possible to accurately determine the degree day thresholds for that pest. As with the disease prediction models already described, however, degree day models are monitoring only the environmental conditions, not whether there is actually enough of a pest or pathogen to warrant control.

Degree day prediction models exist for Poa annua seed head formation, crabgrass germination, and several turfgrass insect pests. Degree day models have important potential applications for disease prediction as well. For example, it is known that brown patch is a summer disease. Even though hot, humid weather may occur briefly in spring, it does not seem to trigger brown patch until soil temperatures reach a critical threshold. Because soil temperatures can vary considerably from week to week, a degree day threshold might be the most appropriate way to determine when in early summer to start using a daily brown patch infection period prediction system.

**Predictions for root diseases.** Summer patch and necrotic ring spot are difficult diseases to manage because fungicide applications must be applied before symptoms occur. A degree day model combined with soil moisture might be an accurate means of determining when fungicide applications should be applied to be most effective.

In general, root diseases such as summer patch, necrotic ring spot, take-all patch, Pythium root rot and even nematode problems are difficult to predict using the environmental factors used for brown patch, Pythium blight, and other foliar diseases. Moisture on the leaves is a limiting factor for diseases that begin with infection of leaves. The pathogens that cause root diseases are certainly affected by moisture and temperature, but they are also associated with conditions such as soil compaction, low mowing heights, heat stress, and root zone pH. Turf managers should act to reduce the stress factors associated with these diseases rather than relying on fungicide applications. It may be possible, however, to use factors such as soil moisture and temperature for root disease warnings.

## Disease Prediction Immunoassays

All of the prediction methods just described are based solely on environmental monitoring. They determine when conditions are right for disease development. They are unable to determine if a previous fungicide application is still actively suppressing disease or if the fungus population is sufficient to cause significant disease. New developing technology may provide this missing information. Tests are available for rapid and quantitative detection of pathogens in turfgrass. Called immunoassays, or antibody tests, they use antibodies formed by the immune systems of animals.

## Anthracnose Foliar Blight Model
(on annual bluegrass)

**Environmental Factors Monitored**
Leaf Wetness - hours
Air Temperature - degrees Celsius, average for a 3-day period

An Anthracnose Severity Index (ASI) table has been generated which allows severity factors to be accumulated each day until a "threshold" is reached, triggering a fungicide application.

**Field validation**
This model was validated by its creators under summer conditions in Michigan.

**Comments**
One limitation to the practical use of this model is that leaf wetness is difficult to monitor accurately. There are no published reports on how well this model predicts anthracnose outside of the Michigan area. Anthracnose is often a stress disease enhanced by low fertility, low mowing heights, and compaction.These factors would also affect what ASI threshold should trigger a fungicide application. In some area, a cool-weather form of this disease commonly occurs which would not be predicted by this model.

This is currently the only published turfgrass disease prediction system which uses severity values rather than individual infection periods to recommend a management action. A major advantage to this system is that the thresholds could be modified for different climates and different stress factors. The concept behind this type of model could be applied to a number of other turf diseases which vary in severity from year to year.

Highly purified samples of turf disease fungi can be injected into animals. The animals do not become diseased, but their immune systems still recognize these fungal proteins as "foreign." Antibodies specific to each fungus are formed. The antibody-producing cells can be grown in culture for inexpensive mass production of antibodies. The antibodies can be attached to enzymes which can cause a color change. Such tests are called ELISA, enzyme-linked immunosorbent assays, to describe the method. The color change occurs only when the correct fungus is detected. The attached enzyme results in a very sensitive test that detects even tiny amounts of a fungus.

ELISA field kits require no specialized equipment or training and indicate the presence of the fungus by a color change in about 10 minutes. The same technology is used for home pregnancy tests and a number of other medical tests. At this time, kits are available for detection of the fungi that cause brown patch, dollar spot, and Pythium blight. Each test is developed with antibodies specific to only one pathogen. Thus, a separate test must be run for each disease.

It is important to sample turf in areas where disease is expected to develop first, sometimes called "hot spots." It is also important to avoid including thatch and soil in the sample because the fungal pathogens are almost always present in thatch and soil, even when they are not actively causing disease.

The next question is whether a threshold fungus population requiring treatment is present. A meter is available that measures the intensity of the color development in the test. Results can also be compared to a color chart that accompanies the kits. A darker color reflects a greater amount of fungus detected in the sample.

In field evaluations of immunoassays thresholds, most researchers have found that the meter readings were highly variable. Most agree that the greatest benefit of the antibody field kits is their ability to confirm a diagnosis quickly without a microscope at the early stages of a disease. ELISA kits can also be used in conjunction with environmentally-based predictions to determine if a fungicide is still suppressing fungal activity.

## The Future

One of the limitations to the use of disease prediction systems on golf courses is that fungicide applications must be made quite soon after a prediction occurs. This may not seem practical for some turf managers at this time. However, future pesticide regulations may require greater justification for fungicide applications, and prediction systems offer a scientific basis for your decisions.

Fungicides applied according to disease predictions may offer improved efficacy if the chemical can be applied when disease control is needed most. If turf managers gain confidence in the accuracy of a model, they may actually reduce fungicide applications even when weather conditions are making them nervous about disease.

Further research is necessary to make the current prediction models more accurate and for the development of models for additional diseases. Disease severity is affected by many factors in addition to environmental ones. These include differences in cultivar susceptibility and pathogen races in various geographical areas. Other important factors that affect disease severity are nutrient levels, use of plant growth regulators, mowing height, and various soil factors.

Predictive models will become fine-tuned over time to become more accurate, but they must always be carefully evaluated before use in new areas to make sure that the predictions are appropriate for the local conditions.

Disease prediction by environmental monitoring and immunoassays will probably be a part of every fungicide application decision in the future. As these technologies improve, turf managers should be able to get better control through more precise timing of applications and also have the confidence to extend spray intervals when conditions are not conducive for disease.

Immunoassays that can measure fungicide residues may be developed in the future and would be an invaluable tool in applications decisions. Now that biological agents are becoming available for turf disease management, these could be applied according to prediction systems to determine if this improves their efficacy. Environmental and immunoassays prediction systems are an easy and accurate way to document and justify when fungicide and biocontrol applications are necessary.

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## FIELD TIPS

### Getting Started With Disease Prediction

*Equipment:* Two companies currently sell computerized weather stations which include some of the disease prediction models described in this article: 1.) Metos® Golf from Gempler's, 1-800-234-5333, P.O. Box 270, 211 Blue Mounds, Rd., Mt. Horeb, WI 53572. 2.) Envirocaster® from Neogen Corporation, 1-800-234-5333, 620 Lesher Place, Lansing, MI 48808. Neogen Corporation also produces the Alert@ immunoassay field kits.

Most golf courses already have some kind of weather station, some of which calculate degree days. Careful record keeping can help turf managers develop prediction systems specific to their golf courses by comparing records of environmental conditions with disease records. Most of the disease models currently available could even be calculated without a computer using weather station data, although the process would be time-consuming.

*Where to place the equipment:* Some turf managers prefer to monitor "hot spots" where disease first appears. Others prefer to place equipment in a more "average" area. Others find accessibility and safety to be important factors and place the equipment near the maintenance buildings.

*Field evaluation:* Disease prediction systems should not be considered oracles to be obeyed without consideration of all available information sources. All systems need to be field tested in each new locale. Try to leave a nontreated area and monitor disease development to be compared to disease predictions from the computer. This is especially important if the disease model was developed in a different region.

When testing models, be certain of your disease diagnosis. Also, be sure to monitor environmental conditions exactly as specified in the disease model. For example, the Massachusetts brown patch model measures relative humidity duration just above the turf surface at putting green height. If it is monitored at higher levels, where relative humidity is lower, predictions may be inaccurate.

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