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Scientists within the NE-1025 multi-state turf research project are studying the biology, ecology, and management of anthracnose of annual bluegrass turf on golf courses. Results from these experiments will be used to devise a comprehensive set of best management practices for the control of anthracnose disease on golf courses.

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PURPOSE

The purpose of *USGA Turfgrass and Environmental Research Online* is to effectively communicate the results of research projects funded under USGA's Turfgrass and Environmental Research Program to all who can benefit from such knowledge. Since 1983, the USGA has funded more than 450 projects at a cost of $29 million. The private, non-profit research program provides funding opportunities to university faculty interested in working on environmental and turf management problems affecting golf courses. The outstanding playing conditions of today's golf courses are a direct result of ***using science to benefit golf***.

Best Management Practices for Anthracnose on Annual Bluegrass Turf

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John Inguagiato, Bruce Clarke, Tom Hsiang, and Frank Rossi

SUMMARY

Scientists within the NE-1025 multi-state turf research project are studying the biology, ecology, and management of anthracnose (caused by *Colletotrichum cereale*) of annual bluegrass turf. They are examining the biology of the pathogen, assessing fungicidal control and fungicide resistance development, evaluating the effect of cultural practices on anthracnose severity, and developing annual bluegrass and bentgrass selections for resistance to this disease. The paper's points include:

- The frequency and severity of anthracnose epiphytotics on golf course putting greens has increased over the past decade and is thought to be associated with some of the management practices used by superintendents to improve playability (ball roll).
- Besides annual bluegrass, outbreaks are also increasingly common on creeping bentgrass (*Agrostis stolonifera*) and may develop on other cool-season turf species including ryegrasses (*Lolium spp.*), fescues (*Festuca spp.*), Kentucky bluegrass (*P. pratensis*), and velvet bentgrass (*A. canina*).
- It is recommended that golf course superintendents initiate a preventive fungicide program at least one month prior to the normal onset of anthracnose in their area. Of the eight chemistries available for anthracnose control, only the benzimidazole, DMI (demethylation inhibitors), and QoI (strobilurins)classes have significant curative activity.
- Resistance has developed in anthracnose to site-specific fungicide classes including the QoIs, benzimidazoles, and DMI fungicides.
- Best management practices for the control of anthracnose disease on annual bluegrass putting green turf include implementing a frequent low N-rate fertility program initiated in late spring and continuing through summer.

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Anthracnose (caused by *Colletotrichum cereale*) is a destructive fungal disease of weakened turf that occurs throughout the United States, Canada, and Western Europe (15) and is particularly severe on annual bluegrass (*Poa annua*). The frequency and severity of anthracnose epiphytotics on golf course putting greens has increased over the past decade (13, 14) and is thought to be associated with some of the management practices used by superintendents to improve playability (ball roll). It is possible that combinations of management factors may be enhancing the severity of this disease.

Scientists within the NE-1025 multi-state turf research project are studying the biology, ecology, and management of anthracnose of annual bluegrass turf on golf courses. They are examining the biology of the pathogen, assessing fungicidal control and fungicide resistance development, evaluating the effect of cultural practices on anthracnose severity, and developing annual bluegrass and bentgrass selections for resistance to this disease.

On annual bluegrass, symptoms of anthracnose first appear as orange to yellow colored spots that range from 0.25 to 0.5 inches in diameter. *(Photo courtesy of Bruce Clarke)*

Completed and ongoing field trials within this five-year project (2005-2010) have evaluated registered and experimental fungicides, fungicide programs, and annual bluegrass management practices including nitrogen fertility, chemical growth regulation, mowing, rolling, topdressing, verticutting, and irrigation, as well as the potential for some practices to interact. Ultimately, results from these experiments will be used to devise a comprehensive set of best management practices for the control of anthracnose disease on golf courses.

Host Susceptibility

Anthracnose can be found on cool- and warm-season turf in roughs, fairways, and tees, but often the disease is most destructive on annual bluegrass maintained at a putting green height of cut. Outbreaks are also increasingly common on creeping bentgrass (*Agrostis stolonifera*) and may develop on other cool-season turf species including ryegrasses (*Lolium spp.*), fescues (*Festuca spp.*), Kentucky bluegrass (*P. pratensis*), and velvet bentgrass (*A. canina*). Although the disease is often most severe during warm weather, outbreaks may occur throughout the year causing either a foliar blight or a basal rot of leaf sheaths, crowns, and stolons (15). Anthracnose is often present on turf mowed at a higher height without producing severe damage, which suggests that plant health (vigor and stress) is a major factor that determines disease severity. The disease can cause extensive injury on turf maintained at low fertility or turf grown under suboptimal conditions (drought stress, excess shade, high humidity).

In close-cut turf, the lower stems may become affected resulting in water-soaked, blackened tissue that is easily pulled from infected crowns. *(Photo courtesy of John Inguagiato)*

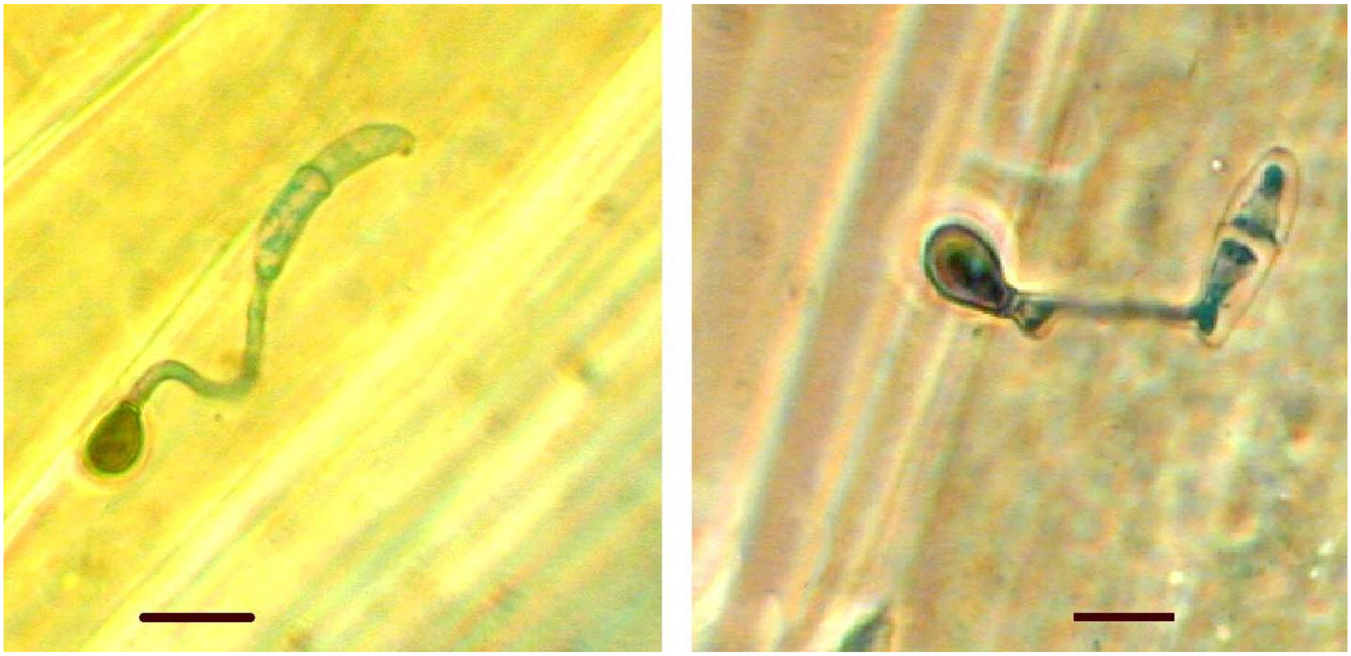
The greater susceptibility of annual bluegrass to anthracnose is probably related to a number of factors including the weak perennial nature of this grass species. Annual bluegrass is well known for its prolific seedhead (flowering) expression that predominantly occurs in the spring (April through early June). Seedhead development requires considerable metabolic energy, which re-allocates photosynthate away from roots and shoots toward seedheads just before the most stressful the time of growing season. Summer stress tolerance has been associated with increased root depth and number. Thus, the reallocation of photosynthate away from roots and crowns probably weakens annual bluegrass and increases its susceptibility to anthracnose. Breeding for improved tolerance to anthracnose disease is one objective of the annual bluegrass breeding program in Pennsylvania and the bentgrass breeding program in New Jersey.

The True Causal Agent of Anthracnose on Cool-season Turf

For over 90 years the pathogen responsible for turfgrass anthracnose was known by the same name as the fungus that causes anthracnose disease in corn, *Colletotrichum graminicola* G.W. Wils, because the pathogens so closely resemble one another. Recent DNA fingerprinting studies, however, indicate that the pathogen responsible for anthracnose in cool-season turf, while closely related to the corn pathogen, is a distinct fungal species, *C. cereale* Manns (5). This same fungus has been found across North America colonizing numerous cool-season grasses in field crops, prairies, residential lawns, ornamental grasses, and other environments (4, 5). Outside of the golf course environment, it appears that *C. cereale* rarely induces disease because the fungus can colonize other host plants without causing visible damage.

Despite the fact that *C. cereale* can be found on many cool-season grasses, DNA fingerprints of individual isolates collected from North America, Japan, Australia, and Europe indicate that this fungus is subdivided into groups of host-specific populations (4, 5). With few exceptions, turfgrass pathogens are members of different populations of *C. cereale* than those found on other grass hosts. In addition, the populations of *C. cereale* infecting annual bluegrass are distinct

Infested foliar or stem tissue are often covered with numerous acervuli (reproductive structures) with distinctive black spines (setae) that are used as diagnostic features for disease identification. *(Photo courtesy of Tom Hsiang)*



Once in contact with a susceptible plant, spores germinate to produce hyphae and a specialized structure known as an appressorium that adheres to the host tissue allowing the fungus to penetrate into the plant. *(Photos courtesy of Tom Hsiang)*

from the populations that infect creeping bentgrass. Such host-specificity is illustrated on golf courses by the appearance of the disease on one grass species at a time in mixed swards of annual bluegrass and creeping bentgrass (15). Although anthracnose can be found on many plants, the host specificity of *Colletotrichum* species indicates that stands of non-turfgrass hosts are not likely to harbor strains that could cause anthracnose on turfgrasses.

Research with DNA fingerprinting indicates that *C. cereale* does not infect warm-season grasses (4). Anthracnose outbreaks on warm-season turfgrass, caused by other species of *Colletotrichum*, are rare and typically cause little damage.

Biology and Epidemiology

Because the anthracnose pathogens on turf and certain field crops were thought to be the same organism throughout most of the 20th century, much of the ecology, epidemiology, and pathogenic process of *C. cereale* are inferred from research on corn and sorghum. There appear to be environmental and host factors that promote both anthracnose foliar blight and basal rot in cool-season turfgrasses, but these are poorly understood. In addition, the increase in anthracnose disease on turf during the past decade has given rise to speculation that more virulent strains of *C. cereale* may have emerged. However, no research data supporting this hypothesis have been reported. Although successful field inoculations of annual bluegrass with *C. cereale* have been conducted, detailed studies of the biology of this pathogen have been hindered, in part, because a reliable method for infecting turf under controlled conditions in the greenhouse and growth chamber is lacking. Such studies are currently being conducted by NE-1025 scientists, but definitive results have yet to be published.

Symptomology and the Disease Cycle

On annual bluegrass, symptoms first appear as orange to yellow colored spots that range from 0.25 to 0.5 inches in diameter. As the disease spreads, spots may coalesce into large, irregularly-shaped areas of infected turf on putting greens, tees, and fairways. Older or senescing leaves are often colonized first resulting in yellow leaf lesions. In close-cut turf, the lower stems may become affected resulting in water-soaked,

Chemical Class	Common Name	Topical MOA	Utility	Resistance Risk	Trade Name(s)
benzimidazole	thiophanate-methyl	acropetal penetrant	preventive/curative	high	3336, Fungo, Systec, T-Storm
dicarboximides	iprodione	localized penetrant	preventive	moderate	Chipco 26GT, Iprodione Pro
DMI	fenarimol	acropetal penetrant	preventive/curative	moderate	Rubigan
	metaconazole	acropetal penetrant	preventive/curative	moderate	Tourney
	myclobutanil	acropetal penetrant	preventive/curative	moderate	Eagle
	propiconazole	acropetal penetrant	preventive/curative	moderate	Banner Maxx, Savvi, Propiconazole Pro, Spectator
	triadimefon	acropetal penetrant	preventive/curative	moderate	Bayleton
	triticonazole	acropetal penetrant	preventive/curative	moderate	Trinity, Triton
nitrile	chlorothalonil	contact	preventive	low	Daconil, Chlorothalonil, Chlorostar, Concorde, Echo, Manicure
phenylpyrrole	fludioxonil	contact	preventive	low	Medallion
phosphonates	fosetyl-Al	true systemic	preventive	low	Signature, Prodigy
	phosphite salt	true systemic	preventive	low	Alude, Magellan, Resyst, Vital
polyoxins	polyoxin D	translaminar	preventive	moderate	Endorse
QoI	azoxystrobin	acropetal penetrant	preventive/curative	high	Heritage
	fluoxastrobin	acropetal penetrant	preventive/curative	high	Disarm
	pyraclostrobin	acropetal penetrant	preventive/curative	high	Insignia
	trifloxystrobin	acropetal penetrant	preventive/curative	high	Compass

Table 1. Currently available fungicides for anthracnose control

blackened tissue that is easily pulled from infected crowns. Infested foliar or stem tissue are often covered with numerous acervuli (reproductive structures) with distinctive black spines (setae) that are used as diagnostic features for disease identification.

From these acervuli the pathogen produces masses of reproductive spores called conidia that can be spread by water or mechanically (foot traffic, mowing, etc.) to healthy plants. Once in contact with a susceptible plant, spores germinate to produce hyphae and a specialized structure known as an appressorium that adheres to the host tissue allowing the fungus to penetrate into the plant. Based on studies of corn and sorghum, *C. cereale* is thought to overwinter in turf as dormant resting structures called sclerotia or as fungal mycelium in infected plant debris.

Temperature Required for Infection

Anthracnose foliar blight is generally favored by higher temperatures (85 - 95° F) in the summer and autumn. However, basal rot symptoms can be observed year round, often occurring simultaneously with foliar blight symptoms during periods of heat stress. Laboratory studies indicate that some isolates of *C. cereale* grow best between 70 and 88º F, and are able to cause foliar infection between 81 and 91º F (8). These observations correlate with summer outbreaks of foliar blight and basal rot but do not explain the development of anthracnose basal rot symptoms under cool conditions (winter or spring). Additional research is needed to ascertain the optimal temperatures required for infection by cool-weather strains of this pathogen.

Anthracnose Management: Chemical Control

Research and experience indicate that preventive fungicide applications are far more effective than curative applications for the control of anthracnose on putting greens. However, due to our lack of knowledge regarding the disease cycle and epidemiology of anthracnose, the best timing for preventive applications remains unknown. Generally, it is recommended that golf course superintendents initiate a preventive fungicide program at least one month prior to the normal onset of anthracnose in their area.

Fungicides belonging to eight chemical classes are currently available for anthracnose control: the benzimidazoles, DMIs (demethylation inhibitors), dicarboximides (i.e., iprodione), nitriles, phenylpyrroles, phosphonates, polyoxins, and QoIs (strobilurins) (Table 1). These products can be separated into two groups: multi-site inhibitors and single-site inhibitors. As the name implies, multi-site inhibitors inhibit several to many biochemical processes in the fungal cell. In contrast, single-site inhibitors suppress only one biochemical process. This is an important distinction because it determines the risk of a given product for fungicide resistance. Single-inhibitors have a moderate or high risk for resistance development, whereas multi-site inhibitors generally have a low resistance risk.

In addition to being more effective, preventive applications also expand the number of products available for use. Of the eight chemistries available for anthracnose control, only the benzimidazole, DMI, and QoI classes have significant curative activity. The nitrile, phenylpyrrole, phosphonate, and polyoxin fungicides have little to no curative activity against anthracnose, but are very effective in tank mixes or when applied on a preventive basis (6, 17).

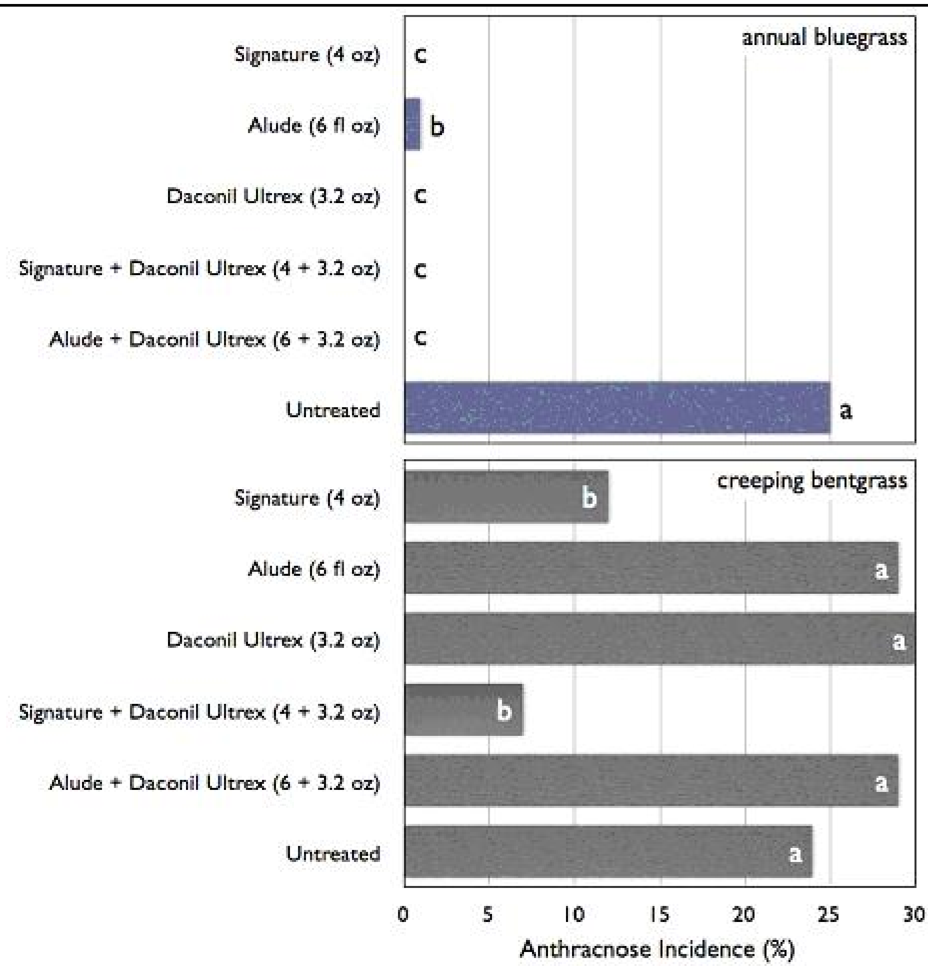


Figure 1. Comparison of phosphonate fungicides for preventive control of anthracnose on annual bluegrass (top) and creeping bentgrass (bottom) putting greens. All fungicides were applied on a 14-day interval in 2 gal. H_2O per 1000 ft^2 with a CO_2-powered sprayer at 40 psi using TeeJet 8004 nozzles. Applications to annual bluegrass were initiated May 23, 2005 and data were collected on August 15, 2005. Applications to creeping bentgrass were initiated June 29, 2006 and data were collected August 6, 2006.

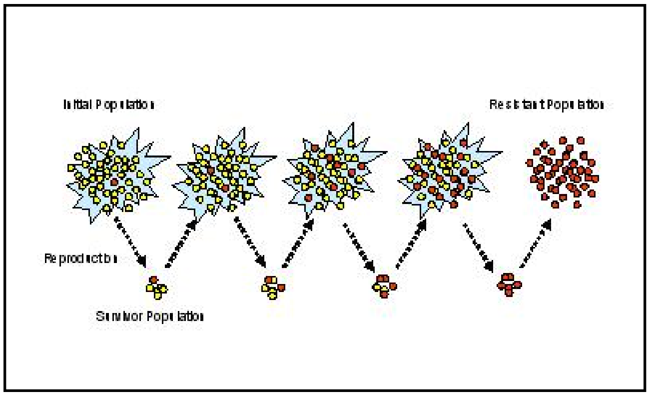


Figure 2. This is a simplified model of a multiple step process over time where repeated applications of a single-site mode of action fungicide selects for naturally resistant individuals from a population. As more fungicide applications are made, the frequency of resistant survivors increases. Eventually, a high frequency of resistance can be selected for in anthracnose populations.

Moreover, tank mixtures and alternation of products within these eight chemical groups have generally been more efficacious than single products used sequentially in NJ trials.

Even though the benzimidazole, DMI, and QoI chemistries have curative activity, golf course superintendents should not to rely on this control strategy when anthracnose has become a persistent disease problem. These chemistries are also at-risk for fungicide resistance, as discussed later in this article, and curative applications may encourage resistance development in anthracnose populations.

While primarily used to control *Pythium* diseases, the phosphonates have recently been shown to be very effective against anthracnose when used preventively. Fosetyl-Al was the first phosphonate fungicide, released in the early 1980s. Originally marketed as Aliette and now sold as Signature or Prodigy, fosetyl-Al is a complex molecule that is broken down to release PO_3^- in the plant after application.

Since 2000, a new generation of phosphonates has been released into the turf market: the phosphite salts. These products contain PO_3^- in the form of a Na^+, K^+, and/or NH_4^+ salt. Phosphonates have direct fungicidal properties and are also thought to reduce anthracnose by improving overall turf health and stimulating host defense responses. The risk of fungicide resistance for phosphonates is considered low to moderate because of these potential multiple modes of action.

Certain formulations of fosetyl-Al also contain a copper phthalocyanine pigment, which imparts a green or blue-green color to the turf after application. Copper phthalocyanines are large, macrocyclic molecules that absorb and refract light, conduct electricity, and have a variety of other biological properties. These pigments are known to increase the overall quality of putting green turf after several successive applications.

Research in North Carolina and Pennsylvania focused on evaluating fosetyl-Al and phosphite salts for anthracnose management. When applied on a preventative basis, fosetyl-Al

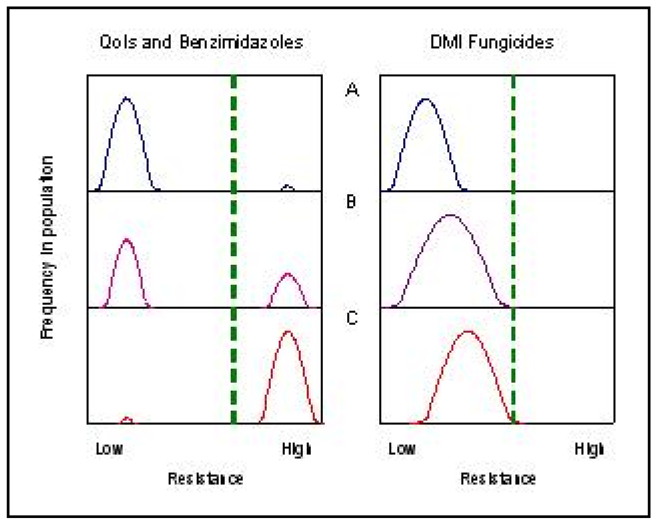


Figure 3. Patterns of Resistance Development to QoI, Benzimidazole and DMI-fungicides. The green line represents the highest allowed rate of fungicide application, and the red areas represent the proportion of the population that can be controlled. Sensitive populations (A) change in response to repeated fungicide applications over time (B). For QoIs and benzimidazoles, a fungicide-immune population develops that is no longer controlled by allowable fungicide rates. For DMIs, the population becomes more fungicide-tolerant, but still can be controlled by fungicides. In cases where prolonged selection for resistance has occurred (C), QoI or benzimidazole immune individuals completely dominate the population and cannot be controlled at all by fungicide applications. Most DMI-tolerant individuals can be controlled with high rate applications. *Figure adapted from Wolfram Koeller (Cornell University)*

provided excellent control on both creeping bentgrass and annual bluegrass. While the phosphite salts have been very effective on annual bluegrass, these products have only provided moderate anthracnose control on creeping bentgrass over three years of testing in North Carolina (Figure 1).

Proper application techniques are essential to a successful fungicide program for anthracnose. Research in Pennsylvania indicates that fungicides should be applied in 2 gal. $H_2O/1000\ ft^2$ using nozzles that produce medium to coarse droplet sizes. Applications in lower water volumes or using extremely coarse droplet sizes can significantly reduce fungicide performance.

Fungicide Resistance

Fungicide resistance has complicated anthracnose management. Resistance has not been an issue for multi-site fungicides like chlorothalonil, but is a concern for those with a site-specific mode of action. Resistance has developed in anthracnose to site-specific fungicide classes including the QoIs, benzimidazoles, and DMI fungicides (22).

Resistance typically results from repeated use of fungicides from a single fungicide class and can result in immunity or tolerance to that fungicide class. Resistance develops independently to each fungicide class (e.g., a QoI-resistant fungal population may be sensitive to benzimidazoles and vice versa). Repeated applications of the same fungicide over time can quickly select for a higher frequency of resistant individuals (Figures 2 and 3). Unfortunately, once resistance to a chemical class develops, it does not go away as long as the resistant isolates persist in the population (competitive with sensitive isolates and tolerant to environmental extremes), even if fungicides from that chemical class are not used or are used sparingly in the future.

The development of resistance can be delayed by limiting the number of applications from one fungicide class. Repeated sequential applications, late curative applications, and low label rate applications tend to encourage the development of resistance. The use of multi-site, contact fungicides is an important strategy for reducing the overall potential for resistance development because it can reduce the total amount and number of high risk, single-site fungicide applications. Tank mixing fungicides (especially with multi-site fungicides) may not necessarily stop resistance development, but it can prevent total control failure from a fungicide application (i.e. a tank mix of chlorothalonil with a QoI fungicide still selects for QoI-resistance, but the chlorothalonil will contribute to disease control of both QoI-resistant and QoI-sensitive individuals.).

	Turf Area Infested				
Nitrogen (N) Interval †	June 11	June 20	July 19	August 17	August 30
	%				
every 28 days	9.0 a	14.6 a	34.3 a	40.0 a	56.0 a
every 7 days	3.6 b	9.2 b	16.4 b	27.2 b	41.8 b
CV (%)	45.1	34.7	34.6	18.4	13.7

Means followed by different letters denotes means that are significantly different at the 0.05 probability levels.

† Nitrogen was applied as an NH_4NO_3 solution containing 0.1 lb/1,000 sq ft of N from May 7 to Oct. 9, 2004.

Table 2. Anthracnose disease response to N fertilization of annual bluegrass turf mowed at 0.125 in. in North Brunswick, NJ during 2004.

QoI Fungicides

The QoI fungicide azoxystrobin (Heritage) was commercially released for use on turf in 1997. Resistance of *C. cereale* to the QoI fungicides (Heritage, Compass, Disarm, and Insignia) developed quickly (1) and was fairly widespread in the U.S. by 2004. QoI-resistant individuals of *C. cereale* are immune and cross-resistant to all fungicides in this chemical class, even when applied at 10 times the standard rates or higher. Thus, the use of QoI fungicides for anthracnose control should be discontinued for locations with a history of poor QoI fungicide performance and/or confirmed resistance by laboratory testing.

There is no evidence that QoI fungicide resistance in fungal populations will decrease over time. However, for any given location, resistance may be localized to one or only a few putting greens. Subsequently, QoIs may still be effective on other putting greens where resistance has not developed.

Benzimidazoles

Benzimidazole fungicides have been used on turf since the 1960s and currently only thiophanate-methyl is labeled for use on cultivated grasses. Resistant isolates of *C. cereale* were found as early as 1989 in Michigan (10) and more recently in a number of other locations throughout the US (22). Like QoI-resistance, resistance to the benzimidazoles results in complete immunity for individuals and is permanent in established populations of anthracnose. Benzimidazole use for anthracnose control should be discontinued at locations with a history of poor benzimidazole performance and/or confirmed resistance by laboratory testing.

DMI-fungicides

DMIs have been used on turfgrasses since the 1980s and several DMIs are currently available for use on cultivated grasses. Unlike QoI and

			Turf Area Infested	
			2004	2005
Nitrogen interval†	Mefluidide‡	Trinexapac-ethyl§	August 30	July 30
--days--	----------fl. oz. per 1,000 sq ft------------		---------------- % ----------------	
28	0	0	65.0	84.9
28	0	0.125	51.3	86.5
28	0.69	0	57.4	82.0
28	0.69	0.125	50.3	85.3
7	0	0	48.9	66.6
7	0	0.125	43.0	67.6
7	0.69	0	50.0	69.0
7	0.69	0.125	25.1	45.9
LSD			6.8	9.5

† Nitrogen was applied as an NH_4NO_3 solution containing 0.1 lb per 1,000 sq ft of N from May 7 to October 9, 2004 and May 21 to August 3, 2005.

‡ Mefluidide (Embark 0.2L) was applied as a split application of 0.69 fl. oz. per 1,000 sq. ft. on April 7 and 21, 2004 and April 6 and 20, 2005.

§ Trinexapac-ethyl (Primo MAXX 1ME) was applied at 0.125 fl. oz. per 1,000 sq. ft. every 14 days from April 7 to September 22, 2004 and April 6 to August 10, 2005. Initial TE application was delayed on turf previously treated with ME until April 21 in 2004 and April 20 in 2005.

Table 3. Anthracnose disease response to N fertilization, mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 0.125 inches in North Brunswick, NJ during 2004 and 2005.

benzimidazole resistance, *C. cereale* gradually develops tolerance to DMI fungicides, which means that good control may be achieved with high labeled rates or shorter application intervals. In California, isolates 2 to 10 times more tolerant to propiconazole (e.g., Banner MAXX) than sensitive isolates have been found on putting greens, but these isolates could still be controlled with the high label rate (2 fl. oz.) of Banner MAXX when applied at 14-day intervals (22). This suggests that DMI resistance is still manageable with high rates of DMIs. However, continued use of DMI fungicides at such locations will eventually result in complete failure to control anthracnose, so it is prudent to alternate the DMIs with other fungicide chemistries.

Additionally, there is a clear difference in the intrinsic activity of the different DMI fungicides (21). On average, propiconazole was roughly 5 times more toxic to *C. cereale* than myclobutanil (Eagle) and 40 times more toxic than triadimefon (Bayleton) in laboratory studies. Season-long applications of propiconazole, myclobutanil, or triadimefon in New Jersey field work resulted in 7.5, 33, and 79% anthracnose severity, respectively (17). The intrinsic activities of new DMIs such as triticonazole (Trinity) and metaconazole (Tourney) are being examined at this time. The potential for resistance development to the DMIs can be reduced by alternating fungicide chemistries, using the most intrinsically active DMI (propiconazole), and applying a higher labeled rate during cooler temperatures (phytotoxicity or thinning can occur at high label rates when some DMIs are applied during high temperatures) to obtain the maximum disease control with this class of fungicides.

Multi-site Fungicides

Since multi-site fungicides have a low risk for resistance, these are important tools in an anthracnose management program. Chlorothalonil used alone or in a tank mixture can be very efficacious, especially when used preventively. As mentioned above, tank mixes can also provide better disease control if QoI, benzimidazole, or DMI applications are made to resistant or populations with reduced sensitivity. Since 2001, seasonal limits have been imposed for the use of chlorothalonil on golf courses, so it is important to conserve its use for difficult to control diseases such as anthracnose.

Other Fungicides

So far, no cases of resistance have been reported for the other classes of site-specific

Mowing Height	Turf Area Infested			
	August 2	August 11	August 23	September 15
	------------------------------- %	----------------------------------		
0.110 inch	4.2	36.8	51.7	61.8
0.125 inch	2.6	32.2	48.0	53.6
0.140 inch	1.1	28.8	40.5	44.5
$LSD_{(0.05)}$	2.2	NS	8.8	7.3
CV (%)	34.1	16.9	13.9	9.9

LSD (least significant difference) represents the difference between two means that must be exceeded to be considered statistically different.

Table 4. Anthracnose disease response to mowing height on annual bluegrass putting green turf in North Brunswick, NJ during 2004

Lightweight Rolling Treatment	Turf Area Infested			
	August 2	August 11	August 23	September 15
	%			
none	3.0 a	34.2 a	49.0 a	56.2 a
every other day	2.3 b	31.0 a	44.4 b	50.4 b
CV (%)	34.1	16.9	13.9	9.9

Means followed by different letters denotes means that are significantly different at the 0.05 probability levels.

Table 5. Anthracnose disease response to lightweight rolling on annual bluegrass putting green turf in North Brunswick, NJ during 2004.

fungicides used to control anthracnose including the polyoxins, phenylpyrroles, and phosphonates. Of these, the polyoxins and phenylpyrroles are more likely to have future resistance problems due to their mode of action, so these should be used judiciously.

Anthracnose Management: Cultural Practices

Nitrogen (N) Fertility

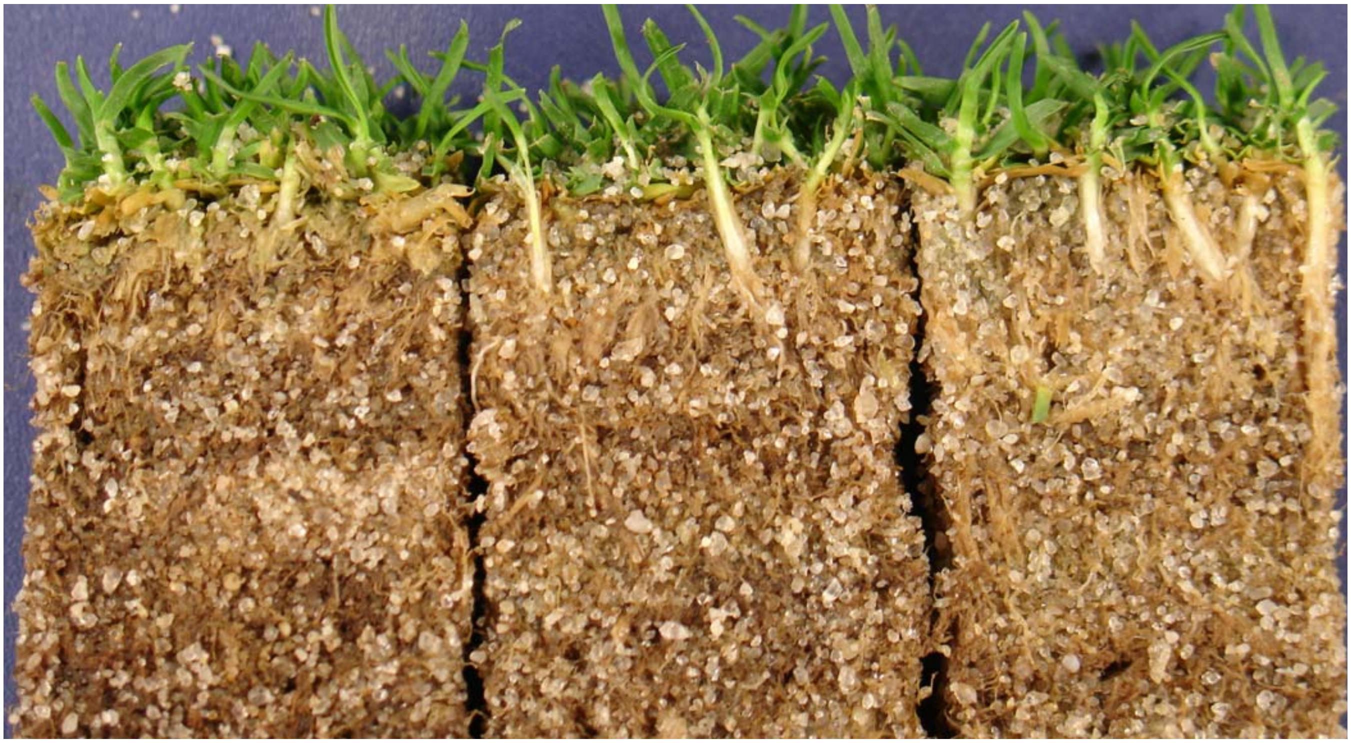
Minimizing N fertility is one approach used by golf course superintendents to increase ball roll (green speed) on putting green turf. However, management trials on annual bluegrass putting green turf in New Jersey indicate that soluble N applied every 7 days at a low rate (0.1 lb. per 1000 ft^2) from late spring through summer can reduce anthracnose severity 5 to 24% compared to the same rate of N applied every 28 days (11) (Table 2). Additionally, fungicide efficacy for the control of anthracnose was increased in plots that received an additional 0.125 lb. of N per 1000 ft^2 every 14 days from May through August (6). Specific mechanisms associated with reduced anthracnose severity in plants with greater N fertility are currently unknown, although increased plant vigor has been proposed (20).

Superintendents have frequently asked about the potential role, if any, of late- and early-season granular-N fertilization and are seeking guidance on the relevance of this practice to anthracnose control on annual bluegrass turf. Work on anthracnose foliar blight of fairway turf indicated that the annual N fertilization should be moderate (3 lbs. of N per 1000 ft^2) and a greater proportion of the annual N fertilizer should be applied in autumn versus spring to reduce disease severity (8).

These effects are possibly explained by a depletion of carbohydrate reserves induced by aggressive spring N fertilization and are exacerbated by low net photosynthesis during summer. Annual N rate and season of fertilization need to be evaluated for anthracnose basal rot under putting green conditions, as well as the possibility of an interaction between summer soluble-N applications and granular-N fertilization programming. Research trials addressing these objectives will be initiated late summer 2008 in New Jersey.

Plant Growth Regulators

Plant growth regulators (PGRs) are widely used to reduce shoot growth between mowings, improve shoot density, increase stress tolerance, and enhance playability of putting green surfaces. Trinexapac-ethyl (Primo) applied to annual bluegrass putting green turf at 0.125 fl. oz. per 1,000 ft^2 every 14 days from May through August reduced disease from late June to late July (6). Other research in New Jersey from 2003 through 2007 indicated that trinexapac-ethyl or mefluidide used alone had infrequent and inconsistent effects on anthracnose, but did not greatly aggravate disease severity. Additionally, mefluidide and trinexapac-ethyl used in combination reduced anthracnose severity 6 to 14% compared to plots that only received one of these plant growth regulators during the last 2 years of a 3-year trial (11).



Light frequent sand topdressing buries and protects crowns and leaf sheaths. Note depth of crowns in the middle (1 ft^3 per 1000 ft^2 per week) and right (2 ft^3 per 1000 ft^2 per week) profile samples are deeper than the profile sample on the left (no topdressing). *(Photo courtesy of John Inguagiato)*

At advanced stages of disease (end of the season), the combination of weekly N fertilization with mefluidide and trinexapac-ethyl application provided the greatest reduction in disease severity (Table 3).

Many superintendents were using chemical growth regulation strategies not addressed in previous research, so further assessment was conducted from 2005 to 2007. Treatments effects evaluated included rate (0.1, 0.125, and 0.2 fl. oz. per 1,000 ft^2) and frequency (7 versus 14 days) of trinexapac-ethyl application, and combinations of trinexapac-ethyl with mefluidide (Embark) or ethephon (Proxy), which are commonly used to regulate seedhead development of annual bluegrass. To date, data from this trial have not been completely analyzed. However, it is clear that use of these growth regulators alone or in combination are not increasing anthracnose severity.

Verticutting

Verticutting is another common management practice used on putting greens to minimize puffiness associated with thatch accumulation and improve surface playability. Verticutting has been reputed to enhance wounding of host plant tissue and thereby enhance anthracnose (9, 13, 15). Contrary to this perception, verticutting to a shallow depth (3.0 mm) did not have a substantial effect on anthracnose severity in New Jersey (11). Infection studies with *Colletotrichum* in annual bluegrass and corn have demonstrated that wounds are not required for host penetration (3, 16, 19). However, Uddin et al. (18) reported that verticutting to a 5-mm depth increased anthracnose in annual bluegrass. Thus, verticutting to a depth that cuts crowns and stolons (severe wounding) and removes thatch may enhance plant stress and increase anthracnose, whereas verticutting to groom (light vertical mowing) the leaf canopy appears to have little effect on disease severity.

Mowing and Rolling Practices

It is well known that a lower cutting height will increase ball roll distance (green speed) on a putting green. Lower cutting height has also been associated with increased anthracnose severity (2). More frequent mowing (double or triple cutting) is used to increase green speed and is thought to intensify wounding of leaf tissue. Moreover, lightweight rolling is used to smooth the turf canopy and improve ball roll. Frequent use of these practices either alone or in combination was thought to increase stress and susceptibility to anthracnose on putting greens.

Research in New Jersey during 2004 and 2005 found that a 0.015-inch increase in mowing height (0.110- to 0.125-inch or 0.125- to 0.141-inch) was sufficient to reduce anthracnose severity (Table 4). But contrary to expectations, increasing mowing frequency from a daily single- to double-cut did not increase anthracnose severity, and lightweight vibratory rolling every other day either had no effect or slightly reduced anthracnose severity (Table 5). Additional analysis of this data is underway, but it appears that the practices of double-cutting and rolling (rather than lowering the cutting height) should be used to improve ball roll without intensifying anthracnose severity.

Research in New York is currently evaluating the possibility that mower setup factors including walk behind mower design, bedknife position, and frequency of clip may affect basal rot anthracnose. Moreover, traffic stress from maneuvering mowing and rolling equipment on the edge of putting greens has been suggested as a potential cause of enhanced anthracnose on putting greens. A trial has been initiated in New Jersey to determine if routine mowing and rolling operations can affect anthracnose depending on the location of the equipment traffic on a putting green (i.e., perimeter versus center).

Topdressing Practices

Topdressing used to smooth putting surfaces and manage thatch accumulation has been suggested as contributing to anthracnose epidemics. Trials were initiated in New Jersey to determine whether rate and frequency of sand topdressing influenced disease development. Initial data analyses indicate that sand topdressing may slightly increase disease at early stages of disease but later reduces disease severity. Light, frequent applications (topdressing every 7 or 14 days at 1 or 2 ft^3/1,000 ft^2) provided the most rapid and substantial reduction of anthracnose. Sand topdressing every 21 or 42 days at a higher rate (4 ft^3/1,000 ft^2) also reduced disease by August in 2006 and 2007.

A companion study in 2005 and 2007 assessed whether methods of sand incorporation and sand particle shape (i.e., round vs. sub-angular) affected disease severity. The incorporation methods evaluated in this study (i.e., stiff-, soft-bristled brush, vibratory rolling, or none) had no effect on anthracnose. Moreover, both sand types at first enhanced disease in July, but continued topdressing reduced disease severity later in the season (August and September) each year compared to non-topdressed turf.

Irrigation Management

Proper irrigation management is critical to maintaining plant health and the playability of putting green turf. A trial was established in New Jersey to determine whether irrigation regime (i.e., 100, 80, 60, and 40% of reference evapotranspiration, ET_o) influences anthracnose disease. This trial is being continued in 2008. However, initial data indicate that anthracnose severity was increased in plots irrigated with 40% or 60% ET_o compared to turf receiving 80 or 100% ET_o. Further data collection and analysis is needed to determine the veracity of these results.

Summary

Currently, best management practices for the control of anthracnose disease on annual bluegrass putting green turf include implementing a frequent low N rate fertility program initiated in late spring and continuing through summer. Soluble N applied every 7 days at 0.1 lb per 1000 ft^2 from late spring through summer has been effective at reducing disease severity. However, the annual N rate and seasonal aspect of fertilization needs to be further studied, as well as the possibility of an interaction between summer soluble-N applications and granular-N fertilization programming. Chemical growth regulation strategies including the use of mefluidide, ethephon, and trinexapac-ethyl do not intensify disease severity and on occasion may reduce severity.

Large reductions in disease severity have also occasionally been observed where frequent low N rate fertilization is combined with the use of seedhead suppressants (mefluidide or ethephon) in the spring and sequential applications of the vegetative growth regulator trinexapac-ethyl throughout the growing season. If feasible, double cutting and lightweight rolling should be used to achieve greater ball roll (green speed) rather than lowering mowing heights. Increasing mowing height as little as 0.015 inch can decrease anthracnose severity, whereas, daily double cutting and lightweight rolling increases ball roll and do not intensify disease. In fact, rolling may slightly reduce disease severity.

Preventive fungicide applications (generally one month prior to the normal onset of symptoms) are far more effective than curative applications. The benzimidazole, DMI, dicarboximide (iprodione), nitrile, phenylpyrrole, phosphonates, polyoxins, and QoIs fungicide chemistries can effectively control anthracnose, but resistance has been a problem with several of these groups. Repeated sequential applications of single-site (benzimidazole, DMI, and QoI) fungicides, late curative applications and low label rate applications tend to encourage the development of resistance and, therefore, should be avoided.

The use of multi-site, contact fungicides is an important strategy for reducing or delaying the overall potential for resistance development. Tank mixtures and alternation of these chemical groups are often more efficacious than single product applications and should be used to reduce the potential for fungicide resistance. Recent research suggests that fungicides should be applied in 2 gal.of H_2O per1000 ft^2 using nozzles that produce medium- to coarse-sized droplets.

Although much has been learned about the biology and management of anthracnose through this project, many questions remain unanswered. We must continue to gain a more comprehensive understanding of the anthracnose system on annual bluegrass and bentgrass that will enable us to develop more specific and better targeted management programs. Very little is known about the life history of *C. cereale* and the epidemiology of anthracnose, including where and how the pathogen survives and the weather conditions that drive infection and symptom expression. Such information would aid in the development of a useful predictive model for basal rot anthracnose.

Moreover, this knowledge would enable turfgrass managers to more effectively target fungicide applications or other management practices to key points in the disease cycle. For example, if the timing of initial infections was known, then golf course superintendents could apply preventive fungicide applications at the most effective time(s), thereby potentially providing more effective control with the most efficient (reduced) chemical inputs.

The genetic mechanisms that confer fungicide resistance are now well understood in *C. cereale* and related fungi. Using this knowledge, scientists will now be able to investigate how pathogen populations respond to fungicide applications, how resistance develops over time, and which resistance management strategies are most effective. Continuing cultural management research will clarify the effect of topdressing, irrigation, and traffic on anthracnose disease severity from which best management practices can be enhanced. Continuing work on selecting and breeding annual bluegrass may lead to new varieties of annual bluegrass with improved tolerance to anthracnose disease.

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