Best management practices for anthracnose on annual bluegrass turf

Although our understanding of anthracnose disease on *Poa annua* greens is incomplete, several cultural and management practices can reduce its occurrence and its severity.

Anthracnose (caused by *Colletotrichum cereale*) is a destructive fungal disease of weakened turf that occurs throughout the U.S., Canada and Western Europe (15) and is particularly severe on annual bluegrass (*Poa annua*). The frequency and severity of anthracnose epiphytotics on golf course 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 and ball-roll distance. Combinations of management factors may be enhancing the severity of this disease.

Scientists within the NE-1025 multistate 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. 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 interaction among practices. 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* species), fescues (*Festuca* species), Kentucky bluegrass (*Poa 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, very low mowing heights or turf grown under suboptimal conditions (drought stress, excess shade, high humidity).

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 occurs predominantly in the spring (April through early June). Seedhead development requires considerable metabolic energy, which reallocates photosynthate away from roots and shoots toward seedheads just before the most stressful time of

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the 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 more than 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.

Annual bluegrass putting green turf shows initial symptoms of anthracnose. **Photo courtesy of B. Clarke**

Even though *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 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 inhabit 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 *Colletotrichum 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 annual bluegrass has been successfully inoculated with *C. cereale* in the field, 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 inch (0.64-1.3 centimeters) in diameter. As the disease spreads, spots may coalesce into large, irregularly shaped areas of infected turf on 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, 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 (12). 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 F-95 F [29.4 C-35 C]) 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 F and 88 F (21.1 C-31.1 C) and are able to cause foliar infection between 81 F and 91 F (27.2 C-32.7 C) (7). 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.

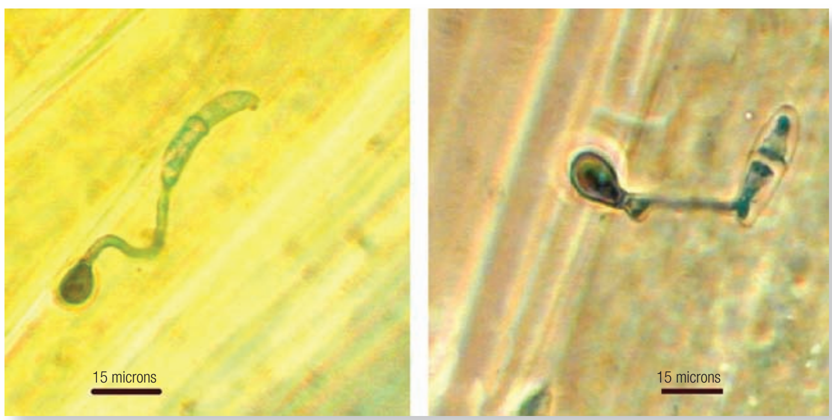
Anthracnose management: chemical control

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

Fungicides belonging to eight chemical classes are currently available for anthracnose control:

Colletotrichum cereale colonizes older senescing leaves of annual bluegrass. **Photo courtesy of J. Inguagiato**

Acervuli with setae on leaf sheath. **Photos courtesy of T. Hsiang**



Germinating anthracnose conidium produces an appressorium on plant tissue.

the benzimidazoles, dicarboximides (specifically, iprodione), DMIs (demethylation inhibitors), nitriles, phenylpyrroles, phosphonates, polyoxins and QoIs (strobilurins) (Table 1).

These products can be separated into two groups: multisite inhibitors and single-site inhibitors. As the name implies, multisite 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 multisite inhibitors generally have a low resistance risk.

Preventive versus curative

In addition to being more effective, preventive applications also expand the number of products available for use. Of the eight chemical classes 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). Moreover, in New Jersey trials, using tank-mixtures and alternating among the eight chemical groups have generally been more efficacious than using a single product sequentially.

Although the benzimidazole, DMI and QoI chemistries have curative activity, superintendents should not rely solely on curative applications for anthracnose control. These chemistries are also at risk for fungicide resistance, as discussed later in this article, and curative applications may encourage resistance development in

Fungicides for anthracnose control

Chemical class	Common name	Topical mode of action	Utility	Resistance risk	Trade name, manufacturer
Benzimidazole	thiophanate-methyl	acropetal penetrant	preventive/curative	high	Cleary's 3336, Cleary Chemical Fungo, The Scotts Co. SysTec, Regal Chemical T-Storm, Lesco
Dicarboximides	iprodione	localized penetrant	preventive	moderate	Chipco 26GT, Bayer Iprodione Pro, BASF
DMI	fenarimol	acropetal penetrant	preventive/curative	moderate	Rubigan, Gowan Co.
	metconazole	acropetal penetrant	preventive/curative	moderate	Tourney, Valent
	myclobutanil	acropetal penetrant	preventive/curative	moderate	Eagle, Dow AgroSciences
	propiconazole	acropetal penetrant	preventive/curative	moderate	Banner Maxx, Syngenta Propiconazole Pro, Micro Flo Co. Savvi, Regal Chemical Spectator, Lesco
	triadimefon	acropetal penetrant	preventive/curative	moderate	Bayleton, Bayer
	triticonazole	acropetal penetrant	preventive/curative	moderate	Trinity, BASF Triton, Bayer
Nitrile	chlorothalonil	contact	preventive	low	Daconil, Syngenta ChloroStar, Regal Chemical Concorde, Griffin LLC Echo, Sipcam Agro USA Manicure, Lesco
Phenylpyrrole	fludioxonil	contact	preventive	low	Medallion, Syngenta
Phosphonates	fosetyl-Al	true systemic	preventive	low	Chipco Signature, Bayer Prodigy, Lesco
	phosphite salt	true systemic	preventive	low	Alude, Cleary Chemical Magellan, Nufarm Americas Resyst, Regal Chemical Vital, Phoenix Environmental Care
Polyoxins	polyoxin D	localized penetrant	preventive	moderate	Endorse, Cleary and Arysta LifeScience
QoI	azoxystrobin	acropetal penetrant	preventive/curative	high	Heritage, Syngenta
	fluoxastrobin	acropetal penetrant	preventive/curative	high	Disarm, Arysta LifeScience
	pyraclostrobin	acropetal penetrant	preventive/curative	high	Insignia, BASF
	trifloxystrobin	acropetal penetrant	preventive/curative	high	Compass, Bayer

Note. This list of products and manufacturers is not intended to be complete. Other turf fungicide products containing the same active ingredients may be available.

Table 1. Currently available fungicides for anthracnose control.

anthracnose populations.

Phosphonates

Although primarily used to control *Pythium* diseases, the phosphonates have recently been shown to be very effective against anthracnose when used preventively. Fosetyl-Al, released in the early 1980s, was the first phosphonate fungicide labeled for use on turf. Originally marketed as Aliette and now sold as Chipco Signature or Prodigy, fosetyl-Al is a complex molecule that is broken down to release the phosphite ion 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 phosphite (PO_3^-) in the form of a sodium (Na^+), potassium (K^+) and/or ammonium (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 has focused on evaluating fosetyl-Al and phosphite salts for anthracnose management. When applied on a preventive basis, fosetyl-Al has provided excellent control on both creeping bentgrass and annual bluegrass. Although 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).

Application techniques

Proper application techniques are essential to a successful fungicide program for the control of anthracnose. Research in Pennsylvania indicates that fungicides should be applied in 2 gallons of water/1,000 square feet (81.5 milliliters/square meter) 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.

Comparing fungicide control

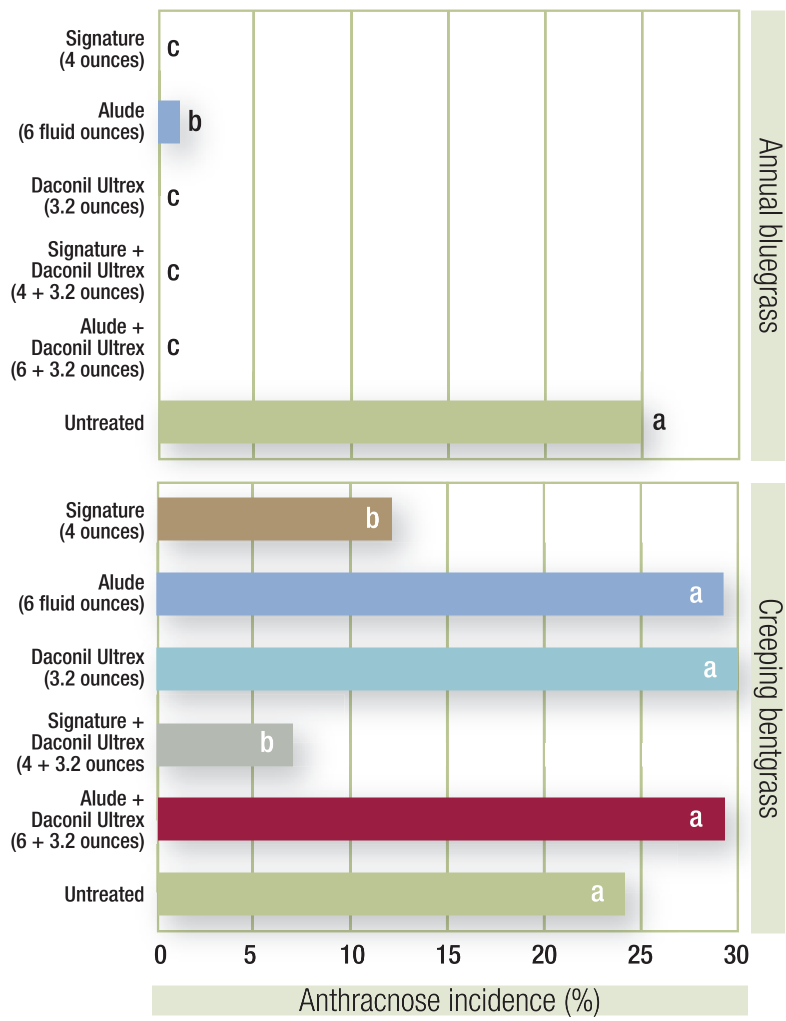


Figure 1. Comparison of phosphonate fungicides for preventive control of anthracnose on annual bluegrass (**top**) and creeping bentgrass (**bottom**) greens. All fungicides were applied on a 14-day interval in 2 gallons water/1,000 square feet with a carbon dioxide-powered sprayer at 40 pounds/square inch (275.8 kilopascals) using TeeJet 8004 nozzles. Applications to annual bluegrass were initiated May 23, 2005, and data were collected on Aug. 15, 2005. Applications to creeping bentgrass were initiated June 29, 2006, and data were collected Aug. 6, 2006.

Fungicide resistance

Fungicide resistance has complicated anthracnose management. Resistance has not been an issue for multisite fungicides like chlorothalonil, but it 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 (21).

How resistance develops

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 to each fungicide class develops independently (for example, a QoI-resistant fun-

How resistance develops

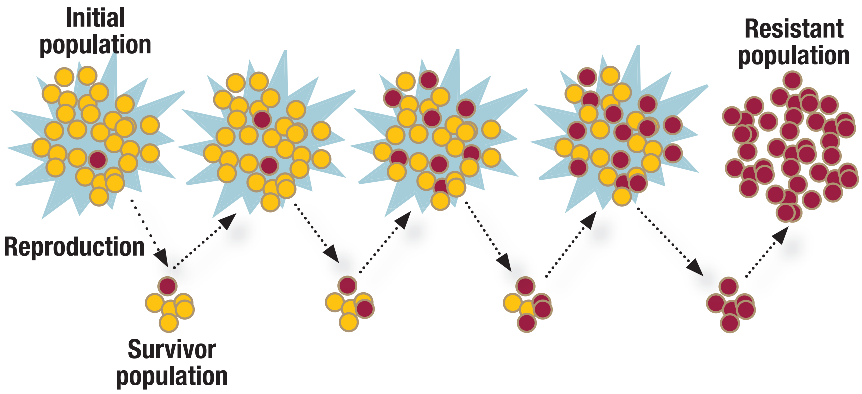


Figure 2. This is a simplified model of a multiple-step process over time, where repeated applications of a single-site mode of action fungicide select for naturally resistant individuals from a population. As more fungicide applications are made, the frequency of resistant survivors increases. In anthracnose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

Pattern of resistance development

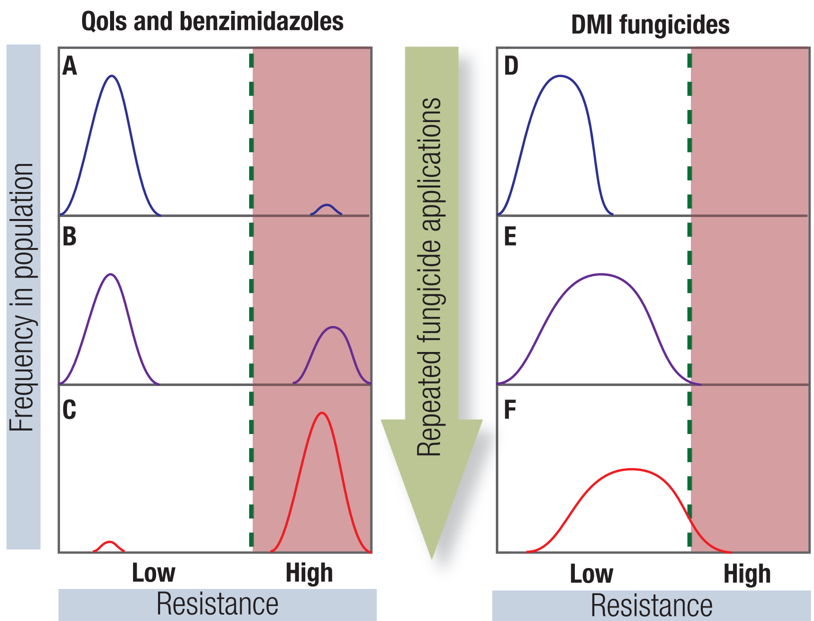


Figure 3. Patterns of resistance development to QoI, benzimidazole and DMI fungicides. Sensitive populations (**A, D**) change in response to repeated fungicide applications over time (**B, E**). For QoIs and benzimidazoles, a fungicide-immune population develops that cannot be controlled at all by fungicide applications, and it completely dominates the population (**C**). For DMIs, the population becomes more fungicide-tolerant, but most DMI-tolerant individuals can still be controlled with high-rate applications (**F**). For each fungicide group, the green line represents the highest labeled rate of fungicide; the proportion of the population that is sensitive to the fungicide and can be controlled is shown in the white boxes to the left, and the proportion of the population that is no longer sensitive to the fungicide and cannot be controlled is shown in the red areas to the right. **Adapted from Professor Wolfram Koeller, Cornell University**

gal population may be sensitive to benzimidazoles and vice versa). Repeated applications of the same fungicide or fungicides from the same fungicide class over time can quickly select for a higher frequency of resistant individuals (Figures 2,3). Unfortunately, once resistance to a chemical class develops, it does not go away as long as the resistant isolates persist in the population, even if fungicides from that chemical class are not used or are used sparingly in the future. Resistant isolates are as "fit" as sensitive ones with the added bonus of being able to survive certain fungicide applications.

Delaying resistance

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 multisite, 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 multisite fungicides) may not stop resistance development, but it can prevent total control failure from a fungicide application; for example, a tank-mix of chlorothalonil with a QoI fungicide still selects for QoI resistance, but the chlorothalonil will contribute to disease control of individuals that are both resistant and sensitive to QoIs.

QoI fungicides

The QoI fungicide azoxystrobin (Heritage) was commercially released for use on turf in 1997. Resistance of *Colletotrichum 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 the fungicides are applied at 10 times standard rates or higher.

Thus, the use of QoI fungicides for anthracnose control should be discontinued for locations with a history of poor QoI performance and/or resistance confirmed by laboratory testing. There is no evidence that QoI resistance in fungal populations will decrease over time; resistance is likely to be permanent. However, for any given location, resistance may be localized to one or only a few greens. Subsequently, QoIs may still be effective on other greens where resistance has not developed. QoI fungicides can also still be used for the control of other diseases (for example, *Rhizoctonia* diseases and summer patch) where the anthracnose pathogen has developed resistance to the QoI fungicides.

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 *Colletotrichum cereale* were found as early as 1989 in Michigan (10) and more recently in a number of other locations throughout the U.S. (21). 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 resistance confirmed 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. Whereas *Colletotrichum cereale* can quickly develop resistance to QoI and benzimidazole fungicides, it gradually develops a tolerance to DMI fungicides, which means that good control may be achieved with high labeled rates or shorter application intervals. In California, isolates that are two to 10 times more tolerant to propiconazole (for example, Banner MAXX, Syngenta) than sensitive isolates have been found on greens, but these isolates could still be controlled with the high label rate (2 fluid ounces [59.1 milliliters]) of Banner MAXX when applied at 14-day intervals (21). This suggests that pathogens that have developed tolerance to DMIs are still manageable with high rates of DMIs. To both maintain the utility of these fungicides and minimize non-target effects of excessive use (potential plant growth regulation), 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 (22). On average, propiconazole was roughly five times more toxic to *C. cereale* than myclobutanil (Eagle, Dow AgroSciences) and 40 times more toxic than triadimefon (Bayleton, Bayer) in laboratory studies. In New Jersey fieldwork, season-long applications resulted in anthracnose severity of 7.5% (Banner Maxx), 33% (Eagle) and 79% (Bayleton) (17). The intrinsic activities of new DMIs such as triticonazole (Trinity, BASF; Chipco Triton, Bayer) and metconazole (Tourney, Valent) are being examined at this time.

The potential for resistance development to the DMIs can be reduced by alternating fungicide chemical classes, 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 fungicide class.

Multisite fungicides

Since multisite 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 populations 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 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 because of their mode of action, so these should be used judiciously.

Anthracnose management: cultural practices

Nitrogen fertility

Minimizing nitrogen fertility is one approach used by superintendents to increase ball-roll distance (green speed) on putting green turf. However, management trials on annual bluegrass greens in

Anthracnose and nitrogen, 2004

Nitrogen interval†	% turf area infested‡				
	June 11	June 20	July 19	Aug. 17	Aug. 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

†Nitrogen was applied as an NH_4NO_3 solution containing 0.1 pound nitrogen/1,000 square feet (0.49 gram/square meter) from May 7 to Oct. 9, 2004.
‡Means followed by different letters are significantly different from one another.

Table 2. Anthracnose disease response to nitrogen fertilization of annual bluegrass turf mowed at 0.125 inch (3.2 millimeters) in North Brunswick, N.J., during 2004.

New Jersey indicate that soluble nitrogen applied every seven days at a low rate of 0.1 pound/1,000 square feet (0.49 gram/square meter) from late spring through summer can reduce anthracnose severity 5% to 24% compared to the same rate of nitrogen 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 pound of nitrogen/1,000 square feet (0.61 gram/square meter) every 14 days from May through August (6). Specific mechanisms associated with reduced anthracnose severity in plants with greater nitrogen 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 fertilization and are seeking guidance on the relevance of this practice to controlling anthracnose on annual bluegrass turf. Work on anthracnose foliar blight of fairway turf indicated that annual nitrogen fertilization should be moderate (3 pounds nitrogen/1,000 square feet [14.6 grams/square meter]), and a greater proportion of the annual nitrogen fertilizer should be applied in autumn rather than spring to reduce disease severity (8). These effects may be explained by a depletion of carbohydrate reserves induced by aggressive spring nitrogen fertilization and exacerbated by low net photosynthesis during summer stresses.

Annual nitrogen 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 applications of soluble nitrogen and granular nitrogen fertilization programs. Research trials addressing these objectives will be initiated in late summer 2008 in New Jersey.

Anthracnose response, 2004 and 2005

Nitrogen interval (days)†	Embark (mefluidide)‡	Primo (trinexapac-ethyl)§	Aug. 30, 2004	July 30, 2005
	Fluid ounce/1,000 square feet		% turf area infested	
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#			6.77	9.45

†Nitrogen was applied as an NH_4NO_3 solution containing 0.1 pound nitrogen/1,000 square feet from May 7 to Oct. 9, 2004, and May 21 to Aug. 3, 2005.

‡Mefluidide (Embark 0.2L) was applied as a split application of 0.69 fluid ounce/1,000 square feet (0.22 milliliter/square meter) on April 7 and 21, 2004, and April 6 and 20, 2005.

§Primo MAXX 1ME was applied at 0.125 fluid ounce/1,000 square feet (0.04 milliliter/square meter) every 14 days from April 7 to Sept. 22, 2004, and April 6 to Aug. 10, 2005. Initial Primo application was delayed on turf previously treated with Embark until April 21 in 2004 and April 20 in 2005.

#LSD (least significant difference). The difference between two means (that are within the same level as the other two factors) must be equal to or greater than the LSD value to be considered statistically different.

Table 3. Anthracnose disease response to nitrogen fertilization, Embark and Primo application on annual bluegrass turf mowed at 0.125 inch (3.2 millimeters) in North Brunswick, N.J., during 2004 and 2005.

Plant growth regulators

Plant growth regulators (PGRs) are widely used to reduce shoot growth between mowing, improve shoot density, increase stress tolerance and enhance playability of putting green surfaces. Primo (trinexapac-ethyl, Syngenta) applied to annual bluegrass greens at 0.125 fluid ounce/1,000 square feet (0.039 milliliter/square meter) 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 Primo or Embark (mefluidide, PBI Gordon) used alone had infrequent and inconsistent effects on anthracnose, but did not greatly aggravate disease severity. Additionally, in plots where Embark and Primo were used in combination, anthracnose severity was reduced 6% to 14% compared to plots that received only one of these plant growth regulators during the last two years of a 3-year trial (11). At advanced stages of disease (end of the season), the combination of weekly nitrogen fertilization with Embark and Primo application provided the greatest reduction in disease severity (Table 3).

Many superintendents were using chemical growth regulation strategies not addressed in previous research; thus, further assessment was conducted from 2005 to 2007. Treatment effects evaluated included rate (0.1, 0.125 and 0.2 fluid ounce/1,000 square feet [0.03, 0.04 and 0.06 millimeter/square meter]) and frequency (seven versus 14 days) of Primo application, and combinations of Primo with Embark or Proxy (ethephon, Bayer), which are commonly used to regulate seedhead development of annual bluegrass. Data from this trial have not been completely analyzed, but 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 greens to minimize puffiness associated with thatch accumulation and to improve surface playability. Verticutting has been reputed to enhance wounding of host plant tissue and thereby increase anthracnose severity (9,13,15). Contrary to this perception, verticutting to a shallow depth (0.1 inch [3.0 millimeters]) 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, other researchers (18) have reported that verticutting to a 0.2-inch (5-millimeter) 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 severity, 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 distance. Frequent use of these practices either alone or in combination was thought to increase stress and susceptibility to anthracnose on putting greens.

As expected, research in New Jersey during 2004 and 2005 found that a 0.015-inch (0.38-millimeter) increase in mowing height (0.110 to 0.125 inch, or 0.125 to 0.141 inch [2.8 to 3.2 millimeters, or 3.2 to 3.6 millimeters]) was sufficient to reduce anthracnose severity (Table 4). Contrary to expectations, increasing mowing frequency from a single daily mowing to double-cutting daily 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 under way; 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 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 greens has been suggested as a potential cause of enhanced anthracnose on greens. A trial has been initiated in New Jersey to determine whether routine mowing and rolling operations can affect anthracnose, depending on the location of the equipment traffic on a putting green, that is, perimeter (edge) or center.

Topdressing practices

Topdressing used to smooth putting surfaces and manage thatch accumulation has been sug-

Anthracnose and mowing height, 2004

Mowing height		% turf area infested†			
inches	millimeters	Aug. 2	Aug. 11	Aug. 23	Sept. 15
0.110	2.8	4.2 a	36.8 a	51.7 a	61.8 a
0.125	3.2	2.6 ab	32.2 a	48.0 ab	53.6 b
0.140	3.6	1.1 b	28.8 a	40.5 b	44.5 c

†Means followed by different letters are significantly different from one another.

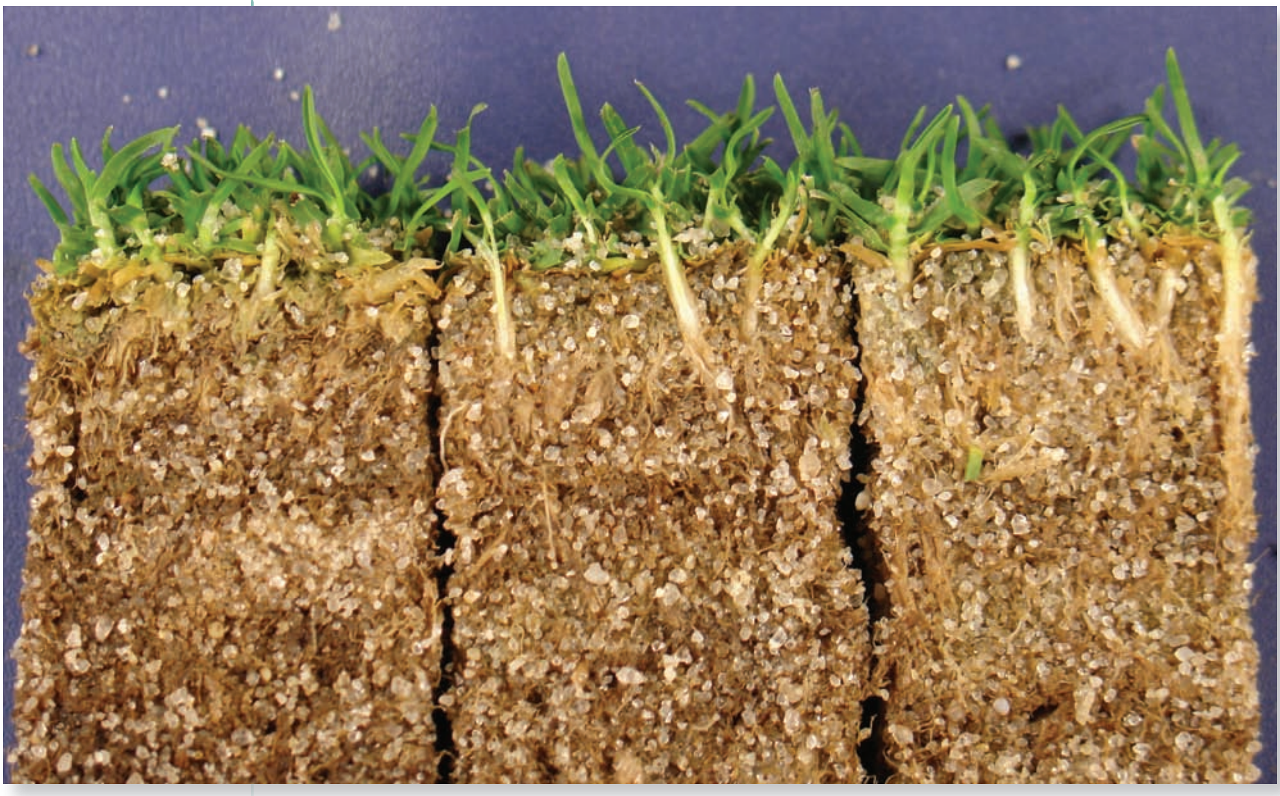
Table 4. Anthracnose disease response to mowing height on annual bluegrass putting green turf in North Brunswick, N.J., during 2004.

Anthracnose and rolling, 2004

	% turf area infested†			
Lightweight rolling	Aug. 2	Aug. 11	Aug. 23	Sept. 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

†Means followed by different letters are significantly from one another.

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



Light, frequent sand topdressing buries and protects crowns and leaf sheaths. Note the depth of crowns in the **middle** (1 cubic foot/1,000 square feet/week [0.0003 cubic meter/square meter]) and **right** (2 cubic feet/1,000 square feet/week [0.0006 cubic meter/square meter]) profile samples are greater than the profile sample on the **left** (no topdressing). **Photo courtesy of J. Inguagiato**

gested 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 anthracnose at early stages of the disease but later reduces disease severity. Light, frequent applications (topdressing every seven or 14 days at 1 or 2 cubic feet/1,000 square feet [304.8 or 609.6 cubic centimeters/square meter]) provided the most rapid and substantial reduction of anthracnose. Sand topdressing every 21 or 42 days at a higher rate (4 cubic feet/1,000 square feet [1,219.2 cubic centimeters/square meter]) 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 (that is, round versus subangular) affect disease severity. The incorporation methods evaluated in this study (that is, stiff-bristled brush, 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 turf that was not topdressed.

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 (that is, 100%, 80%, 60% and 40% of reference evapotranspiration, ET_o) influences anthracnose disease. This trial is being continued in 2008, but 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-nitrogen-rate fertility program initiated in late spring and continuing through summer. Soluble nitrogen applied every seven days at 0.1 pound/1,000 square feet (0.49 gram/square meter) from late spring through summer has been effective at reducing disease severity. However, the annual nitrogen rate and seasonal aspect of fertilization need to be further studied as well as the possibility of an interaction between summer applications of soluble nitrogen and granular nitrogen fertilization programs.

Chemical growth regulation strategies including the use of Embark, Proxy and Primo do not intensify disease severity and, on occasion, may reduce severity. Relatively large reductions in disease severity have also occasionally been observed where frequent low-nitrogen-rate fertilization is combined with the use of seedhead suppressants (Embark or Proxy) in the spring and sequential applications of the vegetative growth regulator Primo throughout the growing season.

If it is feasible, superintendents should use double-cutting and lightweight rolling instead of lowering mowing heights to achieve greater ball-roll distance (green speed). Increasing mowing height as little as 0.015 inch (0.38 millimeter) can decrease anthracnose severity, whereas daily double-cutting and lightweight rolling increase ball-roll distance and do not intensify disease. In fact, rolling may slightly reduce disease severity.

Preventive fungicide applications (generally one month before the normal onset of symptoms) are far more effective than curative applications. The benzimidazole, DMI, dicarboximide (iprodione), nitrile, phenylpyrrole, phosphonate, polyoxin and QoI 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 multisite 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 gallons of water/1,000 square feet (81.5 milliliters/square meter) using nozzles that produce medium to coarse droplet sizes.

Conclusions

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 *Colletotrichum 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 superintendents 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 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.

Fungicide resistance remains a problem for anthracnose control, and is a continuing risk for new site-specific fungicides. Scientists are actively investigating 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. And, continuing work on selecting and breeding annual bluegrass may lead to new varieties of annual bluegrass with improved tolerance to anthracnose disease.

Disclaimer

Use pesticides only according to the directions on the label. No endorsement is intended for products mentioned, nor is criticism meant for products not mentioned. Trade names are used only to give specific information; this publication does not recommend one product instead of another that might be similar.

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- John Kaminski, Ph.D., University of Connecticut
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- Joseph Roberts, Rutgers University
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The research says

→ Controlling anthracnose disease on annual bluegrass greens requires initiating a frequent low-nitrogen-rate fertility program in late spring and continuing it through summer. Further study is needed on annual nitrogen rate, seasonal aspects of fertilization and the possibility of an interaction between summer applications of soluble nitrogen and granular nitrogen fertilization programs.

→ Using Embark, Proxy and Primo does not intensify anthracnose disease severity and may reduce it. Frequent low-nitrogen-rate fertilization combined with the use of seedhead suppressants in spring and sequential applications of Primo throughout the growing season may reduce disease severity.

→ Increasing mowing height as little as 0.015 inch can decrease anthracnose severity; daily double-cutting and lightweight rolling increase ball-roll distance and do not intensify disease; and rolling may slightly reduce disease severity.

→ Preventive fungicide applications are more effective than curative applications. Repeated sequential applications of single-site fungicides from the same class, late curative applications and low-label-rate applications tend to encourage the development of resistance.

→ Multisite fungicides have a negligible risk of resistance and can help reduce overall selection pressure for resistance. Tank mixes can be more efficacious and reduce the impact of resistance, but resistance to the individual mixing partners must still be managed.

→ Topics for future research include clarifying the effect of topdressing, irrigation and traffic on anthracnose disease severity, and understanding where and how the anthracnose pathogen survives and the weather conditions that drive infection and symptom expression.

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