ANTHRACNOSE SEVERITY INFLUENCED BY CULTURAL MANAGEMENT OF ANNUAL BLUEGRASS PUTTING GREEN TURF

by

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and approved by

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ABSTRACT OF THE DISSERTATION

Anthracnose Severity Influenced by Cultural Management of

Annual Bluegrass Putting Green Turf

By JOHN C. INGUAGIATO

Dissertation Directors:
Dr. James A. Murphy and Dr. Bruce B. Clarke

Anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman) has become a devastating disease of annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] putting green turf over the past 15 years. Factors responsible for the increased incidence and severity of anthracnose epiphytotics are not well understood, although speculation has focused on the influence of cultural practices on this disease. Six field trials were conducted from 2003 to 2007 to evaluate effects of cultural practices on anthracnose severity of annual bluegrass putting green turf in factorial arrangements. Nitrogen fertilization, mowing height and topdressing practices provided the most consistent and greatest influence on disease. Nitrogen applied from May through September at 4.9 kg ha^{-1} every 7 d reduced anthracnose severity 5 to 24% compared to the same rate applied every 28 d. Mowing at 3.6 mm reduced disease 3 to 21% compared to 2.8 mm, while 3.2 mm had intermediate disease severity. Mowing frequency (7 vs. 14 times wk^{-1}) had little effect on anthracnose. Sand topdressing applied every 7 d at 0.3 L m^{-2} and 14 d at 0.6 L m^{-2} reduced anthracnose severity compared to no topdressing or similar rates applied less often, although greater rates applied less often (i.e., 21 d at 1.2 L

m^{-2}) provided comparable results. Topdressing with sub-angular sand occasionally reduced anthracnose more than rounded sand. Lightweight rolling every other day reduced disease severity 5 to 6% under moderate disease pressure. The plant growth regulators trinexapac-ethyl, mefluidide and ethephon had inconsistent effects on anthracnose severity; however these materials typically did not increase disease and in some cases reduced it. For example, the combination of 7 d N fertilization, mefluidide and trinexapac-ethyl application occasionally reduced disease more than each factor alone. Also, trinexapac-ethyl applied at shorter intervals (7 vs. 14 d) and increased rate (0.08 vs. 0.05 kg a.i. ha^{-1}) reduced anthracnose when disease severity was high. Cultural practices that may wound turf (e.g., verticutting and brushing) had little effect on anthracnose. These results provide the foundation for the development of best management practices to minimize anthracnose severity of annual bluegrass putting green turf.

PREFACE

Chapter 1 of this dissertation, representing original research completed in partial fulfillment of the requirements for the doctoral degree in Plant Biology has already appeared in published form elsewhere. Chapters 2 and 3 have been accepted and are pending publication.

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LITERATURE REVIEW

INTRODUCTION

Anthracnose disease epiphytotics, caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman (Crouch et al., 2006), have become a common malady of putting green turf throughout the United States, the United Kingdom and Europe (Smiley et al., 2005) over the past 15 years. Annual bluegrass (ABG) [*Poa annua* L. (Hausskn) T. Koyama] maintained as putting green turf is particularly susceptible, although the disease is not uncommon on similarly managed creeping bentgrass (*Agrostis stolonifera* L). Anthracnose often causes significant turf loss and disruption of play on putting greens (Dernoeden, 2002; Landschoot and Hoyland, 1995b); thus it has become a primary disease concern of golf course superintendents in cool climatic regions of the United States (Dernoeden, 2002).

Increased incidence and severity of anthracnose epiphytotics have encouraged speculation about factors which might contribute to disease outbreaks. Recent research has demonstrated resistance of the fungus to benzimidazole (Wong et al., 2008), sterol demethylation inhibitor (Wong and Midland, 2007) and strobulurin (Avila-Adame et al., 2003; Wong et al., 2007) fungicide classes which were previously known to be efficacious against *C. cereale*. Additional speculation has focused on cultural management practices of putting green turf. In recent years, practices intended to increase ball roll distance on putting green turf have been implemented by turf managers (Vermeulen, 2003; Zontek, 2004) which may enhance plant stress and/or result in wounding, thus potentially predisposing the host to anthracnose disease (Smiley et al., 2005). However, the impact of these factors alone or in combination on anthracnose disease of ABG putting green turf have yet to be determined.

ANTHRACNOSE DISEASE

Symptomology

Two phases of the disease are commonly recognized; a foliar blight which typically occurs during high summer temperatures, and a basal rot which can occur at any time of year (Smiley et al., 2005). Symptoms of both phases initially appear on affected leaf blades as six to 12 mm zones of chlorotic tissue on which later develop acervuli and melanized setae. Basal rot is further characterized by a necrotic, water-soaked or black rot of crown tissue concealed beneath outer leaf sheaths (Smiley et al., 2005). As disease progresses in the field, individual infection centers coalesce forming large irregularly shaped areas (1 m in diameter) of blighted turf (Smiley et al., 2005). Chlorotic tissue eventually turns reddish-brown and collapses.

Causal Agent

The incitant of anthracnose disease of the Poaceae, subfamily Pooideae including turfgrasses, is the anamorphic fungus *C. cereale*. This fungus was only recently distinguished from the closely related pathogen of maize (*Zea mays* L) *C. graminicola* (Ces.) G.W. Wils. (Crouch et al., 2006). This species distinction was made from a phylogenetic and network-based analysis of three genetic loci [*ITS1/5.8S/ITS2*; HMG (*MAT1-2*); *SOD2*] from 107 isolates of *Colletotrichum* obtained from native grasses, turfgrasses and maize throughout North America. Furthermore, the authors speculated from this dataset that further subdivision of *C. cereale* into two or more species may be possible; although insufficient information is currently available to make this distinction. The teleomorph of the newly described *C. cereale* remains unknown (Crouch et al., 2006).

The appearance of *C. cereal*e grown under light at room temperature in culture (potato dextrose agar) is variable. Generally, the fungus grows radially as an aerial gray mycelial network containing dense darkly pigmented setae, or as lower growing brown/black mycelial growth with distinct salmon/orange colored conidial masses (Crouch et al., 2006). Mycelia of *C. cereale* are typically hyaline and septate. The asexual fungus produces erumpent acervuli on infected plant tissue (Smith et al., 1989). Melanized setate develop from mycelia within acervuli; they are usually dark brown/black, septate, 85 to 300 µm in length tapering to an acute point (Smith et al., 1989). These unique structures are commonly used as a diagnostic feature in the field to identify the pathogen (Smiley et al., 2005). Conida emanating from acervuli, are falcate to fusiform with acute apices measuring 6 to 34 µm in length and 2 to 6 µm wide (Crouch et al., 2006). Individual spores of *C. cereale* are hyaline (salmon/orange color en mass) aseptate and guttulate with granulated contents (Crouch et al., 2006; Smith et al., 1989). Germination tubes emerge from conidia producing dark brown/black, rounded to irregular shaped appressoria which range in size from 8.5 to 11.6 µm x 6.5 to 10.2 µm (Crouch et al., 2006).

Hosts

Anthracnose occurs on numerous species within the Pooideae subfamily of grasses, however, it is most common on ABG and to a lesser extent on creeping bentgrass (Crouch et al., 2006). Annual bluegrass is one of the most widely distributed turfgrasses

(Huff, 2003), although it is rarely intentionally sown and is commonly considered to be a weed in high maintenance turf areas due to its poor tolerance to abiotic and biotic stresses (Turgeon, 1980; Vargas and Turgeon, 2004). However, the persistence and ability of ABG to provide a high quality, fine textured turf with high shoot density under low mowing makes it a tolerable component of putting green turf (Huff, 2003).

Annual bluegrass is an allotetraploid derived from *Poa infirma* H.B.K., an annual species, and *Poa supina* Schrad., a creeping perennial species (Tutin, 1952). Generally, ABG is considered to have a bunch-type or weakly-stoloniferous growth habit. It is characterized as having a folded vernation, a pointed membranous ligule (0.8 to 3 mm), auricles are absent, and leaf blade tapers slightly to a boat-shaped tip (Turgeon, 1980). Annual bluegrass produces panicle-shaped inflorescences particularly during spring (Turgeon, 1980). Two forms of ABG differing in life cycle and morphology are typically recognized (Huff, 2003). The annual form (*P. annua* f. *annua* L.) survives as a winter annual germinating in the late summer or early autumn, growing vegetatively throughout the winter and producing an inflorescence and seeds in the spring. Once an inflorescence is produced the annual form senesces in early summer (Uva et al., 1997). This form typically possesses an upright, bunch-type growth habit and is a prolific seed producer (Huff, 2003). The alternative form of ABG commonly found in putting green turf is *P. annua* f. *reptans* (Hausskn.) T. Koyama (Huff, 2003). This form is a more desirable turf species due to its more perennial nature, increased tiller density, and weakly-stoloniferous prostrate growth habit (Huff, 2003).

Annual bluegrass possesses only fair tolerance to high temperatures and medium tolerance to low temperatures (Beard, 1973). Poor tolerance to environmental stress limits survival of this turf species either directly or indirectly by predisposing ABG to diseases such as dollar spot, summer patch and anthracnose (Smiley et al., 2005).

Epidemiology

Environmental conditions favoring the development of anthracnose disease are not well understood. Foliar blight and basal rot anthracnose can both occur during high humidity and high summer temperatures (Smiley et al., 2005). Danneberger et al. (1984) monitored temperature and leaf wetness duration for anthracnose foliar blight on ABG and demonstrated that disease severity was influenced strongly by increasing temperatures (18 to 28 C) and more than 18 hr of leaf wetness. Basal rot anthracnose is also observed during cool temperatures and under such conditions is sometimes referred to as winter anthracnose (Smiley et al., 2005). The specific environmental conditions in which C. cereale penetrates its host are currently unknown.

Anthracnose incidence is greater when turf is stressed (Smiley et al., 2005). Numerous sources of stress have been suggested to enhance the incidence and severity of this disease. An early report of an anthracnose epiphytotic of ABG in New Jersey noted that the disease occurred during a period of hot, humid summer weather which was preceded by increased precipitation (Sprague and Evaul, 1930). Anthracnose of ABG in a greenhouse study was also enhanced when grown under drought stress [available soil water levels $< 18\%$ (w/w)] (Danneberger et al., 1995). Poorly draining soils and soils which supply inadequate N, P and K have been suggested to promote disease development (Smiley et al., 2005). Cultural practices which impart stress such as insufficient fertilization, low mowing heights, plant growth regulators and mechanical injury and have also been suggested to increase anthracnose incidence and severity (Dernoeden, 2002; Smiley et al., 2005; Vermeulen, 2003).

CULTURAL MANAGEMENT PRACTICES

Nitrogen Fertilization

Fertilization is a fundamental component of turfgrass management. Nitrogen (N) is required by turfgrasses in the greatest quantity (other than O, H and C) to sustain growth (Turner and Hummel Jr., 1992). Specifically, N is used by the plant to form complex molecules such as chlorophyll, amino acids, proteins, nucleic acids, enzymes and vitamins which maintain essential plant functions (Huber and Thompson, 2007). Supplemental N application is often necessary since most soils do not retain sufficient quantities of this nutrient to meet the needs of growing turfgrasses (Huber and Thompson, 2007).

Recommendations for N fertilization of ABG putting green turf typically ranges from 132 to 308 kg ha^{-1} yr^{-1} (Beard, 2002; Beard et al., 1978; Vargas and Turgeon, 2004). However, N is often applied at less than 147 kg ha^{-1} annually to limit leaf growth and reduce the frictional resistance to ball roll (Radko, 1985a; Zontek, 2004b); conditions perceived to be favorable for putting green playability. Inadequate N fertilization likely results in suboptimum levels of N in plants during the growing season compromising plant function and vigor.

Nitrogen deficient turfgrasses are more susceptible to diseases such as dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and red thread [*Laetisaria fuciformis* (McAlpine)] (Smiley et al., 2005), but the relationship between N and anthracnose is not well understood. In a fungicide efficacy study maintained at two N levels, anthracnose was more severe when an ABG putting green was fertilized at 73 kg N ha^{-1} compared to 122 kg N ha^{-1} annually (Crouch et al., 2003). Similarly, anthracnose basal rot severity of a mixed ABG/creeping bentgrass putting green declined with increasing N rate (4.8, 14.6 and 24.2 kg N ha^{-1}) applied every 14 d (Uddin et al., 2006). Conversely, Danneberger et al. (1983) reported reduced severity of anthracnose foliar blight on an ABG fairway turf with annual N applications of 146 kg ha^{-1} compared to 292 kg ha^{-1}. In the same study, N sources (urea, sulfur coated urea and isobutylidene diurea) did not affect anthracnose severity (Danneberger et al., 1983). However Uddin et al. (2006) observed that isobutylidene diurea applied as an aqueous solution at 4.8 kg N ha^{-1} reduced anthracnose basal rot compared to urea and methylene urea applied in aqueous solution at the same rate.

Plant Growth Regulators

Chemical plant growth regulation has become an integral component of putting green management over the past 15 years (Danneberger, 2003b; Danneberger, 2006; Frabotta, 2008). Plant growth regulators used on turfgrass have been classified according to their respective modes of action (Table 1). However, only mefluidide, ethephon, trinexapac-ethyl, flurprimidol and paclobutrazol are routinely applied to fine turf areas to reduce growth. Paclobutrazol and flurprimidol are typically only used on putting greens comprised primarily of creeping bentgrass. This class of growth regulators appears to have a stronger repressive effect on ABG than creeping bentgrass, thus they are sometimes used to semi-selectively reduce ABG populations and inhibit ABG encroachment into creeping bentgrass putting greens (Beard, 2002; Woosley et al., 2003).

Mefluidide was introduced in 1978 and used primarily to reduce mowing requirements along roadsides (Watschke et al., 1992). The compound is foliarly absorbed and suppresses seedhead development and vegetative growth by inhibiting cell division (Watschke et al., 1992). On ABG putting green turf, mefluidide is applied to suppress spring seedhead formation, thus improving uniformity and smoothness of the playing surface (Danneberger, 2003b). Inhibiting ABG seedhead production with mefluidide favors allocation of carbohydrates to roots (Cooper et al., 1988) and improves root growth (Cooper et al., 1987). However, mefluidide has also been reported to induce a post-inhibition growth enhancement in turf 6 to 10 weeks after treatment (Cooper et al., 1988; Spak et al., 1993). Cooper et al. (1988) observed that carbohydrates levels in leaves, stems and roots of mefluidide treated ABG declined following the post-inhibition growth enhancement. Following mefluidide application a temporary phytotoxic response may occur (Kane and Miller, 2003) which reduces turf quality. The effect of mefluidide on anthracnose severity is unknown; furthermore, other growth regulators are commonly applied to turf previously treated with mefluidide and the influence of these materials and their potential interactions are also unknown.

More recently, ethephon has been used instead of mefluidide to suppress ABG seedheads due to the reduced risk of phytotoxicity associated with this material (Kane and Miller, 2003). A less objectionable yellow-green turf color is not uncommon on ethephon treated turf; however this is typically overcome by mixing with other compounds such as trinexapac-ethyl. Ethephon is applied to turf as (2-chloroethyl)phosphonic acid which is inactive at pH ≤ 4.5; however in the plant it is converted to ethylene (active form) at pH values of 6 to 8 (Biddle et al., 1976). The mechanism involved in ABG seedhead suppression with ethephon is not well understood (Ervin and Zhang, 2008). In addition to seedhead suppression, ethephon has been reported to influence other morphological features. Ethephon applications have been reported to reduce canopy height and increase density of Kentucky bluegrass (*Poa pratensis* L.); although internodes were elongated and crowns were elevated resulting in a "puffy" turf (Dernoeden, 1984). Improved root growth has been reported following spring ethephon application to Kentucky bluegrass at 2.24 kg a.i. ha^{-1} (Christians and Nau, 1984) or ABG at 1000 mg a.i. L^{-1} (Eggens and Wright, 1985). However, increased rates (3.4 to 7.6 kg a.i. ha^{-1}) applied during the summer reduced root growth of perennial ryegrass (*Lolium perenne* L.) (Jiang and Fry, 1998) and creeping bentgrass (McCullough et al., 2006) or had no effect on Kentucky bluegrass (Christians, 1985; Dernoeden, 1984).

Ethylene is an important signaling molecule in plant-pathogen interactions (Ecker and Davis, 1987; Roby et al., 1986). Chitinase (an antifungal metabolite) activity has been positively correlated with increased ethylene production in melon (*Cucumis melo* cv. Cantaloup charentais) in response to elicitors (purified mycelia extract) derived from *Colletotrichum lagenarium*, the causal agent of anthracnose in melon (Roby et al., 1986). Ethylene has also been shown to induce plant defense response genes which enhance lignin synthesis and phytoalexin production in carrot (*Daucus carota* L.) (Ecker and Davis, 1987). Ethephon may induce plant defense compounds in ABG, thus limiting infection of *C. cereale*; however this hypothesis has not been tested.

Trinexapac-ethyl use on putting green turf has become commonplace within the past 15 yr (Danneberger, 2003b; Stewart et al., 2008). It is routinely applied every 7 to 14 d throughout the season to improve vigor and playability of putting greens by reducing vertical shoot growth while increasing stand density and uniformity (Ervin and Koski, 1998; McCullough et al., 2005). Trinexapac-ethyl suppresses shoot elongation by limiting conversion of gibberellic acid-20 (GA_{20}) to the active form GA_1 through inhibition of 3β-hydroxylase activity (Rademacher, 2000). Uptake of trinexapac-ethyl occurs rapidly in leaf sheaths; 80% of the compound was absorbed within an hour of treatment (Fagerness and Penner, 1998b). Turf managers have begun applying trinexapac-ethyl at higher rates (e.g., > 0.05 kg a.i. ha^{-1}) and more frequent application intervals (e.g., every 7 vs. 14 d) than were common for putting green turf only a few years ago (Danneberger, 2006; Foy, 2008). However, little is known about the impact of trinexapac-ethyl applied at increased rates and shorter intervals on turf growth or anthracnose severity.

The influence of trinexapac-ethyl on turfgrass diseases is not well understood. Trinexapac-ethyl has been associated with reduced dollar spot incidence in creeping bentgrass; it was postulated that increased superoxide dismutase activity (Zhang and Schmidt, 2000a) and elevated levels of total non-structural carbohydrates (Golembiewski and Danneberger, 1998) improved turf tolerance to infection. Alternatively, other studies concluded that trinexapac-ethyl had no effect on dollar spot incidence (Burpee et al., 1996; Fidanza et al., 2006; Stewart et al., 2008) or brown patch disease (caused by *Rhizoctonia solani* Kuhn) (Burpee, 1998). Furthermore, Stewart et al. (2008) reported that curative applications of fungicides with trinexapac-ethyl delayed turf recovery from dollar spot damage compared to fungicides alone. Vincelli and Doney (1999) reported that applications of trinexapac-ethyl at 0.050 kg a.i. ha^{-1} every 28-d to creeping bentgrass putting green turf did not affect anthracnose, whereas Crouch et al. (2003) observed that trinexapac-ethyl applied to ABG putting green turf at the same rate every 14 d reduced the severity of this disease compared to non-TE treated turf.

Table 1. Classification of plant growth regulators used on turfgrasses.

Mode of Action	Class	Active Ingredient	Trade Name
late gibberellic acid inhibitor	A	trinexapac-ethyl	Primo MAXX
early gibberellic acid inhibitor	B	flurprimidol	Cutless
	B	paclobutrazol	Trimmit
cell-division inhibitor	C	mefluidide	Embark
herbicides	D	glyphosate	Roundup
	D	sethoxydim	Poast
hormones	E	ethephon	Proxy
	E	indole butyric acid	Kickstand
	E	gibberellic acid	ProGibb
natural sources	F	humic substances	many
	F	seaweed extracts	many

Verticutting

Verticutting is commonly used to reduce irregular shoot growth, puffiness, excessive thatch and non-uniform shoot density of putting green turf with the goal of improving turfgrass quality and increasing ball roll distance (Vargas and Turgeon, 2004). Uddin et al. (2008) reported that verticutting to a 5 mm depth (deep verticutting) increased the severity of anthracnose on a mixed ABG/creeping bentgrass green compared to a 3 mm depth or no verticutting, but the influence of verticutting on the development of this disease in relation to other management practices has yet to be determined.

Mowing

Mowing is a fundamental practice of turfgrass culture required to maintain function of recreational and utility areas (Beard, 1973). It is well known that there is an inverse relationship between mowing height and ball roll distance (BRD)—a common measure of putting green playability (Nikolai, 2005). Annual bluegrass can tolerate routine mowing at heights less than 3.2 mm (Vargas and Turgeon, 2004), although plant stress is often enhanced at lower heights of cut (Fry and Huang, 2004). Putting greens are commonly maintained at or below 3.2 mm (Beard, 2002; Zontek, 2006) and are frequently affected by anthracnose or other biotic and abiotic stresses (Dernoeden, 2002; Vermeulen, 2003). Backman et al. (2002) observed that ABG turf mowed at 3.2 and 3.6 mm had greater anthracnose severity compared to 4.0 mm. Similarly, Uddin et al. (2008) determined that mowing a mixed ABG/creeping bentgrass green at 1.9 mm increased anthracnose severity compared to 3.2 or 4.1 mm. The severity of other diseases such as summer patch (caused by *Magnaporthe poae* Landschoot and Jackson) (Davis and Dernoeden, 1991), melting-out [caused by *Drechslera poae* (Baudys) Shoemaker] (Lukens, 1970), and rust (caused by *Puccinia* spp. and *Uromyces* spp.) (Smiley et al., 2005) are also increased as foliage is removed at lower mowing heights, which are thought to be due in part to depleted carbohydrate production and storage. Although reduced mowing heights can enhance anthracnose severity, the effect of mowing height combined with other management practices (e.g., mowing frequency or rolling) has yet to be determined.

More frequent mowing (five times wk^{-1} vs. once wk^{-1}) has been shown to reduce rooting, carbohydrate reserves and clipping yield of Kentucky bluegrass maintained at 25.4 or 50.8 mm (Juska and Hanson, 1961). However, daily mowing is generally required for putting green turf to maintain playing consistency, density and to avoid scalping (Beard, 1973). It is not uncommon to mow putting green turf multiple times a day (e.g., mowing twice per day), which may increase damage (wounding) to leaf tissues and has been suggested to contribute to increased anthracnose severity (Dernoeden, 2002a; Smiley et al., 2005).

Lightweight Rolling

Lightweight rolling is conducted to smooth and improve uniformity of the turf canopy on putting greens as well as to increase BRD (Hartwiger et al., 2001; Nikolai, 2005). Hartwiger et al. (2001) evaluated rolling frequencies on creeping bentgrass turf growing on sand and gravely sandy loam root zones and found that rolling four or seven times wk^{-1} reduced turf quality of both root zones and increased soil bulk density of the gravely sandy loam compared to no rolling or rolling once wk^{-1}; whereas bulk density of the sand root zone was unaffected. Nikolai et al. (2001) observed that rolling creeping bentgrass turf three times wk^{-1} did not affect turf quality or bulk density of sand mixtures [85:15 (sand: peat v/v); 80:10:10 (sand: soil: peat v/v/v)] or a sandy clay loam compared to non-rolled turf. In the same study, the incidence of dollar spot was reduced and Microdochium patch [caused by *Microdochium nivale* (Fr.) Samuels & I. C. Hallett] increased in turf rolled three times wk^{-1} (Nikolai et al., 2001). The effect of lightweight rolling on anthracnose severity is unknown, but has been suggested to enhance disease severity (Dernoeden, 2002a; Smiley et al., 2005).

Topdressing

Topdressing involves the application of a thin layer of soil to the turf surface; to minimize thatch accumulation, smooth the surface, modify soil and provide winter protection (Beard, 1973). Thatch is a layer of organic matter comprised of dead and living crowns, stolons and/or rhizomes that develops above the soil substrate as turf communities mature (Beard, 1973). Excessive thatch accumulation is detrimental to turf health due to increased disease and insect problems, localized dry spots and decreased environmental stress tolerance (Beard, 1973). Elevation of crowns and roots from the soil substrate is another deleterious effect of thatch accumulation (Ledeboer and Skogley, 1967; Hurto et al., 1980) that results in a soft "spongy" (Anonymous, 1957) surface condition that enhances potential for scalping (Beard, 1973). During the past 30 years sand has become the predominant topdressing media (Cooper and Skogley, 1981). Information regarding the effect of topdressing on turfgrass diseases is limited and inconsistent. It has been suggested that sand accumulation within the turf canopy may wound the crown, providing an entry point for *C. cereale* to infect (Smiley et al., 2005). Reports on dollar spot disease indicate severity increased with monthly topdressing of sandy loam (8 to 10% organic matter) at 1.6 L m^{-2} (Engel and Alderfer, 1967), coarse-sand and loamy coarse-sand applied monthly at 0.9 L m^{-2} to creeping bentgrass maintained at 6.4 mm (Cooper and Skogley, 1981). Whereas, other studies found sand topdressing had no effect on dollar spot development of bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] fairway turf receiving 6.4 L m^{-2} of sand once or twice yr^{-1} (Carrow et al., 1987) or creeping bentgrass greens sand topdressed monthly or biweekly at 0.4 or 0.2 L m^{-2}, respectively (Stier and Hollman, 2003). However, disease was reduced by monthly sand topdressing at 3.6 L m^{-2} to fairway turf (Henderson, 2007). Authors of these reports did not speculate on the effects of topdressing on dollar spot severity.

Topdressing programs for putting green turf vary in application rate and interval. Typically sand is applied at low rates with short intervals or increased rates at extended intervals (Beard, 2002). Previous studies have determined that more frequent topdressing is more effective at reducing thatch depth (Callahan et al., 1998; White and Dickens, 1984) and percent organic matter by weight (Carrow et al., 1987) than sand applied less often. However, labor and equipment maintenance costs of frequent topdressing programs can be prohibitive, thus less frequent applications at higher rates are commonly used. It is not understood whether either of these programs may have a potential to enhance anthracnose severity.

Sand particle shape can range from very angular to well rounded (Beard, 2002). Distinction among sand particle shapes used for topdressing is uncommon since local availability often dictates the material used. Round sands are favored as topdressing material over more angular sand (Green Section Staff, 1977); however it is unclear what factors influenced this recommendation. Angular sands are known to pack to a greater density and have more stability than more rounded sands (Yi et al., 2001), although angular sands may have a greater potential to wound the turf and enhance anthracnose severity than round sands. The effect of sand particle shape on anthracnose disease is currently unknown.

Once applied to the turf surface, topdressing sand typically needs to be incorporated into the canopy. Brushes or drag mats are commonly used for this purpose; however this practice may contribute to wounding, particularly when done excessively. Alternative incorporation methods such as hand watering or vibratory rolling (Foy, 1999) may be less abrasive and possibly minimize anthracnose outbreaks. However, experimental data regarding the effect of sand incorporation methods on anthracnose severity are currently unavailable.

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CHAPTER 1. Anthracnose Severity on Annual Bluegrass Influenced by Nitrogen Fertilization, Growth Regulators, and Verticutting

ABSTRACT

Frequency and severity of anthracnose epiphytotics, caused by *Colletotrichum cereale* (Manns) Crouch, Clarke, and Hillman, on annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hauskins) T. Koyama] putting greens have increased over the past decade. This 3 yr field study evaluated the impact of nitrogen (N) fertilization (4.9 kg ha^{-1} every 7- or 28-d), mefluidide (ME; 0 and 0.106 kg a.i. ha^{-1} yr^{-1}) {N-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl] amino] phenyl] acetamide}, trinexapac-ethyl (TE; 0 and 0.050 kg a.i. ha^{-1} every 14-d) [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethylester], verticutting (VC; 0- and 3-mm depth every 14-d) and interactions of these factors on anthracnose of ABG mowed at 3.2 mm. N fertilization frequency had the greatest influence on disease throughout the study; N applied at 4.9 kg ha^{-1} every 7-d reduced damage 5 to 24% compared to a 28-d interval. The plant growth regulators, ME and TE, frequently interacted during the last 2 years of the study; sequential application of ME and TE reduced disease 6 to 14% compared to plots that only received one of these plant growth regulators. At advanced stages of disease, the combination of 7-d N fertilization and ME and TE application had the greatest disease reduction. VC had little effect on anthracnose severity.

INTRODUCTION

Anthracnose is a destructive fungal disease of turfgrasses throughout the United States, Canada, and Western Europe (Smiley et al., 2005; Smith et al., 1989), and is particularly severe on ABG. Crouch et al. (2006) recently redesignated the pathogen causing anthracnose on turfgrasses as *C. cereale* [formerly *C. graminicola* (Ces.) G.W. Wils.]. Two phases of the disease are commonly recognized; a foliar blight which typically occurs during high summer temperatures, and a basal rot which can occur at anytime of year. Symptoms of both phases initially appear on affected leaf blades as six to 12 mm zones of chlorotic tissue that later develop acervuli and melanized setae. Basal rot is further characterized by a necrotic, water-soaked or black rot of crown tissue concealed beneath outer leaf sheaths (Smiley et al., 2005).

The frequency and severity of anthracnose epiphytotics on golf course putting greens have increased over the past decade (Dernoeden, 2002b; Landschoot and Hoyland, 1995a; Mann and Newell, 2005b; Wong and Midland, 2004). Although the reason for this increase is not fully understood, changes in management practices (e.g., lower mowing height and low N fertility) to increase ball roll distance may be partly responsible (Vermeulen, 2003a; Zontek, 2004a). Research documenting the effect of specific factors and potential interactions between management practices on the incidence and severity of anthracnose on ABG turf is limited.

On putting greens, N is often applied at less than 147 kg ha^{-1} annually to limit leaf growth and reduce the frictional resistance to ball roll (Radko, 1985b; Zontek, 2004a). This may result in less than optimum levels of N in plants during the growing season since recommendations for N fertilization of ABG putting greens typically ranges from

132 to 308 kg ha^{-1} yr^{-1} (Beard, 2002; Beard et al., 1978; Vargas and Turgeon, 2004). Turf maintained below optimal N levels can result in enhanced severity of diseases such as dollar spot (*Sclerotinia homoeocarpa* F.T. Bennett) and red thread [*Laetisaria fuciformis* (McAlpine)] (Smiley et al., 2005), but the relationship between N and anthracnose is not well understood. In a fungicide efficacy study maintained at two N levels, anthracnose was more severe when an ABG putting green was fertilized at 73 kg N ha^{-1} compared to 122 kg N ha^{-1} annually (Crouch et al., 2003). Conversely, Danneberger et al. (1983) reported reduced severity of anthracnose foliar blight on an ABG fairway turf with annual N applications of 146 kg ha^{-1} compared to 292 kg ha^{-1}.

Chemical plant growth regulation has become an integral component of putting green management (Danneberger, 2003a). Mefluidide is applied to suppress seedhead formation in ABG putting green turf, which improves uniformity and smoothness of the playing surface. Reducing seedheads with ME re-allocates carbohydrates to roots (Cooper, et al. 1988) thus improving the vigor of ABG and possibly reducing its susceptibility to anthracnose. Trinexapac-ethyl can also improve the vigor and playability of putting greens by reducing vertical shoot growth and increasing stand density and uniformity (Ervin and Koski, 1998; McCullough et al., 2005). Vincelli and Doney (1999) reported that applications of TE at 0.050 kg a.i. ha^{-1} every 28-d to creeping bentgrass (*Agrostis stolonifera* L.) putting green turf did not affect anthracnose, whereas Crouch et al. (2003) observed that TE applied to ABG putting green turf at the same rate every 14-d reduced the severity of this disease.

Verticutting is commonly used to reduce irregular shoot growth, puffiness, excessive thatch and non-uniform shoot density of putting green turf with the goal of improving turfgrass quality and increasing ball roll distance (Vargas and Turgeon, 2004). Uddin and Soika (2003) reported that VC to a 5 mm depth increased the severity of anthracnose on a mixed ABG/creeping bentgrass green compared to a 3 mm depth or no verticutting, but the influence of VC on the development of this disease in relation to other management practices has yet to be determined.

Thus, research is needed to expand upon the limited understanding of the influence of management factors on anthracnose disease. The objectives of this field study were to evaluate the impact of N fertilization, growth regulation (i.e., ME and TE), VC, and the potential interactions of these factors on anthracnose of ABG putting green turf.

MATERIALS AND METHODS

A three-year field study was initiated in 2003 on an ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 5.9 in North Brunswick, NJ. A previous stand of ABG turf was established from the soil seed bank as well as seed introduced in 1992 from soil cores collected from putting greens at the Rutgers Golf Course in Piscataway, NJ. Creeping bentgrass was eliminated from half of the experimental site with glyphosate [N-(phosphonomethyl) glycine] at 3.2 kg a.i. ha^{-1} on 22 August 2001, and the remaining half on 8 August 2002 with the same product and rate. A monostand of ABG was allowed to re-establish in each area from the soil seed bank in September 2001 and 2002. Turf was mown 10 to 14 times wk^{-1} with a triplex greens mower (models 3000-04350 and 3150-04357, Toro Co., Bloomington, MN) at a bench setting of 3.2 mm. When N treatments were not imposed, N was applied uniformly to the field totaling 24.5 kg ha^{-1} from March to April 2003, 44.9 kg ha^{-1} from October to November 2003, 43 kg ha^{-1} from March to April 2004, 21 kg ha^{-1} from October to November 2004, and 40 kg ha^{-1} April 2005. Water soluble forms of N were used for these fertilizations, except on 29 March 2003 when 15.6 kg ha^{-1} of N was applied as isobutylidine diurea. Phosphorous and potassium were applied based on soil test results at 19.5 and 37.1 kg ha^{-1} in 2003, 4.9 and 112.4 kg ha^{-1} in 2004 and 4.4 and 8.3 kg ha^{-1} in 2005, respectively. Silica sand topdressing was applied to the entire study at 88.7 cm^3 m^{-2} and incorporated with a cocoa mat drag (Ace Equipment and Supply Co., Henderson, CO) every 14-d after VC treatment. Turf was irrigated as needed to prevent wilt stress. Dollar spot disease was preventatively controlled from May through October each year with vinclozolin [3-(3, 5-dichlorophenyl)-5-ethenyl-5-methyl-2, 4-

oxazolidinedione] at 1.5 to 2.1 kg a.i. ha^{-1} or boscalid {3-pyridinecarboxamide, 2-chloro-N-[4'-chloro(1,1'-biphenyl)-2-yl]} at 0.4 kg a.i. ha^{-1}. Flutolanil {N-[3-(1-methylethoxy) phenyl]-2-[trifluoromethyl] benzamide} at 3.2 to 6.4 kg a.i. ha^{-1} was used to suppress brown patch (*Rhizoctonia solani* Kuhn) every 14-d from June through August each year. These fungicides were previously found to provide no suppression of anthracnose on ABG greens in New Jersey (Towers et al., 2002b). Annual bluegrass weevils [*Listronotus maculicollis* (Dietz)] were controlled with applications of chlorpyrifos [O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] at 2.3 kg a.i. ha^{-1} on 30 May 2004, bendiocarb (2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate) at 2.3 kg a.i. ha^{-1} on 12 May 2005 and bifenthrin {[2-methyl(1,1'-biphenyl)-3-yl]methyl 3-[2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} at 0.11 kg a.i. ha^{-1} on 28 June 2005. At the conclusion of each year, anthracnose development was arrested to allow for recovery of plots over the fall and winter; chlorothalonil (tetrachloroisophthalonitrile) was applied at 10.1 kg a.i. ha^{-1} on 8 August, 22 September and 7 November 2003; 18.3 kg a.i. ha^{-1} and 9.5 kg a.i. ha^{-1} on 15 and 27 September 2004, respectively; and 13.4 kg a.i. ha^{-1} on 18 August and 7 and 18 September 2005.

Treatment Design

The study used a 2 x 2 x 2 x 2 factorial arranged in a randomized complete block design with four replications. Treatments were repeated in the same locations each year. Factors included N fertilization, ME, TE, and VC. N treatments were 4.9 kg ha^{-1} of N sprayed as an NH_4NO_3 solution every 7- or 28-d from 12 May to 22 September 2003, 7 May to 9 October 2004, and 21 May to 3 August 2005. The entire experimental area was lightly irrigated immediately after N applications. Total N applied during the 7- and 28-d fertilization treatments was 107.5 and 29.3 kg ha^{-1} in 2003, 117.3 and 24.4 kg ha^{-1} in 2004, and 58.6 and 14.7 kg ha^{-1} in 2005, respectively. ME levels were either none or a split application of ME at 0.053 kg a.i. ha^{-1} on 14 and 28 April 2003, 7 and 21 April 2004, and 6 and 20 April 2005. TE levels were either none or TE applied at 0.050 kg a.i. ha^{-1} every 14-d. TE applications on non-ME treated plots were made from 14 April to 16 September 2003, 7 April to 22 September 2004, and 6 April to 10 August 2005. When TE was applied to turf previously treated with ME, the initial TE application dates were 12 May 2003, 21 April 2004 and 20 April 2005. VC levels were either none or VC (model VC-5, Hahn Eclipse & Co., Evansville, IN) to a 3 mm depth (actual) with 1 mm wide blades spaced 13 mm apart every 14-d from 30 May to 7 August 2003, 11 May to 25 August 2004, and 28 May to 5 August 2005. N and plant growth regulators (PGRs) were applied with an operator propelled spray boom outfitted with flat-fan VS8003 nozzles (Spray Systems Co., Wheaton, IL.) calibrated to deliver 408 L ha^{-1} at 269 kPa.

Field Inoculation Procedures

Prior to the initiation of the study, two of the blocks had been used for a previous study and were inoculated with *C. cereale* isolate ValP-04 (obtained from an ABG putting green at the Valentine Research Center, State College, PA) on 24, 25 and 26 July 2002. The remaining two blocks were inoculated on 7, 8 and 9 July 2003 with the same isolate to ensure uniform disease development across the site. *C. cereale* was grown on full strength potato dextrose agar (Difco, Sparks, MD) at 25^{o}C for 20 days under fluorescent light (46.3 to 87.3 µE s^{-1} m^{2}). Conidia were harvested with tap water and diluted to 50,000 conidia mL^{-1} with a hemacytometer (Hausser Scientific, Horsham, PA) using a solution containing 2.4 g potato dextrose broth (Difco, Sparks, MD) per liter of inoculum. The site was lightly irrigated to wet the foliage prior to inoculation. The conidial suspension was applied through a backpack sprayer (model 475, Solo, Newport News, VA) at 814.8 L ha^{-1}. The inoculum was applied between 1800 and 2000 hr for three consecutive evenings when the minimum air temperature was $\geq 21^{o}C$ and relative humidity $\geq 90\%$. The field was covered each night with polyethylene sheets (152 μm thick) to maintain leaf wetness and encourage conidial germination. Sheets were removed by 0900 hr the day after each inoculation. *C. cereale* was reisolated from symptomatic tissue in 2002 and 2003 5- and 18-d post inoculation, respectively.

Data Collection and Analysis

Anthracnose severity was periodically assessed from June through August each year as the percent turf area infested with *C. cereale*. This was accomplished by using a line-intercept grid count method similar to that of Gaussoin and Branham (1989) that produced 546 observations over 3.6 m^2 $plot^{-1}$. The number of observations of symptomatic leaf tissue was then transformed to a percent turf area infested using the formula: (n / 546) x 100; where n was the number of intersections observed over symptomatic leaf tissue. Seedhead expression was assessed from May through June or July each year when changes in seedheads were apparent by visually estimating the percent plot area containing seedheads. Turf quality was visually rated on a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from June through August each year. Disease severity and seedhead expression were taken into consideration when assessing turf quality.

All data were subjected to analysis of variance using the General Linear Model procedure in the Statistical Analysis System software v. 8.2 (SAS Institute Inc., Cary, NC, 1999). Means of main effects were considered significantly different based on an *F* test (at the 0.05 probability level) and interaction means were separated by Fisher's protected least significant difference at the 0.05 probability level. The amount of variation attributable to ANOVA sources (factors) was determined by analysis of the sum of squares.

RESULTS

Anthracnose Severity

Anthracnose developed on 5 June 2003 as a natural infestation on the two blocks inoculated in 2002; disease appeared on the remaining two blocks on 25 July 2003, 18 days after inoculation. Symptoms developed naturally on 11 June 2004 and 7 June 2005 without additional inoculation. Results of disease severity throughout this paper are discussed in terms of actual (absolute) differences in the percent turf area infested with *C. cereale*.

Main Effects

The N fertilization main effect had the greatest influence on anthracnose severity in all three years, accounting for 50 to 64% of the experimental variation in 2003, 33 to 77% in 2004, and 64 to 87% in 2005 (data not shown). N applied every 7-d at 4.9 kg ha^{-1} reduced disease severity 5 to 24% on 12 out of 13 observation dates during the three year study compared to the same rate applied every 28-d (Tables 1, 2 and 3).

ME treated plots had 7 and 9% increased disease severity at the onset of the epidemic on 18 and 30 June 2003, respectively, than non-ME treated turf; but ME had no effect on disease through the remainder of the season (Table 1). Similarly, ME plots had 2% greater disease severity on 11 June 2004 compared to non-ME treated plots; however ME treatment sustained 3 to 6% less severe disease on 20 June, 17 and 30 August 2004 (Table 2). Turf treated with ME reduced disease severity 3 to 6% on all observation dates in 2005 (Table 3).

TE treatment did not affect anthracnose at the onset of the disease in 2003 or 2004, but reduced disease severity 8% later in the season on 25 July 2003 and 7 to 13%

from 19 July to 30 August 2004 compared to non-TE treated turf (Tables 1 and 2). The main effect of TE was not significant in 2005 (Table 3). The VC main effect did not influence disease severity during the study (Tables 1, 2 and 3).

Interaction Effects

The ME x TE interaction was significant on seven of nine dates during 2004 and 2005 (Tables 2 and 3). ME slightly increased disease severity 3% on 11 June 2004 in the absence of TE, whereas ME treatment did not increase disease severity on plots receiving sequential TE applications (Table 4). On all other dates with this interaction, ME had no effect on disease severity when TE was not applied; whereas ME reduced disease severity 6 to 9% on plots that received treatment with TE (Table 4). This interaction also indicated that TE application on plots treated with ME reduced disease severity 11 to 14% on 19 July and 17 August 2004; whereas, TE applied to non-ME plots increased disease severity 3 to 4% on two dates (21 June and 6 July) in 2005 (Table 4).

N fertilization interacted with ME on 7 June 2005 (Table 3) and indicated that ME reduced disease severity only in turf that received 28-d N fertilization (Table 5). By the later stage of the epidemics on 30 August 2004 and 30 July 2005, N fertilization interacted with both ME and TE (Tables 2 & 3). A consistent PGR effect was found only on turf plots receiving the 7-d N fertilization, where the combination of ME and TE reduced disease severity compared to either PGR used alone. Also, disease severity on turf treated with either PGR alone was not different from non-PGR treated plots (Table 6).

Verticutting was involved in a four-way interaction on 30 June 2003 (Table 1) that accounted for 5% of the total variation (data not shown). Verticutting did not affect disease severity on plots that received 7-d N fertilization regardless of growth regulation treatment (Table 7). However, under 28-d N fertilization, verticutting reduced disease severity 30% on non-regulated turf, increased disease severity 16% and 22% on ME and TE treated plots, respectively, and had no effect on turf regulated by both ME and TE.

Seedhead Production

Main Effects

Mefluidide had the greatest influence on seedhead production in each year of the study, resulting in 4 to 52% fewer seedheads from 12 May to 2 July 2003, 35 to 36% fewer seedheads from 4 May to 20 May 2004 and 15% less seedheads on 13 May 2005 compared to non-ME treated turf (Table 8). However, seedheads were 5% greater in ME treated than non-ME treated plots on 8 June 2004 and 4% greater on 13 June 2005 (Table 8).

Seedhead production was unaffected by N fertilization in 2003 (Table 8); however, 28-d N fertilization resulted in 5 to 6% more seedheads from 4 to 20 May 2004 (Table 8). 7-d N fertilization had 2% more seedheads on 13 and 28 June 2005 when seedhead production was very low (2 to 19%) (Table 8).

TE reduced the initial appearance of seedheads only once in three years (i.e., 4 May 2004) (Table 8). However, TE treatment consistently delayed the disappearance of seedheads from turf as evidenced by greater seedhead expression later in the growing season (e.g., 5% more seedheads on 2 July 2003, 3% more on 8 June 2004, and 1 to 3% more from 13 to 28 June 2005) (Table 8). Verticutting resulted in 1 to 4% fewer seedheads on 9 June 2003, 20 May and 8 June 2004 and 28 June 2005 (Table 8) under moderate to low seedhead expression.

Interaction Effects

A ME x TE interaction was observed on four of nine dates over the three year study (Table 8). ME reduced seedheads regardless of TE treatment, except on 13 June 2005 when seedhead expression was waning and relatively low. On this date, neither ME nor TE used alone affected seedhead expression; however, seedhead expression was greater on plots treated with both ME and TE compared to either PGR used alone (Table 9). The TE effect was inconsistent across these interaction dates indicating that seedhead expression was either greater, lower or not different with TE application in the presence or absence of ME.

A N x ME interaction was observed during peak seedhead production on 12 May 2003 (Table 8). N fertilization did not affect seedhead expression in the absence of ME; however, 7-d N fertilization increased seedhead expression of turf treated with ME (Table 10).

Turf Quality

Main Effects

N applied every 7-d improved turf quality compared to 28-d applications of N on each assessment date during the three year study (Table 11). N fertilization every 7-d maintained acceptable, albeit sometimes marginal, turf quality (i.e., ≥ 5, on a 1 to 9 scale) for all evaluation dates. In comparison, plots fertilized every 28-d only exhibited acceptable quality early in 2003 and 2005 when disease pressure was low. Quality differences between the two N treatments were most pronounced when disease was severe. Mefluidide treatment improved turf quality throughout the study except on 28 July 2003 when ME had no effect (Tables 11). TE enhanced quality of turf on all rating dates in 2003 (Table 11), 17 June and 26 August 2004 and 21 July 2005, but slightly reduced turf quality on 6 June 2005 (Table 11). The VC main effect generally did not influence turf quality, except when VC reduced quality on 28 July 2003 (Table 11).

Interaction Effects

An interaction between ME and TE was evident during July of each year and June 2005 (Table 11). The interaction during July of each year indicated that applications of PGRs alone did not improve turf quality; whereas the combined application of ME and TE enhanced turf quality compared to either PGR used alone (Table 12). On 6 June 2005, TE reduced turf quality on plots not previously treated with ME; this was primarily due to increased seedhead expression in TE treated plots (Table 9); and ME increased turf quality regardless of the TE level. The combined application of ME and TE was better than TE but not ME on 28 June 2005 (Table 12).

Other statistically significant interactions influencing turf quality were occasionally observed over the three year study (Table 11). On 2 July 2003, the TE x VC interaction indicated that TE treatment only improved turfgrass quality in the absence of VC (Table 13). A three-way interaction of ME, TE and VC on 26 August 2004 when disease damage was severe indicated that VC did not affect turf quality of plots treated with ME regardless of TE level (Table 14). However, in the absence of ME, VC reduced quality of turf not treated with TE and increased turf quality on plots treated with TE. The N x TE interaction on 21 July 2005 indicated that TE improved quality only when applied to turf that received 7-d N fertilization (Table 15).

DISCUSSION

Low rate N fertilization every 7-d had the greatest reduction in anthracnose severity throughout this study; increasing N by 14.7 kg ha^{-1} month^{-1} during the summer reduced severity 0.25- to 0.73-fold. While increased N has been associated with reduced anthracnose severity on turfgrass (Vargas et al., 1977; Backman et al., 2002; Crouch et al., 2004; Inguagiato et al., 2005; Uddin, 2006), this is the first peer reviewed report of increased N minimizing the severity of this disease. Similarly, stalk rot of maize (*Zea mays* L.), caused by *C. graminicola*, has been reported to be reduced by increased N fertility throughout the season (White et al., 1978). Plant growth and maintenance requires relatively large amounts of N and N deficiency can inhibit growth, decrease photosynthesis (Huber and Thompson, 2007) and reduce tolerance to environmental stress (Orcutt and Nilsen, 2000), potentially increasing susceptibility to stress related diseases such as anthracnose (Smiley et al., 2005). Specific mechanisms associated with reduced anthracnose severity in plants with greater N fertility are currently unknown, although increased plant vigor has been proposed (White et al., 1978; Huber et al., 1987; Krupinsky and Tanka, 2001).

Danneberger et al. (1983) found that over-stimulating ABG fairway turf with N can enhance disease development; N applied at 292 kg ha^{-1} yr^{-1} increased anthracnose foliar blight compared to 146 kg ha^{-1} yr^{-1}. When evaluating the effect of annual N fertility programs on anthracnose severity, Danneberger et al. (1983) observed greater disease when most N was applied during April and May rather than November regardless of total annual N applied. Rapid foliar growth induced by excessive spring N fertilization can deplete carbohydrate reserves, which would be exacerbated by low net photosynthesis during summer stress (Liu and Huang, 2001). Thus, our study indicates that frequent low rate soluble-N fertilization during the middle of the growing season can dramatically reduce anthracnose severity on putting greens. And the work of Danneberger et al. (1983) on anthracnose foliar blight suggests that the annual N fertilization rate should be moderate (146 kg ha^{-1} yr^{-1}) and a greater proportion of the annual N fertilizer should be applied in autumn versus spring to reduce disease severity on fairways; however, this approach needs to be evaluated for anthracnose basal rot under putting green conditions.

The effect of N on seedhead production varied over the course of this three year study. Other studies have reported similar results; increased N fertilization has been found to increase (Chin et al., 1978; Green et al., 2001) and decrease (Beard et al., 1978) seedheads of ABG. In the current study, both N fertility programs provided acceptable turf quality before the onset of disease although turf fertilized every 7-d was observed to have better quality. However, when anthracnose was active, only turf fertilized every 7-d maintained acceptable quality, albeit greatly reduced; whereas the quality of turf fertilized every 28-d was typically unacceptable due to increased disease severity.

Chemical growth regulation generally improved turfgrass quality throughout the study, but the greatest benefits (i.e., reduced seedheads, better turf quality and reduced anthracnose) occurred when ME and TE were used together. Inhibition of ear development in maize increased carbohydrates within stalk pith tissue and eliminated the occurrence of stalk rot symptoms compared to plants with maturing ears, suggesting that the redistribution of photosynthate enhanced resistance to this disease (Mortimore and Ward, 1964). Salzman et al. (1998) identified carbohydrates in *Vitis labruscana* L. cv

Concord which act as sensor molecules inducing pathogenisis related proteins that reduced growth of *Botrytis cinerea* Pers.:Fr. and *Guignardia bidwellii* (Ellis) Viala & Ravaz *in vitro*. Such compounds could be produced in ABG when *C. cereale* is attempting to gain ingress, however, this hypothesis has yet to be tested. Ong and Marshall (1975) found that assimilate redistribution to ABG roots increased when developing seedheads were physically removed compared to where seedheads were allowed to mature. Mefluidide limits seedhead production of ABG (Danneberger et al., 1987) and it provided the greatest control of seedheads in our study. Several studies have shown that application of ME re-allocates photosynthate away from shoots and seedheads to root and crown tissues (Cooper et al., 1987; Cooper et al., 1988; Hanson and Branham, 1987). Since tolerance to summer stress has been associated with increased root depth and number (Bonos and Murphy, 1999; Xu and Huang, 2001), the re-allocation of photosynthate to roots and crowns may improve ABG turf vigor and reduce anthracnose severity.

TE application can also improve physiological characteristics that could enhance plant vigor including increased chlorophyll content (Ervin and Koski, 2001b; McCann and Huang, 2007; Qian and Engelke, 1999; Zhang and Schmidt, 2000b). A loss of photosynthetic capacity through defoliation of maize increases stalk rot incidence (Mortimore and Ward, 1964; Dodd, 1980). PGRs such as TE and ME induce morphological changes in turfgrasses including reduced elongation of internodes (Ervin and Koski, 1998; Ervin and Koski, 2001a; Lickfeldt et al., 2001) that result in a slower growing, more compact turf, which would increase the proportion of the leaf blade remaining after mowing. Since leaf blades have greater photosynthetic efficiency than sheaths (Thorne, 1959), stress associated with routine low mowing would be reduced and photosynthetic capacity increased with the use of TE. Thus, it is possible that the combined use of ME and TE in our study improved physiological and morphological characteristics of the turf (reduced stress) thereby reducing susceptibility to anthracnose, a disease that is known to be more severe on stressed turf (Smiley et al., 2005).

Disease severity initially increased on plots treated with ME 8 to 10 weeks after treatment (WAT) in 2003 and 2004. A post-inhibition growth enhancement (PIGE) has been observed in turf 6 to 10 WAT with ME (Cooper et al., 1988; Spak et al., 1993). Additionally, seedhead expression increased just before disease development 7 to 8 WAT with ME in 2004 and 2005. Therefore, a brief period of greater seedhead development along with PIGE could deplete carbohydrates just before summer stress and predispose turf to anthracnose. Interestingly, turf that received ME and sequential applications of TE during this post-inhibition period in 2004 and 2005 did not exhibit an increase in disease. Thus, TE applications subsequent to ME treatments presumably minimized PIGE, conserved carbohydrate reserves and reduced anthracnose. Vincelli and Doney (1999) observed that TE alone applied every 28-d did not affect anthracnose on creeping bentgrass putting green turf; results from the current study generally support this conclusion although TE alone applied at shorter intervals (i.e., 14-d) to ABG putting green turf occasionally increased or decreased disease severity. Interactions involving N and ME indicate that more frequent (7-d) N fertilization reduced anthracnose severity and negated any effect of ME on disease. However, at later stages of the epidemics, the greatest reduction in disease occurred on plots treated with ME and sequential applications of TE under the 7-d N fertilization schedule.

TE increased disease severity on non-ME treated turf in late June and early July 2005. Previous research has shown that the duration and extent of growth suppression with TE is reduced as temperatures increase (Beasley et al., 2007; Lickfeldt et al., 2001). In our study, temperatures were greater during early June 2005 than the previous two years, which may have reduced TE growth suppression and increased anthracnose. Increased seedheads observed in TE treated turf likely resulted from reduced elongation of the flowering culm, thus preventing their removal with routine mowing. Once seedheads subsided, TE generally improved turf quality or had no effect.

Anthracnose severity has been reputed to be enhanced by wounding of host plant tissue (Landschoot and Hoyland, 1995; Dernoeden, 2002; Smiley et al., 2005). Contrary to this perception, VC to a shallow depth (3.0 mm) did not have a substantial effect on anthracnose severity in our study. Infection studies with *Colletotrichum* in ABG and maize have demonstrated that wounds are not required for host penetration (Bruehl and Dickson, 1950; Smith, 1954; Vernard and Vaillancourt, 2007). However, Uddin and Soika (2003) reported VC to a 5 mm depth increased anthracnose in ABG. Verticutting in our study was shallow (3-mm), did not remove organic matter from the thatch layer, and only cut leaf blades. Thus, VC at depths great enough to cut crowns and stolons (severe wounding) or remove thatch may enhance plant stress and increase anthracnose, whereas VC to groom (light vertical mowing) the leaf canopy had little effect on disease. Routine shallow VC every two weeks also had little effect on turf quality, but was marginally effective at reducing seedheads. Assimilate redistribution to ABG roots when developing seedheads were physically removed (Ong and Marshall, 1975) may explain the observed reduction of anthracnose by VC under 28-d N fertilization on one date in

2003. More frequent VC, or use of equipment with closer spacing of vertical blades, would likely improve the effectiveness of mechanically reducing seedheads but it is not known what effect this would have on anthracnose.

CONCLUSIONS

Management of ABG putting green turf with soluble N applied every 7-d at a low rate (4.9 kg ha^{-1}) from late spring through summer provided the most consistent reduction in anthracnose severity. The growth regulators ME and TE used in combination to suppress seedheads and vegetative growth also reduced the severity of anthracnose on ABG putting green turf, but not as consistently as weekly low rate N fertilization. At advanced stages of disease, the combination of 7-d N fertilization and ME and TE application provided the greatest reduction in disease severity. Use of ME or TE alone had infrequent and inconsistent effects on anthracnose, but should not greatly aggravate disease severity. Shallow VC of the upper leaf canopy (grooming) every two weeks during the growing season had little effect on anthracnose severity.

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Table 1. Anthracnose disease response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003.

	Turf Area Infested			
Main Effects	18 June	30 June	25 July	22 August
	------------------------------	%	--------------------------	
Nitrogen (N) †				
28 d	14.2	36.8	49.9	39.8
7 d	5.7	12.8	31.4	35.9
Mefluidide (ME) ‡				
0	6.6	20.4	41.6	39.3
0.106 kg a.i. ha^{-1}	13.3	29.3	39.8	36.4
Trinexapac-ethyl (TE) §				
0	10.3	26.4	44.5	39.0
0.050 kg a.i. ha^{-1}	9.6	23.4	36.8	36.7
Verticutting (VC) ¶				
0	11.1	25.1	39.9	34.4
3.0 mm	8.8	24.6	41.5	41.3
	ANOVA			
Source of variation				
N	***	***	***	NS
ME	**	***	NS	NS
TE	NS	NS	***	NS
VC	NS	NS	NS	NS
N x ME	NS	NS	NS	NS
N x TE	NS	NS	NS	NS
N x VC	NS	*	NS	NS
ME x TE	NS	NS	NS	NS
ME x VC	NS	*	NS	NS
TE x VC	NS	**	NS	NS
N x ME x TE	NS	NS	NS	NS
N x ME x VC	NS	*	NS	NS
N x TE x VC	NS	*	NS	NS
ME x TE x VC	NS	***	NS	NS
N x ME x TE x VC	NS	**	NS	NS
CV, %	52.9	19.0	13.2	32.4

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 September 2003.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 April 2003.

§ Trinexapac-ethyl was applied every 14-d from 14 April (or 12 May if previously treated with ME) to 16 September 2003.

¶ Verticutting was conducted every 14-d from 30 May to 7 August 2003.

Table 2. Anthracnose disease response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2004.

	Turf Area Infested				
Main Effects	11 June	20 June	19 July	17 Aug.	30 Aug.
	------------------------------------ % ---------------------------------				
Nitrogen (N) †					
28-d	9.0	14.6	34.3	40.0	56.0
7-d	3.6	9.2	16.4	27.2	41.8
Mefluidide (ME) ‡					
0	5.4	13.5	27.2	35.7	52.1
0.106 kg a.i. ha^{-1}	7.2	10.2	23.6	31.5	45.7
Trinexapac-ethyl (TE) §					
0	6.5	11.8	28.7	38.0	55.3
0.050 kg a.i. ha^{-1}	6.1	11.9	22.0	29.1	42.4
Verticutting (VC) ¶					
0	6.3	11.5	25.1	34.5	50.0
3.0 mm	6.3	12.2	25.6	32.7	48.0
		ANOVA			
Source of variation					
N	***	***	***	***	***
ME	**	**	NS	**	***
TE	NS	NS	**	***	***
VC	NS	NS	NS	NS	NS
N x ME	NS	NS	NS	NS	NS
N x TE	NS	NS	NS	NS	NS
N x VC	NS	NS	NS	NS	NS
ME x TE	*	**	*	**	NS
ME x VC	NS	NS	NS	NS	NS
TE x VC	NS	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	NS	***
N x ME x VC	NS	NS	NS	NS	NS
N x TE x VC	NS	NS	NS	NS	NS
ME x TE x VC	NS	NS	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS	NS
CV, %	45.1	34.7	34.6	18.4	13.7

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 7 May to 9 Oct. 2004.
‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 7 and 21 Apr. 2004.
§ Trinexapac-ethyl was applied every 14 d from 7 Apr. (or 21 Apr. if previously treated with ME) to 22 Sept. 2004.
¶ Verticutting was conducted every 14 d from 11 May to 25 Aug. 2004.

Table 3. Anthracnose disease response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005.

	Turf Area Infested			
Main Effects	7 June	21 June	6 July	30 July
	---------------------- % ----------------------			
Nitrogen (N) †				
28-d	7.7	9.7	19.5	84.7
7-d	2.6	3.9	5.2	62.2
Mefluidide (ME) ‡				
0	6.7	8.5	14.2	76.4
0.106 kg a.i. ha^{-1}	3.6	5.2	10.5	70.5
Trinexapac-ethyl (TE) §				
0	5.0	6.3	12.1	75.6
0.050 kg a.i. ha^{-1}	5.3	7.3	12.6	71.3
Verticutting (VC) ¶				
0	5.4	6.6	12.1	71.5
3.0 mm	4.9	7.0	12.6	75.4
	ANOVA			
Source of variation				
N	***	***	***	***
ME	***	***	**	*
TE	NS	NS	NS	NS
VC	NS	NS	NS	NS
N x ME	*	NS	NS	NS
N x TE	NS	NS	NS	**
N x VC	NS	NS	NS	NS
ME x TE	NS	*	*	*
ME x VC	NS	NS	NS	NS
TE x VC	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	**
N x ME x VC	NS	NS	NS	NS
N x TE x VC	NS	NS	NS	NS
ME x TE x VC	NS	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS
CV, %	57.9	47.5	44.0	12.8

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 21 May to 3 Aug. 2005.
‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 6 and 20 Apr. 2005.
§ Trinexapac-ethyl was applied every 14-d from 6 Apr. (or 20 Apr. if previously treated with ME) to 10 Aug. 2005.
¶ Verticutting was conducted every 14-d from 28 May to 5 Aug. 2005.

Table 4. Anthracnose disease response to mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2004 and 2005.

		Turf Area Infested					
		2004				2005	
Mefluidide†	Trinexapac-ethyl‡	11 June	20 June	19 July	17 Aug.	21 June	6 July
kg a.i. ha^{-1}	kg a.i. ha^{-1}	%					
0	0	4.8	12.2	28.3	37.7	6.9	12.2
0	0.050	6.0	14.7	26.1	33.7	10.1	16.1
0.106	0	8.2	11.5	29.2	38.4	5.7	12.0
0.106	0.050	6.2	9.0	17.9	24.5	4.6	9.1
LSD		*2.02*	*2.93*	*6.26*	*4.40*	*2.30*	*3.87*

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 7 and 21 Apr. 2004 and 6 and 20 Apr. 2005.

‡ Trinexapac-ethyl was applied every 14-d from 7 Apr. to 22 Sept. 2004 and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 21 Apr. in 2004 and 20 Apr. in 2005.

Table 5. Anthracnose disease response to N fertilization and mefluidide application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005.

		Turf Area Infested
Nitrogen†	Mefluidide‡	7 June 2005
interval (d)	kg a.i. ha^{-1}	%
28	0	10.1
28	0.106	5.3
7	0	3.4
7	0.106	1.8
LSD		*2.12*

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 21 May to 3 Aug. 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 6 and 20 Apr. 2005.

Table 6. Anthracnose disease response to N fertilization, mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2004 and 2005.

			Turf Area Infested	
			2004	2005
Nitrogen†	Mefluidide‡	Trinexapac-ethyl§	30 Aug.	30 July
interval (d)	kg a.i. ha^{-1}	kg a.i. ha^{-1}	---------------- %	----------------
28	0	0	65.0	84.9
28	0	0.050	51.3	86.5
28	0.106	0	57.4	82.0
28	0.106	0.050	50.3	85.3
7	0	0	48.9	66.6
7	0	0.050	43.0	67.6
7	0.106	0	50.0	69.0
7	0.106	0.050	25.1	45.9
	LSD		*6.77*	*9.45*

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 7 May to 9 Oct. 2004 and 21 May to 3 Aug. 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 7 and 21 Apr. 2004 and 6 and 20 Apr. 2005.

§ Trinexapac-ethyl was applied every 14-d from 7 Apr. to 22 Sept. 2004 and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 21 Apr. in 2004 and 20 Apr. in 2005.

Table 7. Anthracnose disease response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003.

Nitrogen†	Mefluidide‡	Trinexapac-ethyl§	Verticutting¶	Turf Area Infested 30 June 2003
interval (d)	kg a.i. ha^{-1}	kg a.i. ha^{-1}	depth (mm)	%
28	0	0	0	45.0
28	0	0	3.0	15.0
28	0	0.050	0	21.0
28	0	0.050	3.0	42.5
28	0.106	0	0	36.5
28	0.106	0	3.0	52.0
28	0.106	0.050	0	38.0
28	0.106	0.050	3.0	45.5
7	0	0	0	16.0
7	0	0	3.0	8.5
7	0	0.050	0	8.0
7	0	0.050	3.0	7.5
7	0.106	0	0	21.5
7	0.106	0	3.0	16.5
7	0.106	0.050	0	15.0
7	0.106	0.050	3.0	9.5
		LSD		*11.20*

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 Sept. 2003.
‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003.
§ Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept.2003. Initial TE application was delayed on turf previously treated with ME until 12 May 2003.
¶ Verticutting was conducted every 14-d from 30 May to 7 Aug. 2003.

Table 8. Seedhead response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

	Seedhead Expression								
	2003			2004			2005		
Main Effects	12 May	9 June	2 July	4 May	20 May	8 June	13 May	13 June	28 June
	%								
Nitrogen (N) †									
28-d	56.4	24.5	9.8	73.2	37.0	30.9	74.8	16.9	2.4
7-d	59.7	27.2	10.3	68.3	30.8	31.1	75.3	18.9	4.5
Mefluidide (ME) ‡									
0	84.1	32.7	11.8	88.3	51.8	28.6	82.8	15.9	3.6
0.106 kg a.i. ha^{-1}	32.0	19.1	8.3	53.1	15.9	33.4	67.4	19.8	3.3
Trinexapac-ethyl (TE) §									
0	57.8	27.0	7.4	74.8	34.2	29.4	73.9	16.3	2.8
0.050 kg a.i. ha^{-1}	58.3	24.7	12.7	66.7	33.6	32.7	76.3	19.5	4.1
Verticutting (VC) ¶									
0	57.0	27.7	10.9	70.3	35.5	32.2	75.3	18.4	4.1
3.0 mm	59.1	24.1	9.2	71.2	32.3	29.8	74.9	17.3	2.8
				ANOVA					
Source of variation									
N	NS	NS	NS	*	***	NS	NS	**	***
ME	***	***	***	***	***	***	***	***	NS
TE	NS	NS	***	***	NS	**	NS	***	***
VC	NS	*	NS	NS	*	**	NS	NS	***
N x ME	*	NS	NS	NS	NS	NS	NS	NS	NS
N x TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME x TE	NS	***	NS	NS	**	NS	**	**	NS
ME x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x ME x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME x TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	17.2	21.3	35.1	11.5	18.1	12.2	8.1	15.4	40.5

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 Sept. 2003, 7 May to 9 Oct. 2004, and 21 May to 3 Aug. 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003, 7 and 21 Apr. 2004, and 6 and 20 Apr. 2005.

§ Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept. 2003, 7 April to 22 Sept. 2004, and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 Apr. in 2004, and 20 Apr. 2005.

¶ Verticutting was conducted every 14-d from 30 May to 7 Aug. 2003, 11 May to 25 Aug. 2004 and 28 May to 5 Aug. 2005.

Table 9. Seedhead response to mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

		Seedhead Expression			
		2003	2004	2005	
Mefluidide†	Trinexapac-ethyl‡	9 June	20 May	13 May	13 June
kg a.i. ha^{-1}	kg a.i. ha^{-1}	--------------------------- % ---------------------------			
0	0	33.3	49.7	79.4	15.3
0	0.050	33.8	54.1	86.1	16.6
0.106	0	23.1	18.8	68.4	17.2
0.106	0.050	15.0	13.1	66.4	22.5
LSD		*4.60*	*4.30*	*4.30*	*2.00*

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003, 7 and 21 Apr. 2004, and 6 and 20 Apr. 2005.

‡ Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept. 2003, 7 Apr. to 22 Sept. 2004, and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 Apr. in 2004, and 20 Apr. in 2005.

Table 10. Seedhead response to N fertilization and mefluidide application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003.

		Seedhead Expression
Nitrogen†	Mefluidide‡	12 May 2003
interval(d)	kg a.i. ha^{-1}	%
28	0	85.0
28	0.106	27.8
7	0	83.1
7	0.106	36.3
LSD		*8.40*

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 Sept.2003.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003.

Table 11. Turf quality response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

	Turf Quality								
	2003			2004			2005		
Main Effect	9 June	2 July	28 July	17 June	2 July	26 Aug.	6 June	28 June	21 July
	---------- 1-9; 9= best ----------								
Nitrogen (N) †									
28-d	5.5	4.3	2.3	4.9	4.8	3.7	5.3	4.5	3.6
7-d	7.0	6.9	5.4	7.2	7.1	5.3	6.4	7.3	6.6
Mefluidide (ME) ‡									
0	5.6	5.4	3.7	5.7	5.5	4.1	5.2	5.4	4.8
0.106 kg a.i. ha^{-1}	6.8	5.9	4.0	6.4	6.4	4.5	6.6	6.3	5.4
Trinexapac-ethyl (TE) §									
0	5.6	5.2	3.1	5.8	5.8	3.8	6.1	5.9	4.7
0.050 kg a.i. ha^{-1}	6.8	6.1	4.6	6.3	6.1	5.2	5.7	5.9	5.5
Verticutting (VC) ¶									
0	6.1	5.6	4.2	6.0	5.8	4.5	6.0	6.0	5.1
3.0 mm	6.3	5.7	3.5	6.1	6.0	4.5	5.8	5.8	5.1
				ANOVA					
Source of variation									
N	***	***	***	***	***	***	***	***	***
ME	***	**	NS	***	***	***	***	***	**
TE	***	***	***	*	NS	***	**	NS	***
VC	NS	NS	**	NS	NS	NS	NS	NS	NS
N x ME	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x TE	NS	NS	NS	NS	NS	NS	NS	NS	*
N x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME x TE	NS	*	NS	NS	**	NS	***	*	*
ME x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
TE x VC	NS	*	NS	NS	NS	**	NS	NS	NS
N x ME x TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x ME x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N x TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME x TE x VC	NS	NS	NS	NS	NS	*	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	10.3	10.6	21.5	13.2	17.4	16.9	10.0	15.5	16.1

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 Sept. 2003, 7 May to 9 Oct. 2004, and 21 May to 3 Aug. 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003, 7 and 21 Apr. 2004, and 6 and 20 Apr. 2005.

§ Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept. 2003, 7 Apr. to 22 Sept. 2004, and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 Apr. in 2004, and 20 Apr. in 2005.

¶ Verticutting was conducted every 14-d from 30 May to 7 Aug. 2003, 11 May to 25 Aug. 2004, and 28 May to 5 Aug. 2005.

Table 12. Turf quality response to mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

		Turf Quality				
		2003	2004	2005		
Mefluidide†	Trinexapac-ethyl‡	2 July	2 July	6 June	28 June	21 July
kg a.i. ha^{-1}	kg a.i. ha^{-1}	------------------------- 1-9; 9= best -------------------------				
0	0	5.1	5.8	5.6	5.7	4.6
0	0.050	5.6	5.3	4.7	5.2	4.9
0.106	0	5.3	5.9	6.5	6.1	4.8
0.106	0.050	6.5	6.9	6.7	6.6	6.1
LSD		*0.50*	*0.74*	*0.42*	*0.65*	*0.59*

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 Apr. 2003, 7 and 21 Apr. 2004, and 6 and 20 Apr. 2005.

‡ Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept. 2003, 7 Apr. to 22 Sept. 2004, and 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 Apr. in 2004, and 20 Apr. in 2005.

Table 13. Turf quality response to trinexapac-ethyl application and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003.

		Turf Quality
Trinexapac-ethyl†	Verticutting‡	2 July 2003
kg a.i. ha^{-1}	depth (mm)	1-9; 9= best
0	0	4.9
0	3.0	5.4
0.050	0	6.2
0.050	3.0	5.9
LSD		*0.50*

† Trinexapac-ethyl was applied every 14-d from 14 Apr. to 16 Sept.2003. Initial TE application was delayed on turf previously treated with ME until 12 May 2003.

‡ Verticutting was conducted every 14-d from 30 May to 7 Aug. 2003.

Table 14. Turf quality response to mefluidide, trinexapac-ethyl and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2004.

			Turf Quality
Mefluidide†	Trinexapac-ethyl‡	Verticutting§	26 August 2004
kg a.i. ha^{-1}	kg a.i. ha^{-1}	depth (mm)	1-9; 9= best
0	0	0	4.0
0	0	3.0	3.1
0	0.050	0	4.1
0	0.050	3.0	5.1
0.106	0	0	4.0
0.106	0	3.0	3.9
0.106	0.050	0	5.8
0.106	0.050	3.0	5.9
	LSD		*0.76*

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 7 and 21 Apr. 2004.
‡ Trinexapac-ethyl was applied every 14-d from 7 Apr. to 22 Sept.2004. Initial TE application was delayed on turf previously treated with ME until 21 Apr. 2004.
§ Verticutting was conducted every 14-d from 11 May to 25 Aug. 2004.

Table 15. Turf quality response to N fertilization and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005.

		Turf Quality
Nitrogen†	Trinexapac-ethyl‡	21 July 2005
interval (d)	kg a.i. ha^{-1}	1-9; 9= best
28	0	3.4
28	0.050	3.8
7	0	5.9
7	0.050	7.2
LSD		*0.59*

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 21 May to 3 Aug. 2005.
‡ Trinexapac-ethyl was applied every 14-d from 6 Apr. to 10 Aug. 2005. Initial TE application was delayed on turf previously treated with ME until 20 Apr. 2005.

CHAPTER 2. Anthracnose Disease and Annual Bluegrass Putting Green Performance Affected by Mowing Practices and Lightweight Rolling

ABSTRACT

Anthracnose (*Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman) has been a devastating disease on annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] putting green turf over the past 15 years. The objectives of this two year field trial on ABG were to evaluate the impact of mowing height (2.8, 3.2 and 3.6 mm), mowing frequency (seven and 14 times wk^{-1}), lightweight rolling (none and every other day) and possible interactions of those factors on anthracnose severity and golf ball roll distance (BRD). Mowing height had the greatest effect on anthracnose. Mowing at 2.8 mm increased disease severity 3 to 21% compared to 3.6 mm, while 3.2 mm was intermediate to higher and lower heights. Mowing frequency had little effect on anthracnose; although mowing 14 times wk^{-1} occasionally reduced disease severity 1 to 14% compared to seven times wk^{-1}. Rolling every other day also occasionally reduced disease severity 5 to 6% under moderate disease pressure. Mowing at 2.8 mm generally provided the greatest BRD. However, similar or greater BRD were achieved at 3.2 and 3.6 mm using combinations of increased mowing frequency and/or rolling compared to mowing at 2.8 mm seven times wk^{-1} without rolling. Thus, anthracnose severity on ABG greens can be reduced by raising the mowing height as little as 0.4 mm, and BRD ($\geq$ 2.9 to 3.2 m) can be maintained by increasing mowing frequency and/or rolling without increasing disease severity.

INTRODUCTION

Anthracnose (caused by *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman) is a destructive fungal disease of annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] (Crouch et al., 2006) throughout Australia, Canada, the United States, and Western Europe (Peart, 2007; Smiley et al., 2005; Smith et al., 1989). Anthracnose epiphytotics on golf course putting greens have increased in frequency and severity during the past 15 years (Dernoeden, 2002a; Landschoot and Hoyland, 1995b; Wong and Midland, 2004). Reasons for this increase are not fully understood; however, changes in turf management practices (e.g., lower mowing height, increased mowing frequency, lightweight rolling) to enhance playability may be partly responsible (Vermeulen, 2003b; Zontek, 2004b). Research documenting the effect of specific factors and potential interactions between management practices on the incidence and severity of anthracnose on ABG turf is limited (Inguagiato et al., 2008a).

Mowing is a fundamental practice of turfgrass culture required to maintain function (Beard, 1973). It is well known that there is an inverse relationship between mowing height and ball roll distance (BRD)—a common measure of putting green playability (Nikolai, 2005). Annual bluegrass can tolerate routine mowing at heights less than 3.2 mm (Vargas and Turgeon, 2004) although plant stress is often enhanced at lower heights of cut (Fry and Huang, 2004). Putting greens are commonly maintained at or below 3.2 mm (Beard, 2002; Zontek, 2006) and are frequently affected by anthracnose or other biotic and abiotic stresses (Dernoeden, 2002a; Vermeulen, 2003b). Backman et al. (2002) observed that ABG turf mowed at 3.2 and 3.6 mm had greater anthracnose severity compared to 4.0 mm. Similarly, Uddin and Soika (2003) determined that mowing a mixed ABG/creeping bentgrass (*Agrostis stolonifera* L.) green at 1.9 mm increased anthracnose severity compared to 3.2 or 4.1 mm. The severity of other diseases such as summer patch (caused by *Magnaporthe poae* Landschoot and Jackson) (Davis and Dernoeden, 1991), melting-out [caused by *Drechslera poae* (Baudys) Shoemaker] (Lukens, 1970), and rust (caused by *Puccinia* spp. and *Uromyces* spp.) (Smiley et al., 2005) are also increased as foliage is removed at lower mowing heights, thought to be due in part to depleted carbohydrate production and storage. Although reduced mowing heights can enhance anthracnose severity, the effect of mowing height combined with other management practices (e.g., mowing frequency or rolling) has yet to be determined.

More frequent mowing (five times wk^{-1} vs. once wk^{-1}) has been shown to reduce rooting, carbohydrate reserves and clipping yield of Kentucky bluegrass (*Poa pratensis* L.) maintained at 25.4 or 50.8 mm (Juska and Hanson, 1961). However, daily mowing is generally required for putting green turf to maintain playing consistency, density and to avoid scalping (Beard, 1973). It is not uncommon to mow putting green turf multiple times a day (e.g., mowing twice per day), which may increase damage (wounding) to leaf tissues and has been suggested to contribute to increased anthracnose severity (Dernoeden, 2002a; Smiley et al., 2005).

Lightweight rolling is conducted to smooth and improve uniformity of the turf canopy on putting greens as well as to increase BRD (Hartwiger et al., 2001; Nikolai, 2005). Hartwiger et al. (2001) evaluated rolling frequencies on creeping bentgrass turf growing on sand and gravely sandy loam root zones and found that rolling four or seven times wk^{-1} reduced turf quality of both root zones and increased soil bulk density of the gravely sandy loam compared to no rolling or rolling once wk^{-1}; whereas bulk density of the sand root zone was unaffected. Nikolai et al. (2001) observed that rolling creeping bentgrass turf three times wk^{-1} did not affect turf quality or bulk density of sand mixtures [85:15 (sand: peat v/v); 80:10:10 (sand: soil: peat v/v/v)] or a sandy clay loam compared to non-rolled turf. In the same study, the incidence of dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Bennett) was reduced and Microdochium patch [caused by *Microdochium nivale* (Fr.) Samuels & I. C. Hallett] increased in turf rolled three times wk^{-1} (Nikolai et al., 2001). The effect of lightweight rolling on anthracnose severity is unknown, but has been suggested to enhance disease severity (Dernoeden, 2002a; Smiley et al., 2005).

Thus, the objectives of this field trial were to evaluate the impact of mowing height, mowing frequency, lightweight rolling and the potential interactions of these factors on anthracnose severity, BRD and turf quality of ABG maintained as a putting green.

MATERIALS AND METHODS

A two-year field trial was initiated in 2004 on 33-month-old ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 5.4 in North Brunswick, NJ. A monostand of ABG turf was established in September 2002 using seed indigenous to the site and ABG introduced in 1998 from Plainfield Country Club, Plainfield, NJ (Samaranayake et al., 2008). A 3.2 mm mowing height was achieved by September 2003. The site was inoculated with *C. cereale* isolate HFIIA using 20,000 conidia mL^{-1} on 2 Aug. 2004 to ensure uniform symptom development throughout the trial. Inoculum was prepared, harvested and applied to ABG turf in the field using the procedures described by Inguagiato et al. (2008a). *Colletotrichum cereale* was reisolated from symptomatic tissue to confirm presence of the pathogen in 2004 five days after inoculation.

When treatments were not imposed, turf was mowed seven times wk^{-1} with a triplex greens mower (models 3000-04350 and 3150-04357, Toro Co. Bloomington, MN) at a bench setting of 3.2 mm. Nitrogen (water soluble sources) was applied to the trial 19 times from March to November 2004 totaling 173 kg ha^{-1} and 11 times from March to August 2005 totaling 78.2 kg ha^{-1}. Phosphorous and potassium were applied based on soil test results at 17.1 and 136 kg ha^{-1} in 2004 and 10.8 and 20.5 kg ha^{-1} in 2005 as elemental P and K, respectively. The trial was topdressed at 88.7 cm^3 m^{-2} every 14 d from May to September with sub-angular silica sand conforming to the particle size distribution recommended for sand root zones (Staff, 2004). Sand was incorporated immediately after topdressing with a cocoa mat drag (Ace Equipment and Supply Co., Henderson, CO). Irrigation was applied only when wilt stress was evident and to wash-in fertilizer to maintain relatively dry soil conditions. Trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethylester] was applied at 0.05 kg a.i. ha^{-1} every 14 d from 28 Apr. to 22 Sept. 2004 and 26 May to 19 Oct. 2005 to mimic growth regulation practices employed on golf course putting greens. Anthracnose was suppressed in May and June 2004 with chlorothalonil (tetrachloroisophthalonitrile) at 8.1 to 10.1 kg a.i. ha^{-1} and in May 2005 at 12.9 to 13.3 kg a.i. ha^{-1} to permit collection of early-season BRD data on turf undamaged by this disease. The anthracnose epidemic was arrested between trial years with the application of chlorothalonil at 9.5 kg a.i. ha^{-1} on 27 Sept. 2004 to allow plots to recover. Diseases other than anthracnose and various insects were controlled throughout the season. Fungicides utilized for disease control were selected based on previous research showing that they were not effective against the anthracnose pathogen (Inguagiato et al. 2008).

Treatment Design

The trial used a 3 x 2 x 2 factorial arranged in a split-split plot design with four replications. The main plot (4.6 by 7.1 m) factor was mowing height, the subplot (4.6 by 3.0 m) factor was mowing frequency, and the sub-subplot (4.6 by 1.5 m) factor was lightweight rolling. Levels of each factor were randomly assigned within respective experimental units and repeated in the same location each year. Mowing height treatments were bench settings of 2.8, 3.2 or 3.6 mm on a walk-behind mower (model 220B, Deere & Company, Moline, IL) equipped with a grooved front roller (model AMT2979, Deere & Company, Moline, IL). The effective height of cut for this mower was less than the triplex mower used before treatments were imposed; therefore mowing height for the 2.8- and 3.2-mm treatments was reduced gradually over a two to three week period prior to 24 May each year. The 3.6-mm treatment was similar to the pre-existing height of turf mowed with the triplex mower. Mowing frequency treatments consisted of mowing seven or 14 times wk^{-1} (i.e., once or twice daily). Mowing treatments were performed between 0800 and 0930 hr each day through 16 Oct. 2004 and 17 Aug. 2005. Lightweight rolling levels were either none or one pass every other day with a triplex attached vibratory roller (model UR3T, Turfline, Inc., Moscow Hills, MO) immediately after mowing from 24 May to 16 Oct. 2004 and 25 May to 17 Aug. 2005.

Data Collection and Analysis

Anthracnose severity was assessed from August to September 2004 and June through August 2005 as the percent turf area infested with *C. cereale* using a line-intercept grid count method Inguagiato et al., (2008a). Ball roll distance was determined between 1030 and 1500 hr one to three times wk^{-1} in June and July each year before the turf area infested with anthracnose exceeded 5%. Three golf balls were released from a Stimpmeter (Staff, 1996) in two opposing directions within each plot, and the average of these six ball rolls determined BRD. Soil bulk density was measured monthly from July to September 2004 and June to August 2005 at three *in situ* locations per plot using a surface moisture-density gauge (model 3411-B; Troxler Electronic Laboratories, Research Triangle Park, NC) in the backscatter mode. Turf quality was visually rated on a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from June through August each year. Turf quality ratings took into account plant density, uniformity, color, disease severity and algal growth on the turf/soil surface. Algal growth was visually estimated using a 1 to 9 scale (where 9 represented no algae; 8=2 to 5%; 7=5 to 10%; 6=10 to 20%; 5=20 to 35%; 4=35 to 50%; 3=50 to 65%; 2=65 to 80%; 1=80 to 100% of the turf/soil surface covered with algae) on 25 July 2005.

All data were subjected to analysis of variance to identify significant ($p \leq 0.05$) treatment effects using the General Linear Model procedure for a split-split plot design in the Statistical Analysis System software v. 8.2 (SAS Institute Inc., Cary, NC). Means of main effects and significant interactions were separated by Fisher's protected least significant difference test at the 0.05 probability level or lower using the appropriate formulae described by Gomez and Gomez (1984). Frequency distributions of BRDs measured for each treatment combination throughout the study were generated to evaluate treatment effects. Each treatment was compared to turf mowed at 2.8 mm seven times wk^{-1} with no rolling; a low cost (i.e., time, labor and equipment) regiment that consistently produced BRD in the current trial similar to those sought by the industry (2.9 to 3.2 m [Niven, 2008]). These comparisons were made by pooled *t*-tests ($\alpha = 0.05$) or the Satterthwaite approximation (Steel et al., 1997a); methods which compare means of samples with equal or unequal variances, respectively.

RESULTS AND DISCUSSION

Anthracnose Severity

Chlorotic leaves, black rotted crown tissue, acervuli and fusiform conidia consistent with anthracnose basal rot were apparent by 29 July 2004 and, after the field was inoculated on 2 August, the disease gradually increased in severity to a moderate level (45 to 62%) in mid-September (Table 1). Disease developed earlier in 2005 (15 June) as a natural infestation and progressed slowly before dramatically increasing to severe levels (79 to 92%) by 16 Aug. 2005 during favorable conditions for disease development in mid-July and August.

Main factors represented the majority of treatment effects observed throughout this two-yr trial. However, limited significant interactions did occur; presentation of these data are provided to indicate subtle treatment effects observed on individual dates.

Mowing Height

Mowing height had the most pronounced effect on anthracnose throughout the study; frequently (63% of observations) increasing disease severity at lower heights. Mowing at 2.8 mm increased disease severity 3 to 17% and 13 to 21% compared to 3.6 mm in 2004 and 2005, respectively (Table 1). Turf mowed at 3.2 mm had 8 to 10% less disease than mowing at 2.8 mm, but 11% more disease than mowing at 3.6 mm on 19 July 2005 and 5 to 9% more disease on the last observation date of each season (Table 1). Previous reports also indicated that lower mowing heights increase anthracnose severity (Backman et al., 2002; Uddin and Soika, 2003); however, these studies evaluated much greater incremental differences in mowing height (Uddin and Soika, 2003) or a greater mowing height range (Backman et al., 2002). Data from our trial indicates that relatively small increases in mowing height (0.4 mm) at low heights (2.8 and 3.2 mm) can reduce anthracnose severity. Anthracnose is believed to be more severe on weakened or stressed turf (Smiley et al., 2005). Routine mowing, particularly at reduced heights, can stress plants by removing photosynthetic tissue and severing protective cuticular layers (Beard, 1973). Defoliation of the upper nodes of maize (*Zea mays* L.) plants has been reported to reduce total sugars within pith tissues and increase anthracnose severity [caused by *C. graminicola* (Ces.) G.W. Wils.], due at least in part to reduced photosynthetic capacity (Mortimore and Ward, 1964). Similarly, Kentucky bluegrass maintained at lower mowing heights (i.e., greater defoliation) reduces carbohydrates and enhances summer patch (Davis and Dernoeden, 1991) and melting-out diseases (Lukens, 1970). Lower mowing heights can also reduce rooting (Beard and Daniel, 1966; Juska and Hanson, 1961; Liu and Huang, 2002) and tolerance of turfgrasses to environmental stress (Beard and Daniel, 1966). Although not measured in our trial, it is possible that carbohydrates and rooting were enhanced at increased mowing heights, thus reducing plant stress and improving tolerance to anthracnose.

Mowing Frequency

The mowing frequency main effect or its interaction with mowing height affected anthracnose severity on 3 of 4 dates in 2004 and no dates in 2005 (Table 1). Mowing turf 14 times wk^{-1} decreased disease severity 1 and 14% compared to mowing seven times wk^{-1} on 2 Aug. and 15 Sept. 2004, on plots mowed at 3.2 mm (Table 2). Mowing 14 times wk^{-1} at 3.2 or 3.6 mm reduced disease compared to 2.8 mm on these same dates. When mowed 7 times wk^{-1}, mowing height had no effect on 2 Aug., but on 15 Sept., less disease was observed in plots mowed at 3.6 mm compared to plots mowed at 2.8 or 3.2

mm (Table 2). Mowing 14 times wk^{-1} reduced disease 9% compared to mowing seven times wk^{-1} across all heights on 23 Aug. 2004 (Table 1).

Limiting mowing frequency has been recommended to reduce anthracnose severity because it was thought to minimize wounding stress (Dernoeden, 2002a; Smiley et al., 2005). Conversely, data from the current trial indicates that increased mowing frequency had no negative effect on anthracnose, occasionally reducing disease, particularly in turf mowed at 3.2 mm. Frequent mowing of turf is necessary at low mowing heights to increase shoot density (Madison, 1962) and avoid scalping damage (Beard, 1973). Thus, frequent mowing may enhance the plants tolerance to a low mowing height (e.g., 3.2 mm) and reduce the tendency for scalping injury; thereby minimizing stress and occasionally reducing anthracnose severity. It should be noted that, in practice, increased mowing frequency would increase traffic along the perimeter of putting greens due to turning of equipment; however, any effect of increased equipment traffic on anthracnose severity is currently unknown.

Lightweight Rolling

Rolling every other day slightly reduced anthracnose severity (5 to 6%) under moderate disease pressure during 2004 and 2005 (Table 1). Rolling also produced a very small reduction (1%) in anthracnose when disease severity was low on 2 Aug. 2004, but had no effect under similar conditions in 2005. Moreover, rolling had no effect during severe disease pressure (79 to 92%) on the last rating date in 2005 (Table 1). Admittedly, the reduction in anthracnose severity in our trial caused by rolling was subtle and would probably be difficult to perceive on the golf course. More importantly, however, these data indicate that rolling does not enhance disease severity as previously suggested

(Dernoeden, 2002a; Smiley et al., 2005). Rolling has been shown to reduce dollar spot disease on creeping bentgrass greens (Nikolai et al., 2001). Dispersion of dew and gutation water (Nikolai et al., 2001), enhancement of phytoalexin production and increased surface water holding capacity have been proposed as possible reasons for reduced dollar spot incidence although the actual mechanism(s) remains unknown (Nikolai, 2005). Furthermore, routine rolling can produce a more prostrate turf canopy and limit the gradual elevation of plant crowns at the thatch/soil surface during the growing season (Beard, 2002); these effects could reduce the amount of leaf blade and leaf sheath tissue removed or damaged at low mowing heights. This could also enhance photosynthetic capacity since the youngest leaf blades, which would be most often removed by mowing, are the most photosynthetically active (Youngner, 1969). Additionally, maintaining the position of crowns lower in the mat layer may reduce plant exposure to high temperature stress since temperatures are often greatest just below the surface of dense, short-mowed turf (Beard, 1973). It should be noted that the mowing frequency effect in the current trial may be related to the effect caused by rolling since the large, drive roller of our walk-behind mower effectively rolled the turf as it was being mowed.

Ball Roll Distance

Mowing Height

As expected, lower mowing height increased BRD on 67% of measurement dates in 2004 and 100% of the dates in 2005 (Tables 3 and 4). The 2.8-mm mowing height increased BRD 0.13 to 0.25 m and 0.15 to 0.24 m compared to 3.2 mm in 2004 and 2005, respectively, and increased BRD 0.15 to 0.40 m and 0.18 to 0.43 m compared to 3.6 mm in 2004 and 2005, respectively (Tables 3 and 4).

Mowing Frequency

Mowing 14 times wk^{-1} increased BRD compared to seven times wk^{-1} on every observation date of the trial (Tables 3 and 4); differences in BRD ranged from 0.17 to 0.42 m and 0.32 to 0.41 m in 2004 and 2005, respectively. This increase in BRD caused by mowing twice daily (14 times wk^{-1}) was similar or greater than those resulting from lowering the mowing height from 3.6 to 2.8 mm. However, more frequent mowing did not increase, and in some cases decreased disease severity, whereas lowering the mowing height increased severity as much as 21%.

Lightweight Rolling

Rolling every other day did not affect BRD as consistently or to the same extent as lowering the mowing height or increasing the mowing frequency (Tables 3 and 4). However, rolling did increase BRD 0.09 to 0.22 m in 2004 and 0.06 to 0.12 m in 2005 without increasing and in some cases decreasing disease severity. Increased BRD associated with rolling in our trial was less than has previously been reported (Hartwiger et al., 2001; Nikolai et al., 2001) although different types of rollers were used in each study. Nikolai (2004) evaluated lightweight rollers which imparted varying degrees of surface pressure and observed that the type of roller attached to a triplex (similar to the one used in our trial) enhanced BRD less than roller types with greater rolling pressures. Moreover, these previous studies evaluated rolling effects on creeping bentgrass which has a more prostrate growth habit; thus the effect of rolling on ABG in our trial may also have differed due to its more erect growth habit.

The limited interactions observed in the current trial influencing BRD indicated that there were conditions, albeit infrequent, when one management practice tended to offset the effect of another practice. The interaction between mowing frequency and rolling on 15 and 19 July 2004 and 28 June 2005 (Tables 3 and 4) indicated that rolling increased BRD of turf mowed seven times wk^{-1} but had no effect on turf mowed 14 times wk^{-1}; although rolling increased BRD at both mowing frequencies 19 July (Table 5). Mowing 14 times wk^{-1} increased BRD regardless of rolling except on turf rolled every other day on 15 and 19 July. Other factors interacted to influence BRD on a few observation dates; however treatment differences were inconsistent among dates and considered as random effects (data not shown).

Preferred BRD for daily play ranges from 2.9 to 3.2 m for putting greens in the northeastern United States (Niven, 2008). Mowing heights of less than 3.2 mm are commonly used in the golf industry to achieve desired BRD; turf mowed at 2.8 mm seven times wk^{-1} without rolling (least labor intensive treatment) produced a BRD between 2.9 and 3.2 m 64% of the time (or ≥ 2.9 m 82% of the time) (Table 6). Similarly, plots mowed 14 times wk^{-1}, or turf rolled every other day, regardless of mowing height, produced BRDs at or above the 2.9 to 3.2 m range 73 to 100% of the time (Table 6). Pooled *t*-tests indicated that turf mowed at 2.8 and 3.2 mm 14 times wk^{-1} with or without rolling, and turf mowed at 3.6 mm 14 times wk^{-1} and rolled every other day had a 0.2 to 0.4 m greater mean BRD than mowing at 2.8 mm seven times wk^{-1} without rolling (Table 6). Mowing at 3.2 mm seven times wk^{-1} with or without rolling, and mowing at 3.6 mm 14 times wk^{-1} without rolling or seven times wk^{-1} with rolling produced a mean BRD similar ($p > 0.05$) to turf mowed at 2.8 mm seven times wk^{-1} without rolling. Only turf mowed at 3.6 mm seven times wk^{-1} without rolling resulted in a mean BRD less (0.2 m) than that achieved on turf mowed at 2.8 mm seven times wk^{-1} without rolling. Although the mean BRD of turf mowed at 3.2 mm seven times wk^{-1} without rolling was not different from that of turf mowed at 2.8 mm seven times wk^{-1} without rolling, the relatively large frequency of observations (36%) where BRD was in the 2.6 to 2.9 m range would probably be undesirable. These data indicate that a BRD between 2.9 and 3.2 m or greater can be achieved at higher mowing heights (i.e., 3.2 and 3.6 mm) by increasing daily mowing frequency and/or rolling every other day, practices that did not enhance and in some cases reduced anthracnose severity.

Turf Quality

Turf quality was acceptable (≥ 5) for all treatment factors in the study during June and July each year; however quality became unacceptable for all factors in August as disease severity increased (Table 7). Prior to the initiation of disease in July 2004, turf quality was highest at the 2.8- and 3.2-mm mowing heights due to increased turf density (a component of quality in our observations) (Table 7). However, in August 2004 and July 2005, quality was reduced at the 2.8-mm mowing height compared to 3.2 and 3.6 mm because disease severity was greater at this height of cut. Mowing frequency did not affect turf quality in our trial, and rolling slightly improved quality in August 2004 and July 2005 compared to non-rolled turf (Table 7) because rolling reduced disease and improved turf density and uniformity.

Algae was evident in plots on 25 July 2005 when turf quality (i.e., density) was reduced due to disease. Algal cover was generally greater at 2.8-mm compared to 3.2- or 3.6-mm mowing heights (data not shown).

Soil Bulk Density

Soil bulk density ranged from 1.25 to 1.42 Mg m^{-3} during the study (data not shown) and was affected more often by mowing frequency than mowing height or rolling. Mowing 14 times wk^{-1} subtly increased soil bulk density (2%) compared to mowing seven times wk^{-1} on four of six dates during the trial (data not shown). However, this increase in soil bulk density did not appear to be associated with turf performance; turf quality (Table 7) and disease severity (Table 1) were unaffected by mowing frequency when differences in soil bulk density were observed. It is probable that increased soil bulk density would probably be ameliorated by routine hollow tine cultivation (Murphy et al., 1992). This is supported by the overall reduction in soil bulk density (0.12 Mg m^{-3}) from 13 Sept. 2004 to 6 June 2005 caused by one hollow tine cultivation treatment on 25 Oct. 2004. Additionally, freeze-thaw cycles in cool temperate climates could also reduce surface bulk density (Hartwiger et al., 2001; McNitt and Landschoot, 2003).

CONCLUSIONS

As expected, increasing mowing height can reduce anthracnose severity and a relatively small increase (0.4 mm bench setting) in mowing height can reduce disease severity by as much as 11%. However, contrary to expectations, increasing mowing frequency (i.e., mowing twice per day) did not increase and occasionally reduced anthracnose severity and rolling provided a subtle reduction in disease severity under moderate disease pressure. These effects of mowing twice per day and rolling are notable to turf managers challenged with providing acceptable playability (BRD) without increasing anthracnose severity. Mowing twice per day was as effective at increasing BRD as lowering the mowing height from 3.6 to 2.8 mm, and rolling also increased BRD. Thus, anthracnose severity on ABG putting greens can be reduced by raising the mowing height as little as 0.4 mm, yet playability (BRD of 2.9 to 3.2 m or greater) can be maintained by adjustments in other management practices such as increasing mowing frequency and/or rolling without increasing (in some cases reducing) anthracnose severity. These data do not suggest that commercially acceptable control of anthracnose disease should be expected by increasing mowing height, mowing frequency or rolling in the absence of an effective fungicide program. However, a comprehensive management program integrating these practices with moderate N fertility may reduce the quantity and/or application interval of fungicides required to provide commercially acceptable disease control. Increased mowing frequency and rolling may increase surface soil bulk density of putting green turf; however, this did not affect turf performance (turf quality or anthracnose severity) and should be manageable with routine sand topdressing and hollow tine cultivation, and in cool temperate climates, by freezing and thawing during winter months.

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Table 1. Anthracnose disease severity response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004				2005			
Main effects	2 Aug.	11 Aug.	23 Aug.	15 Sept.	17 June	1 July	19 July	16 Aug.
	---------- % ----------							
Mowing height (MH)								
2.8 mm	4.2	36.8	51.7	61.8	2.2	4.8	47.1	92.2
3.2 mm	2.6	32.2	48.0	53.6	0.9	2.0	36.7	83.9
3.6 mm	1.1	28.8	40.5	44.5	1.5	1.9	25.9	79.2
$LSD_{(0.05)}$	*2.2*	*NS*	*8.8*	*7.3*	*NS*	*NS*	*5.4*	*3.2*
Mowing frequency (MF)								
7 mowings wk^{-1}	2.7	34.5	51.0	55.9	1.7	2.6	38.8	84.1
14 mowings wk^{-1}	2.5	30.8	42.4	50.7	1.4	3.2	34.4	86.1
Lightweight rolling (LR)								
none	3.0	34.2	49.0	56.2	1.6	3.1	39.5	84.8
every other day	2.3	31.0	44.4	50.4	1.4	2.7	33.6	85.4
				ANOVA				
Source of variation								
MH	*	NS	*	**	NS	NS	***	***
MF	NS[†]	NS	**	*	NS	NS	NS	NS
LR	*	NS	*	***	NS	NS	**	NS
MH x MF	*	NS	NS	*	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	34.1	16.9	13.9	9.9	51.2	27.7	20.1	3.8

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
[†]NS, not significant.

Table 2. Anthracnose disease severity response to mowing height and mowing frequency on annual bluegrass turf in North Brunswick, NJ during 2004.

	2 Aug.		15 Sept.	
	Mowing frequency, wk^{-1}			
Mowing height	7	14	7	14
mm	---------- % ----------			
2.8	3.6a[†]A[‡]	4.7aA	60.0aA	63.6aA
3.2	3.3aA	2.0bB	60.6aA	46.5bB
3.6	1.3aA	0.8bA	47.1bA	41.9bA

[†]Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
[‡]Means within rows and date followed by the same upper case letter are not significantly different according to Fisher's protected LSD (p = 0.05).

Table 3. Ball roll distance response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004.

	June								July						
Main effects	4	11	14	16	21	24	28	29	1	2	7	13	15	19	20
	---------- m ----------														
Mowing height (MH)															
2.8 mm	2.87	3.26	3.32	3.26	3.60	3.23	3.35	3.44	3.38	3.41	3.50	3.05	3.08	3.14	3.16
3.2 mm	2.99	3.20	3.14	3.14	3.35	3.14	3.38	3.35	3.23	3.26	3.13	2.92	2.99	2.99	3.11
3.6 mm	2.80	3.05	3.08	3.08	3.20	3.02	3.20	3.29	3.02	3.14	3.00	2.88	2.98	2.89	2.92
$LSD_{(0.05)}$	*NS*	*NS*	*0.13*	*0.14*	*0.17*	*0.10*	*NS*	*0.11*	*0.07*	*0.12*	*NS*	*0.11*	*NS*	*0.12*	*0.07*
Mowing frequency (MF)															
7 mowings wk^{-1}	2.77	3.05	2.99	3.02	3.23	2.96	3.23	3.23	3.11	3.11	3.00	2.82	2.93	2.90	2.93
14 mowings wk^{-1}	2.99	3.29	3.38	3.29	3.54	3.29	3.41	3.51	3.32	3.44	3.42	3.07	3.10	3.11	3.20
Lightweight rolling (LR)															
none	2.87	3.11	3.14	3.14	3.29	3.11	3.26	3.32	3.11	3.26	3.16	2.84	2.92	2.91	3.04
every other day	2.93	3.23	3.23	3.20	3.47	3.17	3.35	3.41	3.32	3.26	3.25	3.06	3.12	3.11	3.08
								ANOVA							
Source of variation															
MH	NS†	NS	**	*	**	**	NS	*	***	**	NS	*	NS	**	***
MF	***	**	***	***	***	***	*	**	***	***	*	***	*	**	***
LR	NS	***	**	NS	***	**	*	*	***	NS	NS	***	***	***	NS
MH x MF	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
MF x LR	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	***	***	NS
MH x MF x LR	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	3.8	3.1	2.8	3.6	4.2	2.4	4.0	4.3	4.4	2.9	18.5	5.0	4.4	1.8	3.9

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 4. Ball roll distance response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2005.

	June						July
Main effects	1	7	13	21	22	28	1
	------------------------------ m ------------------------------						
Mowing height (MH)							
2.8 mm	3.25	3.19	3.39	3.39	3.44	3.06	3.49
3.2 mm	3.18	3.10	3.24	3.15	3.24	2.99	3.32
3.6 mm	3.07	2.98	3.08	2.96	3.16	2.83	3.17
$LSD_{(0.05)}$	*0.10*	*0.13*	*0.09*	*0.04*	*0.06*	*0.15*	*0.15*
Mowing frequency (MF)							
7 mowings wk^{-1}	2.98	2.92	3.05	2.96	3.12	2.78	3.15
14 mowings wk^{-1}	3.35	3.26	3.42	3.37	3.44	3.14	3.50
Lightweight rolling (LR)							
none	3.16	3.05	3.21	3.11	3.22	2.93	3.28
every other day	3.17	3.13	3.26	3.22	3.34	2.99	3.37
				ANOVA			
Source of variation							
MH	*	*	***	***	***	*	**
MF	***	***	***	***	***	***	***
LR	NS†	NS	NS	*	**	*	*
MH x MF	NS	NS	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	*	NS
MH x MF x LR	NS	NS	NS	NS	NS	NS	**
CV, %	4.1	3.8	3.6	4.7	4.0	3.7	3.4

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 5. Ball roll distance response to mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004				2005	
	15 July		19 July		28 June	
	Lightweight rolling					
Mowing frequency	None	Every other day	None	Every other day	None	Every other day
wk^{-1}	------------------------------ m ------------------------------					
7	2.75b†B‡	3.12aA	2.76bB	3.04aA	2.71bB	2.84bA
14	3.10aA	3.11aA	3.05aB	3.17aA	3.14aA	3.14aA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD ($p \leq 0.05$).
‡Means within rows and rating date followed by the same upper case letter are not significantly different according to Fisher's protected LSD ($p \leq 0.05$).

Table 6. Frequency distribution (n = 22) of ball roll distances and comparison of mean ball roll distance (BRD) for all combinations of mowing height, mowing frequency and lightweight rolling levels on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

			Ball Roll Distance Ranges (m)									
Mowing height	Mowing frequency	Lightweight rolling	2.3 – 2.6	2.6 – 2.9	2.9 – 3.2	3.2 – 3.5	3.5 – 3.8	3.8 +	mean†	sd	Equality of variances‡	*t*-test§
mm	wk^{-1}	d	%						m		$p > F$	$p > t$
2.8	7	none	0	18	64	18	0	0	3.06	0.17		
2.8	7	every other	0	5	59	36	0	0	3.15	0.17	0.9052	0.0802
2.8	14	none	0	0	14	50	27	9	3.46	0.30	0.0180	< 0.0001
2.8	14	every other	0	0	5	55	41	0	3.47	0.19	0.7457	< 0.0001
3.2	7	none	0	36	59	5	0	0	2.96	0.16	0.8101	0.0633
3.2	7	every other	0	0	23	73	5	0	3.10	0.14	0.3185	0.3672
3.2	14	none	0	0	23	73	5	0	3.26	0.14	0.3654	0.0002
3.2	14	every other	0	0	23	59	18	0	3.34	0.16	0.7279	< 0.0001
3.6	7	none	5	64	32	0	0	0	2.82	0.15	0.4800	< 0.0001
3.6	7	every other	0	27	73	0	0	0	2.98	0.14	0.2879	0.1002
3.6	14	none	0	5	59	36	0	0	3.14	0.15	0.4246	0.1097
3.6	14	every other	0	0	50	45	5	0	3.21	0.15	0.4644	0.0030

†Mean ball roll distance of 22 observations made during 2004 and 2005 for each treatment combination.

‡Equality test between sample variances of ball roll distance distributions for each treatment combination and mowing at 2.8 mm every 7 days without rolling assessed using the ratio of the folded form F statistic. Sample variances are equal when $p > 0.05$.

§Ball roll distance distributions for each treatment combination were compared to mowing at 2.8 mm every 7 days without rolling to determine if BRD differences were observed during 2004 and 2005. A pooled t-test $\alpha = 0.05$ was used to detect differences when sample variances were equal ($p > 0.05$); when unequal ($p \leq 0.05$) comparisons were made using the Satterthwaite approximation.

Table 7. Turf quality response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	Turf quality					
	2004			2005		
Main effects	14 June	16 July	26 Aug.	16 June	14 July	27 Aug.
	------------------------------ 1-9; 9= best ------------------------------					
Mowing height (MH)						
2.8 mm	7.4	7.4	3.6	7.4	5.3	1.1
3.2 mm	7.1	8.1	4.3	7.3	6.3	2.1
3.6 mm	6.8	6.1	4.7	7.4	6.6	2.7
$LSD_{(0.05)}$	*NS*	*0.67*	*0.52*	*NS*	*0.81*	*NS*
Mowing frequency (MF)						
7 mowings wk^{-1}	7.0	7.1	3.9	7.0	6.0	2.0
14 mowings wk^{-1}	7.2	7.3	4.4	7.4	6.0	2.0
Lightweight rolling (LR)						
none	7.1	7.0	3.9	7.3	5.8	2.0
every other day	7.1	7.3	4.5	7.1	6.3	2.0
	ANOVA					
Source of variation						
MH	NS†	***	**	NS	*	NS
MF	NS	NS	NS	NS	NS	NS
LR	NS	NS	**	NS	*	NS
MH x MF	NS	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	NS	NS
CV, %	11.9	8.8	16.5	7.8	15.1	30.7

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

CHAPTER 3. Anthracnose of Annual Bluegrass Putting Green Turf Influenced by Trinexapac-Ethyl Application Interval and Rate

ABSTRACT

Anthracnose incidence and severity caused by *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman on annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] putting greens has become increasingly devastating over the past 15 years. The effect of trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-di-oxocyclohexanecarboxylic acid ethylester] application interval (14 and 7 d) and rate (none, 0.04, 0.05 and 0.08 kg a.i. ha^{-1}) on anthracnose severity was assessed on annual bluegrass turf mowed at 3.2 mm from 2005 to 2007. Trinexapac-ethyl did not enhance disease severity regardless of application rate or interval. Trinexapac-ethyl had no or little effect on the disease in 2005 and 2007, while disease severity was reduced by the growth regulator in 2006. On average, a reduction of 11 to 27% disease severity was observed in trinexapac-ethyl treatments when compared to untreated turf during 2006. Specifically, a shorter application interval (7 vs. 14 d) and greater growth regulator rate (0.08 vs. 0.05 kg a.i. ha^{-1}) resulted in less anthracnose in 2006 when disease pressure was high. Disease severity declined linearly with increasing trinexapac-ethyl rate when applied every 7 d during 2006. Trinexapac-ethyl treatment increased seedheads 8 to 21% compared to untreated turf during the 3-yr trial. Trinexapac-ethyl applied every 7 d at 0.08 kg a.i. ha^{-1} initially reduced turf quality due to moderate phytotoxicity and increased seedheads compared to the same rate applied every 14 d early in the season during 2006

and 2007. However, trinexapac-ethyl treatments improved turf quality once seedheads subsided and disease severity increased later on in 2005 and 2006.

INTRODUCTION

Anthracnose is a destructive disease of turfgrasses, caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman [formerly *C. graminicola* (Ces.) G.W. Wils.], and is particularly severe on annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] throughout the United States, Canada, Western Europe, (Smiley et al., 2005; Smith et al., 1989) and Australia (Peart, 2007). The disease may exist as a foliar blight during high summer temperatures, or a basal rot which may occur any time of year. Symptoms initiate as small (6 to 12 mm) zones of chlorotic turf. Infested tillers (basal rot) are easily removed revealing a necrotic, water-soaked or black rot of tissue concealed beneath the outer leaf sheaths (Smiley et al., 2005). Melanized setae and acervuli develop on leaf blades and sheaths. The prevalence of anthracnose epiphytotics on golf course putting greens has increased over the past 15 years (Dernoeden, 2002; Landschoot and Hoyland, 1995; Mann and Newell, 2005; Wong and Midland, 2004). Factors which predispose turf to this disease are the focus of ongoing research (Murphy et al., 2008); although management practices intended to increase ball roll distance on putting greens are thought to intensify anthracnose severity by enhancing plant stress (Vermeulen, 2003; Zontek, 2004). Moreover, resistance of the fungus to a number of fungicide classes previously known to reduce anthracnose has been demonstrated (Avila-Adame et al., 2003; Crouch et al., 2005; Wong and Midland, 2007; Wong et al., 2007) further complicating efforts to control this disease.

Trinexapac-ethyl (TE) use on putting green turf has become commonplace within the past 15 yr (Danneberger, 2003; Stewart et al., 2008). It is routinely applied throughout the season to improve vigor and playability of putting greens by reducing vertical shoot growth while increasing stand density and uniformity (Ervin and Koski, 1998; McCullough et al., 2005). However, the effect of TE on turfgrass diseases is not well understood.

Trinexapac-ethyl has been associated with reduced dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Bennett) incidence in creeping bentgrass (*Agrostis stolonifera* L.); it was postulated that increased superoxide dismutase activity (Zhang and Schmidt, 2000a) and elevated levels of total non-structural carbohydrates (Golembiewski and Danneberger, 1998) improved turf tolerance to infection. Alternatively, other studies concluded that TE had no effect on dollar spot incidence (Burpee et al., 1996; Fidanza et al., 2006; Stewart et al., 2008) or Rhizoctonia blight (caused by *Rhizoctonia solani* Kuhn) (Burpee, 1998). Furthermore, Stewart et al. (2008) reported that curative applications of fungicides with TE delayed turf recovery from dollar spot damage compared to fungicides alone.

Trinexapac-ethyl applied every 14 d at 0.05 kg a.i. ha^{-1} occasionally reduced disease severity of an ABG putting green in a one year study (Crouch et al., 2003); whereas the growth regulator applied every 28 d at the same rate to creeping bentgrass in another one year study had no effect on this disease (Vincelli and Doney, 1999). Trinexapac-ethyl applied at 0.05 kg a.i. ha^{-1} every 14 d in the absence of other growth regulators had little effect on anthracnose of ABG maintained at greens height over a three year period (Inguagiato et al., 2008). Some golf course superintendents use TE at rates greater than 0.05 kg a.i. ha^{-1} and/or at application intervals less than 14 d (Danneberger, 2006; Foy, 2008), but the impact of TE at higher rates or shorter intervals on anthracnose is currently unknown. Thus, the objective of this study was to evaluate a broader range of TE application intervals and rates for effects on anthracnose severity of ABG putting green turf.

MATERIALS AND METHODS

A three-year field study was initiated in 2005 on an ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 5.5 in North Brunswick, NJ. A monostand of ABG was established in the autumn of 2003 from seed indigenous to the site and ABG introduced in 1998 from Plainfield Country Club, Plainfield, NJ (Samaranayake et al., 2008). The previous mixed species turf [creeping bentgrass, velvet bentgrass (*A. canina* L.) and ABG] was eliminated from the experimental site with glyphosate [N-(phosphonomethyl) glycine] at 4.5 kg a.i. ha^{-1} on 10 September 2003. Thatch was removed and a seedbed was prepared by verticutting (6.4-mm depth) (model 544837, Commercial Grounds Care, Inc. Johnson Creek, WI) the site four times from 29 Aug. to 6 Nov. 2003. An ABG turf developed from the indigenous ABG seed, and a 3.2 mm cutting height was established by May 2004. The trial was inoculated (2 Aug. 2004) with *C. cereale* isolate HFIIA (previously obtained from ABG at the Horticultural Research Farm II, North Brunswick, NJ) at 50,000 conidia mL^{-1} using the inoculum production and field inoculation procedure described by Inguagiato et al. (2008d).

Field Maintenance

Turf was mowed 10 to 14 times wk^{-1} with a triplex putting green mower (models 3000-04350 and 3150-04357, Toro Co., Bloomington, MN) bench set at 3.2 mm. Nitrogen was applied to the field as water soluble sources totaling 120 kg ha^{-1} in 2005, 147 kg ha^{-1} in 2006 and 196 kg ha^{-1} in 2007. Nitrogen was annually distributed in 15 to 18 applications during 2005, 2006 and 2007 at: 53.8, 85.5 and 53.8 kg ha^{-1} from March to May; 44.0, 48.9 and 44.0 kg ha^{-1} from June to August; and 22.0, 34.2 and 97.7 kg ha^{-1}

from September to October, respectively. Phosphorous and potassium were applied based on soil test results at 18.8 and 35.4 kg ha^{-1} in 2005, 22.9 and 45.6 kg ha^{-1} in 2006 and 11.8 and 34.3 kg ha^{-1} in 2007, respectively. The trial was topdressed at 88.7 cm^{3} m^{-2} with silica sand (sub-angular, medium size) every 14 d from May to September each year. Sand was incorporated with a cocoa mat drag (Ace Equipment and Supply Co., Henderson, CO). Irrigation was applied to avoid drought stress yet maintain relatively dry soil conditions and to wash-in fertilizer. Dollar spot disease was preventatively controlled every 14 d during June and July 2005, May through July 2006, and May through August 2007 with vinclozolin [3-(3, 5-dichlorophenyl)-5-ethenyl-5-methyl-2, 4-oxazolidinedione] at 1.5 to 2.0 kg a.i. ha^{-1} or boscalid {3-pyridinecarboxamide, 2-chloro-N-[4'-chloro(1,1'-biphenyl)-2-yl]} at 0.4 to 0.6 kg a.i. ha^{-1}. Flutolanil {N-[3-(1-methylethoxy) phenyl]-2-[trifluoromethyl] benzamide} applied at 3.2 to 7.7 kg a.i. ha^{-1} was used to suppress Rhizoctonia blight every 14 d during June and July 2005 and 2006, and May through August 2007. Algae was controlled as necessary with mancozeb (coordination of Mn^{2+}, Zn^{2+} and ethylene bisdithiocarbamate) at 9.5 to 21.4 kg a.i. ha^{-1} in July and August 2005; and June and July 2007. These fungicides were previously determined not to be efficacious against anthracnose on ABG putting green turf (Towers et al., 2002a). Annual bluegrass weevil [*Listronotus maculicollis* (Kirby)] was controlled with applications of bendiocarb (2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate) at 2.3 kg a.i. ha^{-1} on 12 May 2005; bifenthrin {[2-methyl(1,1'-biphenyl)-3-yl]methyl 3-[2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} at 0.13 kg a.i. ha^{-1} on 27 June 2005, 2 May 2006 and 3 May and 19 June 2007; and trichlorfon [dimethyl(2,2,2-trichloro-1-hydroxyethyl) phosphonate] at 8.5 kg a.i. ha^{-1} on 14 July

2005. Anthracnose development was arrested at the conclusion of each study year to allow turf recovery during the autumn, winter and spring months; chlorothalonil (tetrachloroisophthalonitrile) was applied at 13.1 kg a.i. ha^{-1} on 18 Aug., 7 and 18 Sept. and 2 Oct. 2005; 17.9 kg ha^{-1} on 26 Oct. 2006. Chlorothalonil was also applied at 13.9 and 15.7 kg ha^{-1} on 14 July and 4 Sept. 2006 to slow disease progress and prevent excessive turf loss.

Treatment Design

The trial contained six treatments arranged in a randomized complete block design with four replications. Treatments included a control (untreated) and TE applied every 7 d at 0.04, 0.05 and 0.08 kg a.i. ha^{-1} or every 14 d at 0.05 and 0.08 kg a.i. ha^{-1}. Trinexapac-ethyl applications were made from 6 April through 27 July 2005, 31 Mar. though 13 Sept. 2006 and 28 Mar. through 22 Aug. 2007. Trinexapac-ethyl was applied with an operator propelled spray boom outfitted with flat-fan VS8003 nozzles (Spray Systems Co., Wheaton, IL) calibrated to deliver 408 L ha^{-1} at 269 kPa. Treatments were repeated in the same plot location each year.

Data Collection and Analysis

Anthracnose severity was periodically assessed during June and July 2005, June through September 2006 and July through August 2007 as the percent turf area infested with *C. cereale* using a line-intercept grid count method described by Inguagiato et al. (2008d). Seedhead expression was assessed from April or May through June each year by visually estimating the percent plot area containing seedheads. Turf quality was visually rated on a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from May through July 2005, April through August 2006 and April through July 2007. Turf density, uniformity, color, phytotoxicity, seedhead expression and disease severity were components of turf quality.

All data were subjected to analysis of variance using the General Linear Model procedure in the Statistical Analysis System software v. 9.1.3 (SAS Institute Inc., Cary, NC, 2003). Single degree of freedom contrasts were used to test treatment effects (Steel et al., 1997a). The treatment means associated with the contrast identifying a significant treatment interaction were separated by LSD ($p \leq 0.05$).

RESULTS AND DISCUSSION

Anthracnose Severity

Anthracnose developed throughout the study as a natural infestation on 7 June 2005, 18 June 2006 and 27 June 2007. The epiphytotic progressed slowly until 15 July 2005, when the disease resulted in 27 to 36% turf loss, but no discernable treatment differences were observed that year (Table 1). Disease developed very rapidly in 2006 with 55% of untreated turf being damaged by 3 July. Chlorothalonil was applied to lessen the severity of the epiphytotic on 14 July 2006, yet disease severity continued to increase through mid-August (46 to 73%) before declining in September. Disease severity increased gradually to 45 to 55% turf area infested by 16 Aug. 2007.

Trinexapac-ethyl did not enhance disease severity regardless of application rate or interval throughout this three year study (Table 1). Rather, TE had no or little effect on disease severity in 2005 and 2007, while severity was reduced by TE on all rating dates in 2006. Trinexapac-ethyl applied every 7 or 14 d at 0.04 to 0.08 kg a.i. ha^{-1} reduced disease severity 11 to 27% compared to untreated turf throughout 2006. Shorter TE application interval (i.e., 7 d vs. 14 d) reduced disease severity 9 to 10% across both rates (0.05 and 0.08 kg a.i. ha^{-1}) in July and on 12 Sept. 2006. Similarly, the greatest TE rate (0.08 kg a.i. ha^{-1}) reduced disease severity 8 to 11% compared to the 0.05 kg a.i. ha^{-1} rate across both application intervals during high disease pressure on 21 July and 16 Aug. 2006, and 3% on 3 July 2007 when disease pressure was low. Application rate and interval did not interact to affect disease severity throughout the study. Disease severity declined linearly with increasing rate of TE (0, 0.04, 0.05 and 0.08 kg a.i. ha^{-1} applied every 7 d) during 2006, but there was no rate effect in 2005 and 2007 (Table 1).

Trinexapac-ethyl influenced anthracnose only one out of three years in this trial. Previous studies evaluating TE effects on anthracnose have reported occasional reductions (Crouch et al., 2003; Inguagiato et al., 2008d), little effect (Inguagiato et al., 2008) or no effect of TE on anthracnose (Vincelli and Doney, 1999). Reduced disease severity on TE treated turf has been attributed to improved physiological and morphological characteristics of turf, which could enhance tolerance to anthracnose by improving plant vigor and minimizing stress (Inguagiato et al., 2008d). However, the effect of TE on anthracnose is not well understood and it is possible that additional factors may be involved. Studies reporting disease reductions applied TE to ABG every 14 d at 0.05 kg a.i. ha^{-1} (Crouch et al., 2003; Inguagiato et al., 2008d); whereas TE applied to creeping bentgrass every 28 d at the same rate had no effect on anthracnose (Vincelli and Doney, 1999). Therefore, turf species as well as application interval may affect anthracnose response to TE. In the current trial, TE applied every 7 and 14 d reduced anthracnose severity in 2006, a year when disease pressure was very high; decreasing the application interval to 7 d was occasionally more effective at reducing the disease.

Moderate N fertility is known to reduce anthracnose severity (Danneberger et al., 1983; Inguagiato et al., 2008d). Inguagiato et al. (2008d) noted that TE (applied every 14 d after spring mefluidide {*N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino]phenyl]acetamide} application) produced the greatest reduction in anthracnose when turf was fertilized with N every 7 d at 4.9 kg ha^{-1}; whereas TE had lesser or no effect on similarly treated turf fertilized with N every 28 d. Nitrogen applications were generally uniform in the current trial from June through August each year; however turf did receive an additional 31.7 kg N ha^{-1} from March through May 2006 than was applied during this period in 2005 and 2007. Fagerness et al. (2004) observed that ^{15}N allocation to roots and rhizomes was increased approximately 50%, and allocation to clippings was decreased approximately 25%, in TE treated bermudagrass (*Cynodon dactylon* X *C. transvaalensis* Burtt-Davey). Thus, turf treated with TE (31 March through 13 September 2006) may have increased allocation of N (provided by the increased N applied from March through May) to roots and possibly improved root number, function and viability. Since tolerance to summer stress has been associated with increased root depth and number (Bonos and Murphy, 1999; Xu and Huang, 2001), allocation of N to roots may have improved the vigor of ABG in our trial and reduced anthracnose severity during 2006.

Data from this three-year trial indicate that TE does not enhance anthracnose and can occasionally reduce disease severity even at increased application rates and shorter application intervals. Disease reductions observed only in 2006 suggest that TE applications combined with increased N fertility may result in more consistent reductions in disease severity; however this hypothesis needs to be validated.

Seedhead Expression

The average TE treatment effect increased seedheads 8 to 21% compared to untreated turf when differences occurred during the three-year trial (Table 2). More frequent TE applications (every 7 d) increased seedheads 7 to 21% compared to the 14-d interval (across 0.05 and 0.08 kg a.i. ha^{-1} rates). There was no difference in seedhead expression for TE applied at 0.05 versus 0.08 kg a.i. ha^{-1} across 7- and 14-d intervals throughout the study. However, the number of seedheads increased linearly throughout the study with increasing TE rate (0, 0.04, 0.05 and 0.08 kg a.i. ha^{-1}) applied every 7 d (Table 2). Previous studies have demonstrated that TE can reduce the initial expression of ABG seedheads compared to untreated turf (Fagerness and Penner, 1998a; Inguagiato et al., 2008d), but extend the period of seedhead expression (Inguagiato et al., 2008d). This is probably due to TE reducing the elongation of the flowering culm (Borm and van den Berg, 2008), delaying the initial appearance of seedheads and limiting physical removal of seedheads with routine mowing.

Turf Quality

Turf quality was poor throughout most of the trial mainly due to phytotoxicity in April and May, retention of seedheads during May and June and disease from June to August (Table 3). The average TE treatment effect reduced turf quality in May 2005 and 2006 as well as June and July 2007 compared to untreated turf. This response was due in part to greater number of seedheads associated with TE applications in May 2006 and June 2007, and reduced density (component of turf quality ratings) once tillers senesced after seed set in July 2007. Growth regulation caused a moderate phytotoxic (i.e., yellow-gray turf color and reduced uniformity) effect in TE treated plots reducing turf quality in May 2005. However, turf quality was improved by TE treatment compared to untreated plots later in the season (21 July 2005, and 17 July and 25 Aug. 2006) after seedhead production had ceased and turf density was declining due to disease. The improvement in turf quality of TE treated turf in July and August 2006 was also attributed to the reduction in disease severity during that period, but this effect was not observed in 2005 or 2007.

The interaction between TE interval and rate in April and May 2006 and April 2007 indicated that TE applied every 7 d at 0.08 kg a.i. ha^{-1} reduced turf quality compared to the same rate applied at the 14-d interval; whereas application interval did not affect quality at 0.05 kg a.i. ha^{-1} (Table 3). Initially, the more frequent TE application at the higher rate caused phytotoxicity that reduced quality early in the season. Phytotoxicity was not a concern at the 7 d interval when TE was applied at 0.05 kg a.i. ha^{-1}.

Trinexapac-ethyl applied every 7 d reduced turf quality (Table 3) due to reduced turf uniformity (component of turf quality ratings) in June 2005 and prolonged seedhead retention in June 2007 (Table 2) compared to the 14-d interval across both rates (0.05 and 0.08 kg a.i. ha^{-1}). Greater TE rate (0.08 kg a.i. ha^{-1}) reduced quality across both application intervals due to reduced uniformity in June 2005 and 2006, although the greater rate eventually improved quality during high disease (Table 1) pressure in July. Similarly, TE rate (0, 0.04, 0.05, and 0.08 kg a.i. ha^{-1}) at the 7 d interval produced a significant linear turf quality response on 10 of 13 observations. Increasing TE rate reduced turf quality due to phytotoxic effects in April 2006 and reduced turf color in April 2007 (data not shown); greater seedheads in May and June 2006 and June 2007 (Table 2); reduced uniformity in June 2005 and density in July 2007 following seed set. Conversely, increasing TE rate improved turf quality when disease severity was increasing in July 2005 and July and August 2006, but this effect was not observed in 2007.

CONCLUSIONS

Trinexapac-ethyl did not increase anthracnose severity in this trial. Thus, industry concerns that growth regulation with TE may enhance disease severity were not substantiated. In fact, TE occasionally (2006) reduced anthracnose severity, and beneficial effects were evident at relatively short application intervals (7 and 14 d) and increased rates (0.05 to 0.08 kg a.i. ha^{-1}). Turf managers should be cautious, however, of more aggressive TE application strategies (7 d interval and/or 0.8 kg a.i. ha^{-1}) during the spring because turf quality can be reduced by phytoxicity and a longer period of seedhead retention. Thus, management of ABG putting green turf with TE to improve turf quality and density, reduce clipping yield and improve playability should not be expected to antagonize a program of best management practices designed to control anthracnose on ABG. However, turf managers should not expect the use of TE to consistently reduce anthracnose severity.

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Table 1. Anthracnose disease severity response to trinexapac-ethyl on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	Turf area infested												
	2005			2006					2007				
Trinexapac-ethyl (TE)	14 June	2 July	15 July	23 June	3 July	21 July	16 Aug	12 Sept	3 July	12 July	27 July	4 Aug	16 Aug
	%												
untreated	3.7	7.9	35.1	17.4	54.9	73.4	73.2	44.9	7.1	11.4	23.9	35.7	54.5
0.04 kg a.i. ha^{-1}, 7 d	2.7	3.6	33.0	6.2	27.0	52.9	54.3	25.5	3.6	8.4	17.2	19.9	45.0
0.05 kg a.i. ha^{-1}, 14 d	3.9	7.2	33.7	7.8	33.0	61.8	58.8	33.4	8.2	13.6	22.0	31.5	53.6
0.05 kg a.i. ha^{-1}, 7 d	4.2	5.5	30.3	5.3	27.1	51.2	51.4	22.7	6.9	9.6	17.7	27.3	49.6
0.08 kg a.i. ha^{-1}, 14 d	3.8	4.9	36.0	9.6	31.9	50.5	48.8	26.4	4.9	7.6	20.9	34.9	52.1
0.08 kg a.i. ha^{-1}, 7 d	3.2	5.2	27.2	5.3	18.6	40.8	46.4	19.3	4.3	8.5	18.4	25.0	45.7
<u>Planned *F*-tests</u>	$P > F$												
untreated *vs.* all TE[†]	NS[#]	NS	NS	***	***	***	***	***	NS	NS	NS	NS	NS
14 d *vs.* 7 d[‡]	NS	NS	NS	NS	*	*	NS	*	NS	NS	NS	NS	NS
0.05 *vs.* 0.08 kg a.i. ha^{-1}[§]	NS	NS	NS	NS	NS	**	*	NS	*	NS	NS	NS	NS
interval x rate interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
linear rate of TE,7 d[¶]	NS	NS	NS	***	***	***	***	***	NS	NS	NS	NS	NS

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Comparison of: untreated vs. 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 14 d; 0.05 kg a.i. ha^{-1}, 7 d; 0.08 kg a.i. ha^{-1}, 14 d; and 0.08 kg a.i. ha^{-1}, 7 d.
[‡]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 14 d vs. 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d.
[§]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.05 kg a.i. ha^{-1}, 7 d vs. 0.08 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 7 d.
[¶]Coefficients to determine linear response of TE rates at 7 d interval on anthracnose: -17, -1, 3 and 15 for untreated, 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d, respectively.
[#]NS, not significant.

Table 2. Seedhead production response to trinexapac-ethyl on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	Seedhead expression								
	2005			2006			2007		
Trinexapac-ethyl (TE)	13 May	4 June	14 June	24 May	9 June	19 June	24 Apr	22 May	19 June
	%								
untreated	78.8	46.3	20.0	52.5	29.3	27.5	22.5	53.8	28.8
0.04 kg a.i. ha^{-1}, 7 d	82.5	68.8	21.3	73.8	39.5	39.0	16.3	65.0	46.3
0.05 kg a.i. ha^{-1}, 14 d	81.3	55.0	20.0	60.0	33.3	32.3	22.5	60.0	45.0
0.05 kg a.i. ha^{-1}, 7 d	80.0	64.5	18.8	80.0	39.3	38.8	17.5	66.3	57.5
0.08 kg a.i. ha^{-1}, 14 d	83.8	57.5	20.0	62.5	34.3	30.5	18.8	61.3	40.0
0.08 kg a.i. ha^{-1}, 7 d	83.8	68.8	25.0	85.0	42.5	42.0	17.5	67.5	60.0
Planned *F*-tests	$P > F$								
untreated *vs.* all TE[†]	NS[#]	***	NS	***	***	***	NS	**	***
14 d *vs.* 7 d[‡]	NS	***	NS	***	***	***	NS	NS	***
0.05 *vs.* 0.08 kg a.i. ha^{-1}[§]	NS	NS	NS	NS	NS	NS	NS	NS	NS
interval x rate interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS
linear rate of TE,7 d[¶]	NS	***	NS	***	***	***	NS	**	***

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Comparison of: untreated vs. 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 14 d; 0.05 kg a.i. ha^{-1}, 7 d; 0.08 kg a.i. ha^{-1}, 14 d; and 0.08 kg a.i. ha^{-1}, 7 d.
[‡]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 14 d vs. 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d.
[§]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.05 kg a.i. ha^{-1}, 7 d vs. 0.08 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 7 d.
[¶]Coefficients to determine linear response of TE rates at 7 d interval on seedhead expression: -17, -1, 3 and 15 for untreated, 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d, respectively.
[#]NS, not significant.

Table 3. Turf quality response to trinexapac-ethyl on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	Turf quality												
	2005				2006					2007			
Trinexapac-ethyl (TE)	13 May	13 June	12 July	21 July	10 Apr	11 May	19 June	17 July	25 Aug	18 Apr	14 May	19 June	19 July
	1 – 9 (9 = best)												
untreated	4.0	5.0	4.5	2.3	4.0	5.0	4.8	1.3	3.0	2.5	4.5	6.3	6.0
0.04 kg a.i. ha^{-1}, 7 d	2.5	4.3	4.8	4.0	3.5	4.0	4.0	3.5	4.3	2.3	5.0	4.0	5.0
0.05 kg a.i. ha^{-1}, 14 d	4.0	5.5	4.8	3.5	3.5	4.8	5.0	2.5	3.8	2.0	5.5	5.0	4.5
0.05 kg a.i. ha^{-1}, 7 d	3.5	4.3	4.3	4.0	3.8	4.5	4.5	3.0	5.0	2.3	5.3	4.8	5.3
0.08 kg a.i. ha^{-1}, 14 d	3.5	4.3	5.0	4.0	3.8	4.5	4.0	3.5	5.0	2.8	4.8	5.3	4.8
0.08 kg a.i. ha^{-1}, 7 d	3.5	4.0	4.5	4.3	3.0	3.0	3.5	4.0	5.8	1.3	4.8	4.0	4.5
<u>Planned *F*-tests</u>	$P > F$												
untreated *vs.* all TE[†]	*	NS	NS	***	NS	**	NS	***	*	NS	NS	***	*
14 d *vs.* 7 d[‡]	NS[#]	*	NS	NS	NS	**	NS	NS	NS	NS	NS	**	NS
0.05 *vs.* 0.08 kg a.i. ha^{-1}[§]	NS	*	NS	NS	NS	**	**	**	NS	NS	NS	NS	NS
interval x rate interaction	NS	NS	NS	NS	*(0.7)[††]	*(0.7)	NS	NS	NS	*(1.2)	NS	NS	NS
linear rate of TE,7 d[¶]	NS	*	NS	***	**	***	**	***	**	*	NS	***	*

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Comparison of: untreated vs. 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 14 d; 0.05 kg a.i. ha^{-1}, 7 d; 0.08 kg a.i. ha^{-1}, 14 d; and 0.08 kg a.i. ha^{-1}, 7 d.
[‡]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 14 d vs. 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d.
[§]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.05 kg a.i. ha^{-1}, 7 d vs. 0.08 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 7 d.
[¶]Coefficients to determine linear response of TE rates at 7 d interval on turf quality: -17, -1, 3 and 15 for untreated, 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d, respectively.
[#]NS, not significant.
[††]Number in parenthesis represents Fisher's protected least significant difference ($\alpha = 0.05$) for comparing means involved in the interaction of TE interval (14 *vs.* 7 d) and rate (0.05 *vs.* 0.08 kg a.i. ha^{-1}).

CHAPTER 4. Anthracnose Development on Annual Bluegrass Affected by Seedhead and Vegetative Growth Regulators

ABSTRACT

The impact of plant growth regulators on anthracnose epiphytotics of annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] putting green turf caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman has been a concern of turf managers for several years. Two field trials assessed the influence of ethephon (EP; 0 and 3.8 kg a.i. ha^{-1}) [(2-chloroethyl)phosphonic acid] or mefluidide (ME; 0 and 0.05 kg a.i. ha^{-1}) {*N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino]-phenyl]acetoamide} and application interval of trinexapac-ethyl (TE; none, 14 and 7 d) [4-(cyclopropyl-α-hydroxy-methylene)-3,5-di-oxocyclohexanecarboxylic acid ethylester] on anthracnose severity of annual bluegrass turf mowed at 3.2 mm from 2005 to 2007. Growth regulators generally did not enhance anthracnose severity in either trial, and occasionally reduced disease; however, reductions were not consistent. Ethephon reduced disease 3 to 22% compared to non-EP treated turf on 7 out of 13 observations dates over the 3-yrs. Moreover, shorter TE interval (7 d) reduced anthracnose 4 to 29% compared to non-TE treated turf on approximately 50% of the total observations; whereas the 14-d interval reduced disease 4 to 16% compared to non-TE treated turf on 23 and 38% of the total observations in the two trials. Mefluidide generally had no effect on anthracnose severity throughout the trial. No meaningful interactions affecting anthracnose were evident in these trails. These data indicate that EP, ME and TE can be

used on annual bluegrass putting green turf to reduce seedheads and improve turf quality without intensifying, and occasionally reducing anthracnose severity.

INTRODUCTION

Anthracnose disease, caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman, affects turfgrass species throughout the world (Peart, 2007; Smiley et al., 2005; Smith et al., 1989). Annual bluegrass (ABG) [*Poa annua* L. (Hausskn) T. Koyama] maintained as putting green turf is particularly susceptible, although the disease is not uncommon on similarly managed creeping bentgrass (*Agrostis stolonifera* L). The incidence and severity of anthracnose has increased over the past 15 years often causing significant turf loss and disruption of play (Dernoeden, 2002; Landschoot and Hoyland, 1995; Mann and Newell, 2005). During this time, management practices intended to increase ball roll distance on putting green turf have evolved (Vermeulen, 2003b; Zontek, 2004b). Recent research has demonstrated that some of these practices can increase anthracnose severity likely due to enhanced plant stress (Inguagiato et al., 2008a; Inguagiato et al., 2008b). Management of this disease has become further complicated by the development of *C. cereale* isolates with resistance to a number of fungicide classes previously known to control anthracnose (Avila-Adame et al., 2003; Crouch et al., 2005; Wong and Midland, 2007; Wong et al., 2007).

The use of plant growth regulators on putting green turf has become common on golf courses in North America over the past 15 years (Danneberger, 2006; Frabotta, 2008); however the effect of these materials on disease is not well understood. Trinexapac-ethyl (TE) is commonly used throughout the season to improve vigor and playability of putting greens by reducing vertical shoot growth while increasing stand density and uniformity (Ervin and Koski, 1998; McCullough et al., 2005). Turf managers have begun applying TE at decreased application intervals (e.g., every 7 vs 14 d) than were common for putting green turf only a few years ago (Danneberger, 2006; Foy, 2008). Research has demonstrated that TE applied every 14 d at 0.05 kg a.i. ha^{-1} in the absence of other growth regulators either has no effect or may slightly reduce anthracnose on ABG putting greens, although this effect has been variable between years (Crouch et al., 2003; Inguagiato et al., 2008a). TE applied every 28 d at the same rate has been shown to have no effect on this disease (Vincelli and Doney, 1999). Little is known about the impact of TE applied at shorter intervals on anthracnose severity.

Mefluidide (ME) has been used since the 1980s to suppress spring seedhead formation in ABG putting green turf, thus improving uniformity and smoothness of the playing surface (Danneberger, 2003). Inhibiting ABG seedhead production with ME favors allocation of carbohydrates to roots (Cooper et al., 1988) and improves root growth (Cooper et al., 1987). Inguagiato et al. (2008a) determined that spring applications of ME followed by sequential use of TE every 14 d throughout the season could reduce anthracnose; although ME without TE had little effect on the disease. Further evaluation of the interaction between ME and TE, particularly at more frequent application intervals, is needed to determine its effect on anthracnose.

More recently, ethephon (EP) has been used instead of ME to suppress ABG seedheads due to the reduced risk of phytotoxicity associated with this material (Kane and Miller, 2003). However, the effect of EP alone or in combination with sequential applications of TE on anthracnose incidence and severity is unknown.

Chemical growth regulation is thought to enhance anthracnose severity; however, research is needed to identify the effect of these materials on this disease. Thus, the objectives of this trial were to determine the effect of spring seedhead suppression with

ME or EP, season long vegetative growth regulation with various intervals of TE and the potential interactions between these factors on anthracnose severity, seedhead expression and turf quality of ABG putting green turf.

MATERIALS AND METHODS

A three-year field study was initiated in 2005 on an ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 5.5 in North Brunswick, NJ. A monostand of ABG was established in the autumn of 2003 from seed indigenous to the site and ABG introduced in 1998 from Plainfield Country Club, Plainfield, NJ (Samaranayake et al., 2008). The previous mixed species turf [creeping bentgrass, velvet bentgrass (*A. canina* L.) and ABG] was eliminated from the experimental site with glyphosate [N-(phosphonomethyl) glycine] at 4.5 kg a.i. ha^{-1} on 10 September 2003. Thatch was removed and a seedbed was prepared by verticutting (6.4-mm depth) (model 544837, Commercial Grounds Care, Inc. Johnson Creek, WI) the site four times from 29 Aug. to 6 Nov. 2003. An ABG turf developed from the indigenous ABG seed, and a 3.2 mm cutting height was established by May 2004. The trial was inoculated (2 Aug. 2004) with *C. cereale* isolate HFIIA (previously obtained from ABG at the Horticultural Research Farm II, North Brunswick, NJ) at 50,000 conidia mL^{-1} using the inoculum production and field inoculation procedure described by Inguagiato et al. (2008a).

Field Maintenance

Turf was mowed 10 to 14 times wk^{-1} with a triplex putting green mower (models 3000-04350 and 3150-04357, Toro Co., Bloomington, MN) bench set at 3.2 mm. Nitrogen was applied to the field as water soluble sources totaling 120 kg ha^{-1} in 2005, 169 kg ha^{-1} in 2006 and 196 kg ha^{-1} in 2007. Nitrogen was annually distributed in 15 to 18 applications during 2005, 2006 and 2007 at: 53.8, 85.5 and 53.8 kg ha^{-1} from March to May; 44.0, 48.9 and 44.0 kg ha^{-1} from June to August; and 22.0, 34.2 and 97.7 kg ha^{-1}

from September to October, respectively. Phosphorous and potassium were applied based on soil test results at 18.8 and 35.4 kg ha^{-1} in 2005, 22.9 and 45.6 kg ha^{-1} in 2006 and 11.8 and 34.3 kg ha^{-1} in 2007, respectively. The trial was topdressed at 88.7 cm^3 m^{-2} with silica sand (sub-angular, medium size) every 14 d from May to September each year. Sand was incorporated with a cocoa mat drag (Ace Equipment and Supply Co., Henderson, CO). Irrigation was applied to avoid drought stress yet maintain relatively dry soil conditions and to wash-in fertilizer. Dollar spot disease (caused by *Sclerotnia homoeocarpa* F.T. Bennett) was preventatively controlled every 14 d during June and July 2005, May through July 2006, and May through August 2007 with vinclozolin [3-(3, 5-dichlorophenyl)-5-ethenyl-5-methyl-2, 4-oxazolidinedione] at 1.5 to 2.0 kg a.i. ha^{-1} or boscalid {3-pyridinecarboxamide, 2-chloro-N-[4'-chloro(1,1'-biphenyl)-2-yl]} at 0.4 to 0.6 kg a.i. ha^{-1}. Flutolanil {N-[3-(1-methylethoxy) phenyl]-2-[trifluoromethyl] benzamide} applied at 3.2 to 7.7 kg a.i. ha^{-1} was used to suppress Rhizoctonia blight (caused by *Rhizoctonia solani* Kühn) every 14 d during June and July 2005 and 2006, and May through August 2007. Algae was controlled as necessary with mancozeb (coordination of Mn^{2+}, Zn^{2+} and ethylene bisdithiocarbamate) at 9.5 to 21.4 kg a.i. ha^{-1} in July and August 2005; and June and July 2007. These fungicides were previously determined not to be efficacious against anthracnose on ABG putting green turf (Towers et al., 2002a). Annual bluegrass weevil [*Listronotus maculicollis* (Kirby)] was controlled with applications of bendiocarb (2,2-dimethyl-1,3-benzodioxol-4-yl methylcarbamate) at 2.3 kg a.i. ha^{-1} on 12 May 2005; bifenthrin {[2-methyl(1,1'-biphenyl)-3-yl]methyl 3-[2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} at 0.13 kg a.i. ha^{-1} on 27 June 2005, 2 May 2006 and 3 May and 19 June 2007; and trichlorfon [dimethyl(2,2,2-trichloro-1-hydroxyethyl) phosphonate] at 8.5 kg a.i. ha^{-1} on 14 July 2005. Anthracnose development was arrested at the conclusion of each study year to allow turf recovery during the autumn, winter and spring months; chlorothalonil (tetrachloroisophthalonitrile) was applied at 13.1 kg a.i. ha^{-1} on 18 Aug., 7 and 18 Sept. and 2 Oct. 2005; 17.9 kg ha^{-1} on 26 Oct. 2006. Chlorothalonil was also applied at 13.9 and 15.7 kg ha^{-1} on 14 July and 4 Sept. 2006, respectively, to slow disease progress and prevent excessive turf loss.

Treatment Design

Mefluidide Trial

Mefluidide and TE application interval were evaluated using a 2 by 3 factorial arranged in a randomized complete block design with four replications. Mefluidide levels were either none or two applications of 0.053 kg a.i. ha^{-1} on 6 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007. Timing of ME applications coincided with the production of seedheads in ABG plants maintained nearby at increased mowing heights. Trinexapac-ethyl levels were either none or TE applied every 7 or 14 d at 0.050 kg a.i. ha^{-1}. Trinexapac-ethyl was applied from 4 May to 27 July 2005, 26 Apr. to 20 Sept. 2006, and 25 Apr. to 29 Aug. 2007 for the 14-d interval and 28 Apr. to 26 July 2005, 19 Apr. to 20 Sept. 2006, and 18 Apr. to 29 Aug. 2007 for the 7-d interval.

Ethephon Trial

The effect of EP and TE application interval was evaluated within the same field using a 2 by 3 factorial arranged in a randomized complete block design with four replications. Ethephon levels were either none or two applications of 3.8 kg a.i. ha^{-1} on 5 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007. Trinexapac-ethyl levels were either none or TE applied every 7 or 14 d at 0.050 kg a.i. ha^{-1}. Trinexapac-ethyl applications were made from 5 Apr. to 27 July 2005, 31 Mar. to 20 Sep. 2006, and 28 Mar. to 29 Aug. 2007. Plant growth regulators in both trials were applied with an operator propelled spray boom outfitted with flat-fan VS8003 nozzles (Spray Systems Co., Wheaton, IL) calibrated to deliver 408 L ha^{-1} at 269 kPa. Treatments were repeated in the same plot location each year.

Data Collection and Analysis

Anthracnose severity was periodically assessed during June and July 2005, June through September 2006 and July through August 2007 as the percent turf area infested with *C. cereale* using a line-intercept grid count method (Inguagiato et al., (2008a). Seedhead expression was assessed from May through June each year by visually estimating the percent plot area containing seedheads. Turf quality was visually rated on a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from May through July 2005, April through August 2006 and April through July 2007. Turf density, uniformity, color, phytotoxicity, seedhead expression and disease severity were components of turf quality.

All data were subjected to analysis of variance to identify significant ($p \leq 0.05$) treatment effects using the General Linear Model procedure for a randomized complete block design in the Statistical Analysis System software v. 9.1.3 (SAS Institute Inc., Cary, NC, 2003). Means of main effects and significant interactions were separated by Fisher’s protected least significant difference test at the 0.05 probability level (Steel et al., 1997a).

RESULTS

Anthracnose Severity

Anthracnose developed throughout the study as a natural infestation in mid-June 2005, late-June 2006 and early-July 2007 (Tables 1 and 2). The epiphytotic progressed slowly until mid-July 2005, when disease resulted in 22 to 40% turf loss (Tables 1 and 2). Disease severity reached 55% turf area infested in some treatments by early July 2006. Chlorothalonil was applied to lessen the severity of the epiphytotic on 14 July 2006, although disease severity increased through mid-August (48 to 72%) before declining in September. Disease severity gradually increased to 42 to 58% by mid-August 2007.

Mefluidide Trial

Mefluidide had little effect on disease severity; influencing disease on only two of 13 observation dates during the three-yr trial (Table 1). Mefluidide initially reduced disease severity 2% compared to non-ME treated turf under low pressure on 14 June 2005. At the height of the epidemic in 2006, ME slightly increased disease 4%, but did not affect disease on the remaining dates. There was no ME effect on disease severity in 2007. No interactions between ME and TE were observed throughout the trial.

The TE main effect consistently reduced disease in 2005 and 2006 (75% of observations) but had no effect in 2007 (Table 1). Both TE intervals reduced disease severity 4% on 2 July 2005, although only the 7-d treatment reduced disease (18%) on 15 July. In 2006, both TE intervals reduced disease severity 9 to 29% from 23 June to 16 Aug.; although 7 d applications were more effective at reducing disease than 14 d applications on 16 Aug. (20 vs 12% reduction, respectively).

Ethephon Trial

Ethephon reduced disease severity on 7 out of 13 observation dates throughout the three-yr trial (Table 2). Spring EP applications reduced disease severity 3 to 9% in July 2005 and 7 to 22% from June through September 2006 compared to non-EP treated turf (Table 2). The EP main effect did not influence disease severity in 2007.

Trinexapac-ethyl did not influence disease severity in 2005; however, TE reduced disease severity throughout 2006 and during August 2007 (Table 2). Trinexapac-ethyl applied every 7 d reduced disease 8 to 22% during 2006 compared to non-TE treated turf. Similarly, 14 d TE applications reduced disease severity 6 and 16% early in the epidemic on 23 June and 3 July 2006, respectively (Table 2). Trinexapac-ethyl applied every 14 d did not differ from 7 d applications up to the peak of the epidemic on 21 July 2006. In 2007, the 7-d TE treatment reduced disease severity 15 to 16% compared to non-TE treated on 4 and 16 Aug., and the 14-d TE treatment reduced disease 9% by the last observation date (16 Aug.) (Table 2).

Ethephon and TE interacted late in the epidemic during 2006 and 2007 (Table 2); although these results generally supported the effect of main factors on disease. Subtle treatment differences were inconsistent among years and considered as random effects (data not shown).

Seedhead Expression

Mefluidide Trial

Mefluidide reduced seedheads 12 to 15% throughout the trial when seedhead expression was relatively high (45 to 85%) in May each year (Table 3). The ME main effect was not significant in June each year as seedheads were waning.

The TE main effect influenced seedhead expression on 6 of 9 observation dates (Table 3). Both 7 and 14 d intervals increased seedheads except on 5 June 2007 when only the 14 d interval had greater seedhead expression than non-TE treated turf. Seedheads were 4 to 16% greater in turf treated with TE every 7 d than turf treated every 14 d on 24 May and 9 June 2006 and 5 and 19 June 2007.

An interaction between ME and TE on 4 June 2005 (Table 3) indicated that TE increased seedheads 13 to 14% in the absence of ME (Table 4); whereas TE had no effect on seedheads in turf previously treated with ME. On the same date, ME reduced seedheads 13% in turf subsequently treated every 7 d with TE, but had no effect when TE was applied every 14 d or not at all (Table 4).

Ethephon Trial

Ethephon consistently reduced seedhead expression 12 to 47% throughout the three-yr trial (Table 5). Generally TE treated turf retained seedheads longer, especially when TE was applied every 7 d compared to non-TE treated turf (Table 5), similar to the ME trial. Seedheads were 4 to 12% greater in turf treated with TE every 7 d than turf treated every 14 d on 4 of 9 observation dates.

The interaction between EP and TE (observed on 3 of 9 dates during the trial) indicated that the retention of seedheads with TE was eliminated when TE was applied after EP. Seedheads were more abundant with decreasing TE application interval in the absence of EP (Table 6); whereas TE had no effect on seedheads when applied to EP treated turf. Ethephon reduced seedheads 20 to 61% regardless of TE on each interaction date (Table 6).

Turf Quality

Mefluidide Trial

Mefluidide generally improved turf quality and an interaction with was TE observed on four of these dates (Table 7). Mefluidide improved turf quality at both TE application intervals on 13 May 2005 and 2 June 2006, but had no effect on non-TE treated turf (Table 8). Similarly, ME improved turf quality of 7 d TE treated turf, but had no effect when TE was applied every 14 d or not at all on 28 June 2006. Conversely, ME only improved quality of non-TE treated turf on 14 May 2007.

Trinexapac-ethyl tended to reduce turf quality due to greater seedheads during high to moderate seedhead expression in 2005, 2006, and 2007 (Table 7 and 8). Interactions between ME and TE on 13 May 2005 and 2 June 2006 indicated that ME application negated this reduction in turf quality caused by TE, because there were fewer seedheads in ME treated turf (Table 8). Reduced quality was only observed at the 7-d TE treatment regardless of ME level on 11 May 2006 (Table 7), in the absence of ME on 28 June 2006 (Table 8), and in combination with ME on 14 May 2007. Trinexapac-ethyl improved turf quality in July 2005 and 2006 (Table 7) when disease severity was increasing (Table 2) and seedhead expression had dissipated (Table 3).

Ethephon Trial

Ethephon improved turf quality on 13 of 14 observation dates (Table 9) in part because it reduced seedheads throughout the three-yr trial and decreased disease severity in 2005 and 2006. Spring EP application maintained turf quality at or above the minimum acceptable level (i.e., ≥ 5); albeit marginally acceptable, except in April 2006 and 2007 prior to the resumption of vigorous turf growth, or in July 2005 and 2006 when quality declined during high disease pressure (Table 9).

Trinexapac-ethyl applied every 7 or 14 d improved turf quality on 21 July 2005 and 17 July 2006 during increasing disease pressure (Table 9). Trinexapac-ethyl influenced turf quality earlier in 2007 (14 May) when seedheads were present; TE applied every 14 d improved turf quality compared to non-TE treated turf (Table 9) while 7-d treatment had a similar level of quality to 14-d and non-TE treated turf.

Trinexapac-ethyl interacted with EP to affect turf quality during June 2006 and 2007 (Table 9) as seedheads were waning and prior to severe damage from disease. The interaction generally indicated that improved turf quality with TE use was either only evident (2 June 2005 and 19 June 2007) or more evident (28 June 2006) when EP was also applied (Table 10).

DISCUSSION

Mefluidide applied for seedhead control had little effect on anthracnose severity regardless of TE application in the current trial. Inguagiato et al. (2008a) also reported that spring ME application had little effect on disease; although ME applied in conjunction with TE (applied every 14 d) did reduce anthracnose severity compared to each growth regulator applied alone. They suggested that ME, followed by sequential applications of TE improved plant health in part by reducing seedheads, increasing root growth potential (Cooper et al., 1987; Cooper et al., 1988; Hanson and Branham, 1987) and avoiding post-inhibition growth enhancement (Spak et al., 1993). In the current trial, ME probably did not sufficiently inhibit seedhead production (only 12 to 15% reduction) to adequately divert photosynthate from the developing inflorescence (Ong and Marshall, 1975) to improve root growth and reduce disease.

Ethephon provided better control of seedheads and improved turf quality throughout the three year trial. Disease reductions in EP treated turf may have been due in part to improved plant vigor resulting from seedhead inhibition (Ong and Marshall, 1975), and subsequent reallocation of photosynthate away from seedhead development similar to the effect of ME proposed by Inguagiato et al., (2008a). Improved root growth has been reported following spring EP application at 2.24 kg a.i. ha^{-1} (Christians and Nau, 1984) or 1000 mg a.i. L^{-1} (Eggens and Wright, 1985). However, increased rates (3.4 to 7.6 kg a.i. ha^{-1}) applied during summer reduced root growth (Jiang and Fry, 1998; McCullough et al., 2006) or had no effect (Dernoeden, 1984; Christians, 1985). Therefore, EP should only be applied in the spring at rates similar to those used in this trial to reduce seedheads, improve quality and reduce anthracnose.

Ethylene, the biologically active form of EP, is an important signaling molecule in plant-pathogen interactions (Ecker and Davis, 1987; Roby et al., 1986). Chitinase activity has been positively correlated with increased ethylene production in melon (*Cucumis melo* cv. Cantaloup charentais) in response to elicitors (purified mycelia extract) derived from *Colletotrichum lagenarium*, the causal agent of anthracnose in melon (Roby et al., 1986). Ethylene has also been shown to induce plant defense response genes which enhance lignin synthesis and phytoalexin production in carrot (*Daucus carota* L.) (Ecker and Davis, 1987). In the current study, EP applications may have induced some of these plant defense compounds in ABG, thus inhibiting infection of *C. cereale*; however this hypothesis has not been tested.

Trinexapac-ethyl occasionally reduced anthracnose severity in both the ME and EP trials. Shorter TE application intervals (7 d) were sometimes more effective at reducing disease severity late in the epidemic when disease pressure was greater than extended intervals (14 d). Prior to recent research, turf managers were concerned that TE may enhance anthracnose severity by reducing turf growth, and limiting recovery from disease symptoms. However, results from the current trial and previous studies (Crouch et al., 2003; Inguagiato et al., 2008a; Vincelli and Doney, 1999) indicate that TE does not enhance and may occasionally reduce anthracnose severity. Trinexapac-ethyl has been suggested to reduce disease severity by improving physiological and morphological characteristics of turf which enhance tolerance to anthracnose by improving plant vigor and minimizing stress (Inguagiato et al., 2008a).

Inconsistent reduction of disease on TE-treated turf (e.g. reduced disease two out of three years in these trials) suggest that additional factors may influence the effect of

TE on anthracnose severity. Trinexapac-ethyl had the most pronounced effect on disease severity in 2006; when turf received an additional 31.7 kg N ha^{-1} from March through May compared to these months in 2005 and 2007. Inguagiato et al. (2008a) observed that sequential applications of ME and TE reduced disease when N was applied every 7 d (4.9 kg ha^{-1}); whereas the same growth regulator combination had no effect on disease severity when turf was fertilized every 28 d at the same rate. Additional research has found that TE enhanced nitrogen allocation to roots compared to shoots of hybrid bermudagrass (*Cynodon dactylon* X *C. transvaalensis* Burtt-Davey); which may improve N use efficiency since less N would be removed as clippings (Fagerness et al., 2004). Therefore, it may be possible that TE treated turf, in the current trials, utilized increased N applied in 2006 more efficiently and reduced disease; since increased N fertility is known to reduce anthracnose severity (Inguagiato et al., 2008a).

Seedhead retention was extended when TE was applied, particularly at the 7-d interval. A previous study reported a similar effect of TE on seedheads due to the more decumbent growth habit of TE treated turf which prevented their mechanical removal by routine mowing (Inguagiato et al., 2008a). Although, in some cases applying ME or EP negated the TE effect on seedheads and improved turf quality of TE treated turf early in the season.

CONCLUSIONS

Plant growth regulators (i.e., ME, EP and TE) can be an effective component of ABG putting green management to reduce seedheads and improve turf quality. However, to minimize prolonged seedhead expression and reduced turf quality during the spring on TE treated ABG turf, either ME or EP should be applied. Use of these plant growth regulators should not enhance anthracnose severity when applied at the rates and intervals used in this study. Occasionally, EP and TE may reduce anthracnose although this effect is not consistent. This trial also suggests that TE applied every 7 d at 0.05 kg a.i. ha^{-1} may reduce disease more than 14 d applications at the same rate. Results from this trial and previous work suggest that better seedhead inhibition is needed for ME to effectively reduce anthracnose severity.

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Table 1. Anthracnose disease response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005			2006					2007				
Main effect	14 June	2 July	15 July	23 June	3 July	21 July	16 Aug	12 Sept	3 July	12 July	27 July	4 Aug	16 Aug
	%												
Mefluidide (ME) †													
0	3.4	5.9	33.8	13.2	40.8	59.9	61.3	35.6	7.5	13.2	23.6	34.2	53.0
0.106 kg a.i. ha^{-1}	1.7	3.6	33.2	12.9	35.4	63.6	60.7	27.3	6.7	12.0	27.0	36.2	55.8
Trinexapac-ethyl interval(TE) ‡													
none	3.2	7.3	39.9	19.6	55.2	73.1	71.5	38.5	8.0	12.5	29.6	39.9	58.2
14 d	2.3	3.6	38.9	10.5	32.7	57.9	59.8	29.3	8.3	13.0	23.7	32.9	54.6
7 d	2.1	3.3	21.7	9.1	26.4	54.4	51.6	26.6	5.0	12.4	22.6	32.9	50.5
$LSD_{0.05}$	*NS*	*3.1*	*12.9*	*5.9*	*11.0*	*4.2*	*6.7*	*NS*	*NS*	*NS*	*NS*	*NS*	*NS*
						ANOVA							
Source of variation													
ME	**	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS
TE	NS	*	**	**	***	***	***	NS	NS	NS	NS	NS	NS
ME x TE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %	47.5	61.7	36.1	42.2	27.2	6.4	10.3	38.3	57.8	45.8	30.7	29.9	12.2

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 4 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 4 May to 26 July 2005, 26 April to 20 Sept.2006, and 25 Apr. to 29 Aug. 2007, or every 7 days from 28 Apr. to 26 July 2005, 19 Apr. to 20 Sept. 2006, and 18 April to 29 Aug. 2007.

Table 2. Anthracnose disease response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005			2006					2007				
Main effect	14 June	2 July	15 July	23 June	3 July	21 July	16 Aug	12 Sept	3 July	12 July	27 July	4 Aug	16 Aug
	%												
Ethephon (EP) †													
0	3.9	6.9	33.0	10.2	38.3	62.1	61.1	33.6	7.4	11.6	21.2	31.5	52.6
3.8 kg a.i. ha^{-1}	3.7	3.6	24.0	3.2	16.5	54.2	52.2	22.8	5.5	8.2	20.5	26.3	46.9
Trinexapac-ethyl interval(TE) ‡													
none	3.5	5.5	34.8	11.4	40.3	67.5	63.4	31.4	7.4	11.9	27.7	36.6	57.9
14-d	4.1	5.4	26.6	5.5	23.9	58.0	59.1	32.4	6.3	10.1	18.6	28.2	49.1
7-d	3.8	4.8	24.3	3.1	18.1	48.9	47.6	20.9	5.5	7.8	16.1	21.9	42.3
$LSD_{0.05}$	*NS*	*NS*	*NS*	*4.0*	*9.2*	*10.0*	*8.3*	*9.9*	*NS*	*NS*	*NS*	*12.4*	*8.3*
						ANOVA							
Source of variation													
EP	NS	*	*	***	***	^	**	**	NS	NS	NS	NS	NS
TE	NS	NS	NS	**	***	**	**	*	NS	NS	NS	^	**
EP x TE	NS	NS	NS	NS	NS	NS	^	*	NS	NS	NS	NS	*
CV, %	71.2	56.3	32.9	56.0	31.6	16.1	13.8	32.9	61.3	65.6	48.3	40.3	15.7

^,*, **, *** Significant at the 0.07, 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Ethephon was applied on 5 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} every 14 or 7 days from 5 Apr. to 27 July 2005, 31 Mar. 20 to Sept. 2006, and 28 Mar. to 29 Aug. 2007.

Table 3. Seedhead response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005			2006			2007		
Main effect	13 May	4 June	14 June	24 May	9 June	19 June	22 May	5 June	19 June
	%								
Mefluidide (ME) †									
0	85.0	55.2	20.0	59.6	32.4	30.8	60.0	35.8	35.0
0.106 kg a.i. ha^{-1}	73.3	50.6	21.7	44.6	33.1	32.5	45.0	35.8	36.3
Trinexapac-ethyl interval(TE) ‡									
none	72.4	50.9	18.8	43.8	28.6	26.3	69.4	27.5	26.3
14-d	83.8	55.0	23.1	52.5	32.8	33.0	76.9	31.9	34.4
7-d	81.3	52.8	20.6	60.0	36.9	35.6	75.6	48.1	46.3
$LSD_{0.05}$	*5.8*			*5.8*	*3.3*	*4.3*		*6.4*	*5.7*
				ANOVA					
Source of variation									
ME	***	NS	NS	***	NS	NS	***	NS	NS
TE	**	NS	NS	***	***	***	NS	***	***
ME x TE	NS	**	NS	NS	NS	NS	NS	NS	NS
CV, %	6.9	13.6	17.7	10.4	9.5	12.8	13.2	16.8	15.1

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 4 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 4 May to 26 July 2005, 26 April to 20 Sept.2006, and 25 Apr. to 29 Aug. 2007, or every 7 days from 28 Apr. to 26 July 2005, 19 Apr. to 20 Sept. 2006, and 18 April to 29 Aug. 2007.

Table 4. Seedhead response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ on 4 June 2005.

	Mefluidide	
Trinexapac-ethyl interval	None	0.106 kg a.i. ha^{-1}
d	----------- % -----------	
none	46.3b†A‡	55.5aA
14	60.0aA	50.0aA
7	59.3aA	46.3aB

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
‡Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 5. Seedhead response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005			2006			2007		
Main effect	13 May	4 June	14 June	24 May	9 June	19 June	22 May	5 June	19 June
	------------------------------- % -------------------------------								
Ethephon (EP) †									
0	80.0	55.3	19.6	64.2	33.9	32.8	60.0	37.9	43.8
3.8 kg a.i. ha^{-1}	68.5	32.3	8.1	17.5	10.3	9.5	25.0	10.4	8.3
Trinexapac-ethyl interval(TE) ‡									
none	75.9	36.6	13.8	35.4	17.8	17.1	38.8	18.8	16.5
14-d	73.1	44.8	14.6	37.5	22.1	21.8	43.8	23.1	25.9
7-d	73.8	49.9	13.1	49.6	26.5	24.6	45.0	30.6	35.6
$LSD_{0.05}$		*8.4*		*5.0*	*3.8*	*4.0*		*3.3*	*7.4*
				ANOVA					
Source of variation									
EP	***	***	***	***	***	***	***	***	***
TE	NS	**	NS	***	***	**	NS	***	***
EP x TE	NS	NS	NS	***	NS	NS	NS	***	*
CV, %	6.6	18.0	27.8	11.4	16.1	17.6	14.4	12.7	26.6

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Ethephon was applied on 5 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} every 14 or 7 days from 5 Apr. to 27 July 2005, 31 Mar. 20 to Sept. 2006, and 28 Mar. to 29 Aug. 2007.

Table 6. Seedhead response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2006 and 2007.

	2006		2007			
	24 May 2006		5 June		19 June	
	Ethephon					
Trinexapac-ethyl interval	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}
d	%					
none	52.5c†A‡	18.3aB	28.8cA	8.8aB	28.8cA	4.3aB
14	60.0bA	15.0aB	36.3bA	10.0aB	45.0bA	6.8aB
7	80.0aA	19.3aB	48.8aA	12.5aB	57.5aA	13.8aB

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

‡Means within rows and rating date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 7. Turf quality response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005				2006						2007			
Main effect	13 May	13 June	12 July	21 July	10 Apr	11 May	2 June	28 June	17 July	25 Aug	18 Apr	14 May	19 June	19 July
	---------- 1-9 scale[§] ----------													
Mefluidide (ME)[†]														
0	3.3	4.7	4.9	3.3	3.8	4.3	3.5	4.0	2.7	4.2	3.0	4.9	5.5	5.0
0.106 kg a.i. ha^{-1}	3.9	6.3	4.9	3.6	3.7	4.2	4.3	4.7	2.7	4.1	2.8	5.7	5.5	4.9
Trinexapac-ethyl interval(TE)[‡]														
none	4.0	5.6	4.0	2.3	3.8	4.9	4.3	4.1	1.4	3.5	2.6	5.4	6.4	5.4
14-d	3.6	5.6	5.1	3.4	3.6	4.5	3.9	4.3	2.8	4.4	2.8	5.5	5.5	4.9
7-d	3.3	5.1	5.6	4.6	3.9	3.3	3.5	4.6	3.9	4.5	3.3	5.0	4.6	4.6
$LSD_{0.05}$	*0.4*	*NS*	*1.2*	*0.7*	*NS*	*0.5*	*0.5*	*NS*	*0.6*	*NS*	*NS*	*NS*	*0.7*	*NS*
							ANOVA							
Source of variation														
ME	***	***	NS	NS	NS	NS	***	**	NS	NS	NS	**	NS	NS
TE	**	NS	*	***	NS	***	*	NS	***	NS	NS	NS	***	NS
ME x TE	*	NS	NS	NS	NS	NS	*	***	NS	NS	NS	**	NS	NS
CV, %	9.5	14.8	23.5	20.2	21.0	10.8	12.1	11.4	22.0	28.2	22.5	9.9	12.0	25.0

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

[†] Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 4 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

[‡] Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 4 May to 26 July 2005, 26 April to 20 Sept.2006, and 25 Apr. to 29 Aug. 2007, or every 7 days from 28 Apr. to 26 July 2005, 19 Apr. to 20 Sept. 2006, and 18 April to 29 Aug. 2007.

[§]9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.

Table 8. Turf quality response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2005, 2006, and 2007.

	2005		2006				2007	
	13 May		2 June		28 June		14 May	
	Mefluidide							
Trinexapac-ethyl interval	None	0.106 kg a.i. ha^{-1}	None	0.106 kg a.i. ha^{-1}	None	0.106 kg a.i. ha^{-1}	None	0.106 kg a.i. ha^{-1}
d	1-9 scale§							
none	4.0a†A‡	4.0aA	4.3aA	4.3aA	4.3aA	4.0bA	4.5aB	6.3aA
14	3.3bB	4.0aA	3.5bB	4.3aA	4.3aA	4.3bA	5.3aA	5.8abA
7	2.8bB	3.8aA	2.8bB	4.3aA	3.5bB	5.8aA	5.0aA	5.0bA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
‡Means within rows and rating date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.

Table 9. Turf quality response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005				2006						2007			
Main effect	13 May	13 June	12 July	21 July	10 Apr	11 May	2 June	28 June	17 July	25 Aug	18 Apr	14 May	19 June	19 July
	------------------- 1-9 scale§ -------------------													
Ethephon (EP) †														
0	3.8	4.9	4.5	3.3	3.8	4.8	3.9	4.8	2.3	3.9	2.3	5.1	5.3	5.2
3.8 kg a.i. ha^{-1}	5.3	7.8	6.2	3.7	4.3	6.1	6.7	7.5	3.3	5.3	3.5	6.5	8.1	6.4
Trinexapac-ethyl interval(TE) ‡														
none	4.6	6.6	5.0	2.4	4.3	5.6	5.4	5.3	1.5	4.6	3.0	5.3	7.1	5.9
14-d	4.8	6.8	5.8	4.0	4.0	5.4	5.1	6.3	3.1	4.1	2.9	6.3	6.8	5.6
7-d	4.4	5.8	5.3	4.0	3.8	5.3	5.4	7.0	3.6	5.0	2.8	5.9	6.3	6.0
$LSD_{0.05}$	*NS*	*NS*	*NS*	*0.6*	*NS*	*NS*	*NS*	*0.5*	*0.7*	*NS*	*NS*	*0.7*	*0.6*	*NS*
						ANOVA								
Source of variation														
EP	***	***	**	NS	*	***	***	***	**	*	***	***	***	*
TE	NS	NS	NS	***	NS	NS	NS	***	***	NS	NS	*	*	NS
EP x TE	NS	NS	NS	NS	NS	NS	*	*	NS	NS	NS	NS	*	NS
CV, %	9.2	15.2	20.5	16.6	12.6	7.3	11.7	8.0	25.1	28.2	22.2	11.5	8.4	22.7

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Ethephon was applied on 5 and 20 Apr. 2005, 31 Mar. and 12 Apr. 2006, and 28 Mar. and 11 Apr. 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} every 14 or 7 days from 5 Apr. to 27 July 2005, 31 Mar. 20 to Sept. 2006, and 28 Mar. to 29 Aug. 2007.

§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.

Table 10. Turf quality response to ethephon and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2006 and 2007.

	2006				2007	
	2 June		28 June		19 June	
	Ethephon					
Trinexapac-ethyl interval	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}
d	1-9 scale§					
none	4.3a†B‡	6.5abA	4.3bB	6.3cA	6.0aA	5.8bA
14	4.0aB	6.3bA	5.0abB	7.5bA	4.5bB	6.8aA
7	3.5aB	7.3aA	5.3aB	8.8aA	5.3abB	6.8aA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
‡Means within rows and rating date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.

CHAPTER 5. Sand Topdressing Rate and Interval Effects on Anthracnose Disease Severity of an Annual Bluegrass Putting Green

ABSTRACT

Sand topdressing has been reputed to increase anthracnose caused by *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman on annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] putting green turf. Three field trials were conducted to evaluate the effect of sand topdressing rate (0, 0.3, 0.6 and 1.2 L m^{-2}), frequency (42, 28, 21, 14 and 7 d) and brushing on anthracnose severity of annual bluegrass turf maintained at 3.2 mm during 2006 and 2007. Topdressing at 0.3 L m^{-2} every 7 d enhanced disease initially during the first year of the trial. However, continued topdressing reduced anthracnose severity 3 to 47% later in the epidemic in 2006 and throughout 2007. Topdressing at 1.2 L m^{-2} every 21 and 42 d reduced disease severity 15 to 28% in 2006 and 2007; sand applied every 21 d resulted in less disease (5 to 13%) than the 42 d interval in 2007. Topdressing rate (0, 0.3 and 0.6 L m^{-2}) and interval (28, 14 and 7 d) interacted to affect anthracnose severity in both years. As sand rate increased, a curvilinear disease reduction occurred at the 14- and 7-d intervals in both years. Similarly, when sand was applied shorter topdressing intervals resulted in a curvilinear (2006) and linear (2007) disease reduction. Light brushing every 7 d had no effect on disease in the presence (0.3 L m^{-2}) or absence of topdressing. Topdressing at 0.3 L m^{-2} every 7 d or 0.6 L m^{-2} every 14 d provided the most rapid and effective reduction in disease severity and the best turf quality. These data suggest that wounding and/or

abrasion associated with topdressing typically does not enhance anthracnose severity and that disease becomes less severe as sand accumulates within the turf canopy.

INTRODUCTION

Anthracnose disease epiphytotoics, caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman (Crouch et al., 2006), have increased in incidence and severity during the past 15 years (Dernoeden, 2002a). Annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] maintained as putting green turf is most commonly affected in the United States, although the disease also occurs on creeping bentgrass (*Agrostis stolonifera* L.) (Smiley et al., 2005).

Disease outbreaks on putting green turf are believed to be associated with cultural practices that may enhance abiotic stress (Dernoeden, 2002a; Smiley et al., 2005; Zontek, 2004b). Recent research has demonstrated that reduced summer N fertility (Inguagiato et al., 2008a) and low mowing heights (Inguagiato et al., 2008b) intensify anthracnose epiphytotics on ABG putting greens presumably by reducing plant vigor. Other cultural practices perceived to be stressful, such as sand topdressing, have been thought to increase anthracnose by facilitating fungal entry of the host plant through open wounds (Dernoeden, 2002a; Smiley et al., 2005). However, no empirical or experimental evidence demonstrating the effect of sand topdressing on anthracnose severity have been reported.

Topdressing involves the application of a thin layer of soil (typically sandy soils on putting greens) to the turf surface to minimize thatch accumulation, smooth the surface, modify soil and provide winter protection (Beard, 1973). Information regarding the effect of topdressing on turfgrass diseases is limited and inconsistent. Reports on dollar spot (caused by *Sclerotinia homoeocarpa* F.T. Bennett) indicate that disease severity can increase with monthly topdressing of sandy loam (8 to 10% organic matter) at 1.6 L m^{-2} (Engel and Alderfer, 1967), and coarse-sand or loamy coarse-sand applied monthly at 0.9 L m^{-2} to creeping bentgrass (*Agrostis stolonifera* L.) maintained at 6.4 mm (Cooper and Skogley, 1981). Whereas, other studies found that topdressing had no effect on dollar spot development of bermudagrass [*Cynodon dactylon* (L.) Pers. X *C. transvaalensis* Burtt-Davy] fairway turf receiving 6.4 L m^{-2} of sand once or twice yr^{-1} (Carrow et al., 1987) or creeping bentgrass greens sand topdressed monthly or biweekly at 0.4 or 0.2 L m^{-2}, respectively (Stier and Hollman, 2003). However, disease was reduced by monthly sand topdressing at 3.6 L m^{-2} to fairway turf (Henderson, 2007).

Topdressing programs for putting green turf vary in application rate and interval. Typically sand is applied at low rates with short intervals or increased rates at extended intervals (Beard, 2002). Previous studies have determined that more frequent topdressing is more effective at reducing thatch depth (Callahan et al., 1998; White and Dickens, 1984) and percent organic matter by weight (Carrow et al., 1987) than sand applied less often. However, labor and equipment maintenance costs of frequent topdressing programs can be prohibitive, thus less frequent applications at higher rates are commonly used.

To date, the impact of topdressing on anthracnose disease has not been investigated. However, wounding and abrasion associated with topdressing is believed to enhance the disease. Thus, the objectives of these trials were to determine the effects of i) sand topdressing and incorporation (brushing) applied at a low rate and short interval; ii) sand topdressing at an increased rate and extended intervals; and iii) multiple sand rates, intervals and their potential to interact on anthracnose severity and turf quality.

MATERIALS AND METHODS

Field trials were initiated in 2006 on an ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 6.6 in North Brunswick, NJ. The monostand of ABG turf was established in August 2002 as described by(Inguagiato et al., 2008a). Prior to the initiation of the study, the site was inoculated with *C. cereale* isolate ValP-04 in July 2003 (Inguagiato et al., 2008a).

Turf was mowed seven times wk^{-1} with a walk-behind greens mower (model 220B, Deere & Company, Moline, IL) equipped with a grooved front roller (model AMT2979, Deere & Company, Moline, IL) at a bench setting of 3.2 mm. Nitrogen (water soluble sources) was applied to the trial 18 times from March to October 2006 totaling 164 kg ha^{-1} and 18 times from April to October 2007 totaling 196 kg ha^{-1}. Phosphorous and potassium were applied based on soil test results at 20.2 and 40.7 kg ha^{-1} in 2006 and 11.9 and 34.4 kg ha^{-1} in 2007 as actual P and K, respectively. Irrigation was applied only when wilt stress was imminent and to wash-in fertilizer and topdressing to maintain relatively dry soil conditions. Ethephon [(2-chloroethyl) phosphonic acid] was applied at 3.8 kg a.i. ha^{-1} on 31 Mar. and 12 Apr. 2006 and 28 Mar. and 11 Apr. 2007 for seedhead control. Trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethylester] was applied at 0.05 kg a.i. ha^{-1} every 14 d from 31 Mar. to 22 Sept. 2006 and 28 Mar. to 26 Oct. 2007 to mimic growth regulation practices commonly employed on golf course putting greens. Anthracnose was suppressed on 12 May 2007 with chlorothalonil (tetrachloroisophthalonitrile) at 13.3 kg a.i. ha^{-1} to permit collection of turf quality data on undamaged turf. The disease was also arrested between trial years with applications of chlorothalonil at 15.7 and 17.9 kg a.i. ha^{-}

^{1} on 7 and 26 Sept. 2006, respectively. To encourage recovery from anthracnose damage, the entire field was core-aerified in late-September 2006; soil cores were pulverized, topdressed with sand at 1.7 L m^{-2} and reincorporated using a box-link, brush and cocoa mat drags (Ace Equipment and Supply Co., Henderson, CO). Dollar spot disease was preventatively controlled from April 2006 and May 2007 through October each year with vinclozolin [3-(3, 5-dichlorophenyl)-5-ethenyl-5-methyl-2, 4-oxazolidinedione] at 1.5 to 1.8 kg a.i. ha^{-1} or boscalid {3-pyridinecarboxamide, 2-chloro-N-[4'-chloro(1,1'-biphenyl)-2-yl]} at 0.4 kg a.i. ha^{-1} every 14 d. Brown patch (caused by *Rhizoctonia solani* Kühn) was suppressed with bi-weekly applications of flutolanil {N-[3-(1-methylethoxy) phenyl]-2-[trifluoromethyl] benzamide} at 3.2 to 5.8 kg a.i. ha^{-1} from June through August 2006 and May through July 2007and azoxystrobin [methyl (*E*)-2-{2-[6-(2-cyanophenoxy)pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate] at 0.3 to 0.6 kg a.i. ha^{-1} in September 2006 and from July through August 2007. Thiophanate-methyl was applied at 9.3 kg a.i. ha^{-1} on 8 Sept. 2006 to control summer patch (*Magnaporthe poae* Landschoot and Jackson). Algal growth was suppressed with mancozeb (coordination of Mn^{2+}, Zn^{2+} and ethylene bisdithiocarbamate) at 21.4 kg a.i. ha^{-1} as necessary in June and July 2007. These fungicides had previously been determined not to affect the development of anthracnose at this site. Annual bluegrass weevil [*Listronotus maculicollis* (Kirby)] was controlled with applications of bifenthrin {[2-methyl(1,1'-biphenyl)-3-yl]methyl 3-[2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} at 0.13 kg a.i. ha^{-1} in May both years. Creeping bentgrass and pearlwort [*Sagina subulata* (Sw.) C. Presl] were eliminated from the trial area with applications of fluazifop-P-butyl [Butyl(*R*)-2-(4-{[5-(trifluoromethyl)-2-

pyridinyl]oxy}phenoxy)propanoate] at 0.2 kg a.i. ha^{-1} in May and September 2006 and August and September 2007, and MCPP [2-(2-methyl-4-chlorophenoxy) propionic acid] at 0.5 kg a.i. ha^{-1} in August and September 2007, respectively.

Treatment Design

Three trials were conducted within the same field using a randomized complete block design with four blocks. Treatments in the first trial (Trial 1) were arranged as a 2 by 2 factorial of sand topdressing (no sand and sand applied at 0.3 L m^{-2} [0.3 mm depth] every 7 d) and brushing (no brushing and brushing after sand was applied). The second trial (Trial 2) consisted of sand applied at 1.2 L m^{-2} (1.2 mm depth) every 21 or 42 d and an untreated check. The third trial (Trial 3) was a 3 by 3 factorial arrangement of sand rate (no sand, 0.3 and 0.6 L m^{-2} [0.6 mm depth]) and application interval (every 7, 14 and 28 d). All plots were brushed uniformly regardless of sand rate in this trial, corresponding with the application interval for each treatment.

Treatments were conducted between 1300 and 1600 hr when the turf canopy was dry from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007. Sand was applied by placing the required volume of dry sand for each rate $plot^{-1}$ in a drop spreader (The Scotts Company, Marysville, OH) calibrated to uniformly distribute the material in four passes. The silica sand topdressing (pH 7.0) was sub-angular and conformed to the particle size distribution recommended for sand putting green root zones (Staff, 2004) (Table 1). A brush (91 by 23 cm) was constructed by mounting three broom heads with medium-stiff synthetic bristles (model 7436, Harper Brush Works, Inc. Fairfield, IA) to a plywood board with two extended handles. Individual plots were brushed by manually pulling the brush across each half of the plot four times for sand rates ranging from 0 to 0.6 L m^{-2}

and eight times for 1.2 L m^{-2} of sand. The entire experimental area was lightly irrigated to further settle sand into the turf canopy after topdressing and brushing procedures. All treatments were repeated in the same location each year.

Data Collection and Analysis

Anthracnose severity was periodically assessed from June through September 2006 and June through October 2007 as the percent turf area infested with *C. cereale* using a line-intercept grid count method developed by Inguagiato et al. (2008a). Turf quality was visually on a monthly basis 7 d after topdressing was applied using a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from June through September each year. Turf density, uniformity, color, algae, sandiness (unincorporated sand) seedhead expression and disease severity were taken into consideration when assessing turf quality.

Data for trials one and two were subjected to analysis of variance using the General Linear Model procedure in the Statistical Analysis System (SAS) software v. 9.1.3 (SAS Institute Inc., Cary, NC), and single degree of freedom contrasts were used to test treatment effects (Steel et al., 1997b). Data from trial three were also subjected to analysis of variance to determine main effects and interaction effects. Means of main effects were considered significantly different based on an *F* test (at the 0.05 probability level) and interaction means were separated by Fisher's protected least significant difference test at the 0.05 probability level. Total sum of squares were partitioned using single degree of freedom contrasts to test for linear and quadratic effects as well as potential interactions associated with sand rate and application interval. The treatment by time interaction was tested within years; consecutive non-significant treatment by date observations were pooled and subjected to the same procedures previously described. Parameter estimates were derived for significant and non-significant (if higher order terms were significant) linear and quadratic terms of sand rate and application interval by the Regression procedure in SAS for the pooled data. Surface response curves were constructed from these data using the user defined sub-routine of the Nonlinear Regression procedure in SigmaPlot software v. 9.0 (SYSTAT Inc., Chicago, IL).

RESULTS

Initial anthracnose basal rot symptoms were apparent throughout the field by 20 June 2006 and progressed, at a moderate rate, until 12 July after which disease rapidly increased (Figure 1). The epiphytotic reached peak levels (42 to 74%) from 7 to 16 August before declining through mid-September 2006. Disease developed at a similar time in 2007, but was less severe (peaking at 37%) than the previous year. Anthracnose developed rapidly between 25 July and 25 Aug. 2007 before leveling off and declining after 28 Sept. (Figure 2).

Trial 1: Low Rate-Short Interval

Anthracnose Severity

Sand applied at 0.3 L m^{-2} every 7 d had no effect on disease development until 12 July 2006 when disease severity increased by 8% compared to non-sanded turf (Figure 1). Anthracnose was unaffected by topdressing on 20 July as the epiphytotic intensified; however, continued topdressing substantially reduced anthracnose severity 17 to 26% at the height of the disease outbreak (7 to 16 August) in 2006. As disease subsided and topdressing continued at 0.3 L m^{-2} every seven days, anthracnose severity was dramatically reduced 34 to 47% compared to non-topdressed turf from 28 August to 11 September. In 2007, topdressing at 0.3 L m^{-2} every 7 d consistently (9 out of 10 observations) reduced anthracnose severity (3 to 26%; Figure 2). Furthermore, topdressing reduced disease earlier in the epidemic during 2007 than in 2006 and never increased disease severity. The brushing factor had no effect on anthracnose severity and there was no interaction between sand and brushing throughout the two-year trial (data not shown).

Turf Quality

Turf quality of all treatments was acceptable (i.e., ≥ 5) during June and July before severe disease damage occurred each year, except for the non-topdressed, non-brushed treatment on 19 July 2007 (Table 2). Applying sand at 0.3 L m^{-2} every 7 d improved turf quality on 9 Aug. and 8 Sept. 2006 as well as 19 July and 13 Sept. 2007 compared to non-sand treated turf. Sand interacted with brushing to effect quality on 13 June and 19 July 2007 (Table 2). On these dates, sand topdressing only improved quality of non-brushed turf; brushing did not affect quality regardless of sand treatment. No other brushing or interaction effects on turf quality were observed during the trial.

Trial 2: Increased Rate-Extended Intervals

Anthracnose Severity

Sand applied at 1.2 L m^{-2} every 21 and 42 days did not affect anthracnose from 19 June to 16 August (Figure 3), but did reduce ($p < 0.10$) disease severity 22 to 28% by the last two observation dates in 2006. Topdressing at 1.2 L m^{-2} influenced anthracnose much earlier in 2007, reducing disease 5 and 4% on 18 and 25 July 2007, respectively, when disease severity was low (Figure 4). The topdressing effect was more apparent as the epiphytotics intensified in 2007 reducing anthracnose 15 to 25% from 13 August to 5 October. Topdressing at the 21-d interval reduced disease (5 to 13%) on 5 of 10 observation dates compared to the 42-d interval applied at the same rate in 2007 (Figure 5), although interval had no effect on anthracnose severity in 2006 (data not shown).

Turf Quality

Increased sand application rate (1.2 L m^{-2}) reduced turf quality on 7 July 2006 (Table 3) due to residual sand on the turf surface. However, sand rate did not affect turf quality on the remaining observation dates in 2006. Conversely, topdressing with 1.2 L m^{-2} sand improved turf quality from 19 July through 13 Sept. 2007 compared to non-sanded turf (Table 3). Topdressing every 21 d maintained acceptable turf quality compared to the 42 d interval when applied at the same rate on 19 July and 15 Aug. 2007 (Table 3), by reducing disease severity (Figure 5).

Trial 3: Application Rates & Intervals

Anthracnose Severity

Sand rate and application interval did not affect anthracnose severity from 20 June to 20 July 2006 or from 22 June to 18 July 2007 (Table 4) when disease severity was low. However, sand rates (0, 0.3 and 0.6 L m^{-2}) and application intervals (28, 14 and 7 d) interacted to influence anthracnose severity during the latter portion of the disease epidemic in 2006 ($Rate_{Quadratic}$ x $Interval_{Quadratic}$) and 2007 ($Rate_{Quadratic}$ x $Interval_{Linear}$) (Table 4). Increasing sand rate provided a curvilinear response when applied every 7 and 14 d in 2006 (Figure 6). The response slopes were greatest (that is, greatest disease reduction) at the 7-d interval when rate increased from no sand to 0.3 L m^{-2}, and at the 14-d interval when rate increased from 0.3 to 0.6 L m^{-2}. Similarly, disease declined in a curvilinear manner with increasing rate at the 7- and 14-d intervals in 2007 (Figure 7), although sand applied at 0.3 L m^{-2} every 14 d appeared to reduce disease more effectively than was observed in 2006. Sand rates (0, 0.3 and 0.6 L m^{-2}) applied every 28 d had less of an effect in reducing disease than the same rates applied more often both years of the trial (Figures 6 and 7). Increasing sand rate at 28 d intervals reduced disease severity linearly in 2006, although at the rates evaluated in this trial, the 28 d interval was not as effective at reducing disease than 7 and 14 d intervals (Figure 6). In 2007, disease severity increased in a curvilinear manner from the no-sand to the 0.3 L m^{-2} rate before declining at the 0.6 L m^{-2} rate applied every 28 d (Figure 7).

Shorter application intervals provided a curvilinear response in 2006; disease declined steadily at 0.6 L m^{-2} and had little effect at 0.3 L m^{-2} except when interval was reduced from 14 to 7 d (Figure 6). A linear reduction of anthracnose resulted when sand was applied more often at 0.3 and 0.6 L m^{-2} in 2007 (Figure 7).

Turf Quality

Acceptable turf quality was observed for all treatments in June 2006 and 2007 (Table 5) prior to the onset of disease. Generally, turf quality improved with topdressing; however the interaction in August and September 2006 and July and September 2007 (Table 5) indicated that rate and interval influenced the effect.

Turf quality was never better in non-topdressed than topdressed plots at any combination of application rate and interval (Table 5). Topdressing at 0.3 L m^{-2} required at least a 14 d interval to improve turf quality compared to non-topdressed turf, and further improvement was observed when the interval between topdressings was decreased to 7 d. Topdressing at 0.6 L m^{-2} improved turf quality at all intervals (28, 14 and 7 d) compared to non-topdressed plots, except on 19 July and 13 Sept. 2007 when the 14 and 7 d intervals did not improve turf quality due to excess sand on the turf surface (data not shown). Decreasing the interval between topdressings from 28 to 14 or 7 d often improved turf quality except at the 0.6 L m^{-2} rate the second year (2007).

DISCUSSION

Any wounding or bruising of turf caused by sand topdressing or brushing in these trials did not appear to have a significant effect on disease. Similarly, shallow verticutting (3 mm), which also causes wounding, conducted every 14 d from May to September had little effect on anthracnose (Inguagiato et al., 2008a); whereas, verticutting every 7 d for a month at depths (3 and 5 mm) great enough to remove thatch increased disease severity (Uddin et al., 2008). Inguagiato et al. (2008a) suggested that only extensive wounding (e.g., deep verticutting) may increase this disease; whereas less severe wounding does not increase anthracnose. Vernard and Vaillancourt (2007) demonstrated in maize (*Zea mays* L.) that wounding is not required for anthracnose stalk rot development, caused by *C. graminicola* (Ces.) G.W. Wils., although disease severity tended to be greater on wounded maize plants. Results from our trials support previous research demonstrating that anthracnose is not enhanced by minor wounding; however, future research is needed to quantify the impact of other cultural practices that may cause wounding on the severity of anthracnose on annual bluegrass.

Contrary to expectation these data (Trials 1, 2 and 3) indicate that topdressing at rates ranging from 0.3 to 1.2 L m^{-2} applied every 7 to 42 d generally reduced the disease. Sand accumulation within the turf canopy likely improves the surface structure due to bridging of sand particles around individual tillers. Turf grown on a firmer surface enhances tolerance to low mowing by increasing the effective cutting height since the load of the mower (rollers) is better supported and less likely to settle into the turf canopy. This effect has been reported in previous topdressing studies where sand applications reduced scalping severity of creeping bentgrass (McCarty et al., 2007) and bermudagrass (White and Dickens, 1984) putting green turf. Inguagiato et al. (2008b) demonstrated that slight increases (0.04 mm) in cutting height can reduce anthracnose severity. Therefore, it is probable that topdressing reduced disease severity in part by subtly increasing the effective height of cut.

Cores removed from topdressed plots at the conclusion of these trials contained tillers with elongated sheaths (approximately 7 mm vs. 2 to 3 mm for non-topdressed turf) and deep crowns concealed within an accumulated sand topdressing layer (i.e., mat layer). Elevation of crowns and roots above the soil substrate is one of the deleterious effects of thatch accumulation (Hurto et al., 1980; Ledoboer and Skogley, 1967). Maintenance of turfgrass crowns within thatch often results in turf decline due to the undesirable characteristics of this growth medium. Hurto et al. (1980) found that thatch from a Kentucky bluegrass (*Poa pratensis* L.) turf had lower water retention than the underlying silt loam, and noted that capillary discontinuity at the thatch-soil interface impairs water movement. Wet and dry thatch has also been shown to reduce initial water infiltration rate in sand columns; although sustained water flow was unaffected after 10 min (Taylor and Blake, 1982). Additionally, greater temperature fluctuation and higher thermal maxima occur in thatch compared to underlying soil (Beard, 1973; Zimmerman, 1973). Anthracnose is often most severe during summer stress (Smiley et al., 2005) when poor physical properties of thatch are exacerbated by high temperatures and intense, infrequent rain. Thus, topdressing to reduce thatch and encourage mat layer development should improve characteristics of the growing medium, enhance plant vigor and reduce anthracnose compared to non-topdressed turf. Furthermore, sheaths store carbohydrates (Turgeon, 1980) and the elongated sheaths observed in our topdressed plots may have retained more carbohydrates thereby maintaining growth during stressful summer conditions and contributing to reduced anthracnose severity.

Topdressing did not reduce disease until August 2006 after extensive damage (30 -70%) had occurred. Presumably, insufficient sand had accumulated to improve surface conditions and reduce disease earlier in the epidemic. This was also apparent at extended application intervals after 25 July 2007 when the 42 d interval was less effective at reducing anthracnose severity than the same rate (1.2 L m^{-2}) applied every 21 d. Topdressing treatments reduced disease earlier in the epidemic during 2007 probably because a sand layer (mat) was well developed from treatments applied the previous year.

Relatively low sand rates (0.3 to 0.6 L m^{-2}) applied at short intervals (7 to 14 d) provided the most rapid and substantial disease reduction, particularly during the first year of the trials. The higher sand rate (1.2 L m^{-2}) applied every 21 and 42 d also reduced anthracnose severity, although this effect took longer to develop in 2006. The cumulative amount of sand used throughout the season to topdress turf every 7 or 14 d at 0.3 or 0.6 L m^{-2} was similar to topdressing every 21 d at 1.2 L m^{-2} . However, a total of 3.6 and 4.8 L m^{-2} of sand was applied before anthracnose severity was reduced when topdressing at the higher rate and increased interval (21 d) in 2006 and 2007, respectively, compared to 3.3 and 2.7 L m^{-2} at the low-rate, short-interval treatments during this same time. Stier and Hollman (2003) found that routine mowing removed more sand when applied monthly at 0.4 L m^{-2} compared to biweekly applications at 0.2 L m^{-2}, suggesting that a greater quantity of sand is removed at increased topdressing rates. Therefore, in the current trial, a greater amount of sand topdressed every 21 d at 1.2 L m^{-2} was probably removed by mowing than at the lower, more frequently applied rates, thereby delaying sand accumulation in the canopy and subsequent disease reductions. However, topdressing every 21 d at 1.2 L m^{-2} did effectively reduce anthracnose severity once sufficient sand had accumulated.

Evaluation of sand rates (0, 0.3 and 0.6 L m^{-2}) and intervals (28, 14 and 7 d) in this work clearly illustrates that appreciable disease reductions can be achieved when sand is applied every 7 d at 0.3 or 0.6 L m^{-2}, or every 14 d at 0.6 L m^{-2}. However, sand applied every 7 d at 0.6 L m^{-2} was difficult to incorporate by late-July as the turf canopy had a decreasing capacity to retain the additional sand, resulting in reduced turf quality. Whereas, topdressing every 7 d at 0.3 L m^{-2} or every 14 d at 0.6 L m^{-2} was more readily incorporated into the canopy and generally improved turf quality later in the season due to the effect on disease. Anthracnose severity was also reduced and turf quality improved at the 28 d interval, albeit less effectively than shorter intervals, and generally only at the 0.6 L m^{-2} rate. Topdressing every 28 d at a greater sand rate than was evaluated in the current trial ($\geq$ 0.6 L m^{-2}) may have resulted in more substantial disease reductions, considering that the disease suppressive effects of sand were more pronounced in trial 2 when sand was applied every 21 vs. 42 d at 1.2 L m^{-2}.

Turf managers have reported instances where sand topdressing was believed to increase anthracnose severity of putting green turf. A brief increase in disease severity was observed in the first year (2006) of the current trials (1 and 2) when topdressing at 0.3 L m^{-2} every 7 d or 1.2 L m^{-2} every 21 and 42 d (although not statistically significant at 1.2 L m^{-2}) and in the first year of a two year sand topdressing/foot traffic study conducted at Rutgers Unversity in 2007 and 2008 (unpublished data). However, this effect did not persist in either study as topdressing treatments continued. Thus, it appears that multiple topdressings are required to develop a beneficial mat layer and improve surface firmness before disease is reduced. Furthermore, turf managers often topdress putting greens at lower rates than were used in these trials. Thus additional applications would be required at these rates to produce similar disease reductions that we report here. Therefore, it is possible that disease increases reported by turf managers on putting greens are an indication that topdressing is being applied at insufficient rates and/or frequencies. Turf managers struggling with anthracnose may need to increase sand rates and/or intervals to improve surface characteristics and reduce anthracnose severity.

CONCLUSION

Sand topdressing programs representative of current approaches used to manage putting green turf did not increase anthracnose severity, and in most cases reduced the disease. Data across all trials indicate that a sufficient accumulation of sand was required before disease reduction could be observed. Sand applied every 7 d at 0.3 L m^{-2} and 14 d at 0.6 L m^{-2} provided the most rapid and substantial reduction of disease and improved turf quality. However, extended intervals at increased rates (i.e., 21 d at 1.2 L m^{-2}) provided a similar, but delayed (2006) result. Light brushing every 7 d with and without sand had no effect on anthracnose severity. Wounding/brusing associated with sand topdressing or brushing did not antagonize this disease.

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Table 1. Particle size distribution of sand used for topdressing in trials 1, 2 and 3.

Sieve size opening					
2 mm	1 mm	500 µm	250 µm	149 µm	53 µm
---------------------------------- % (by weight) ----------------------------------					
0	0.17	20.66	69.05	9.75	0.37

Figure 1. Anthracnose disease response to sand topdressing applied at 0.3 L m^{-2} every 7 d (pooled over with and without brushing treatments) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006. Topdressing was applied from 25 May to 31 Aug. 2006. Planned *F*-test indicates significant differences at the 0.05 (*), 0.01 (**) and 0.001 (***) probability levels.

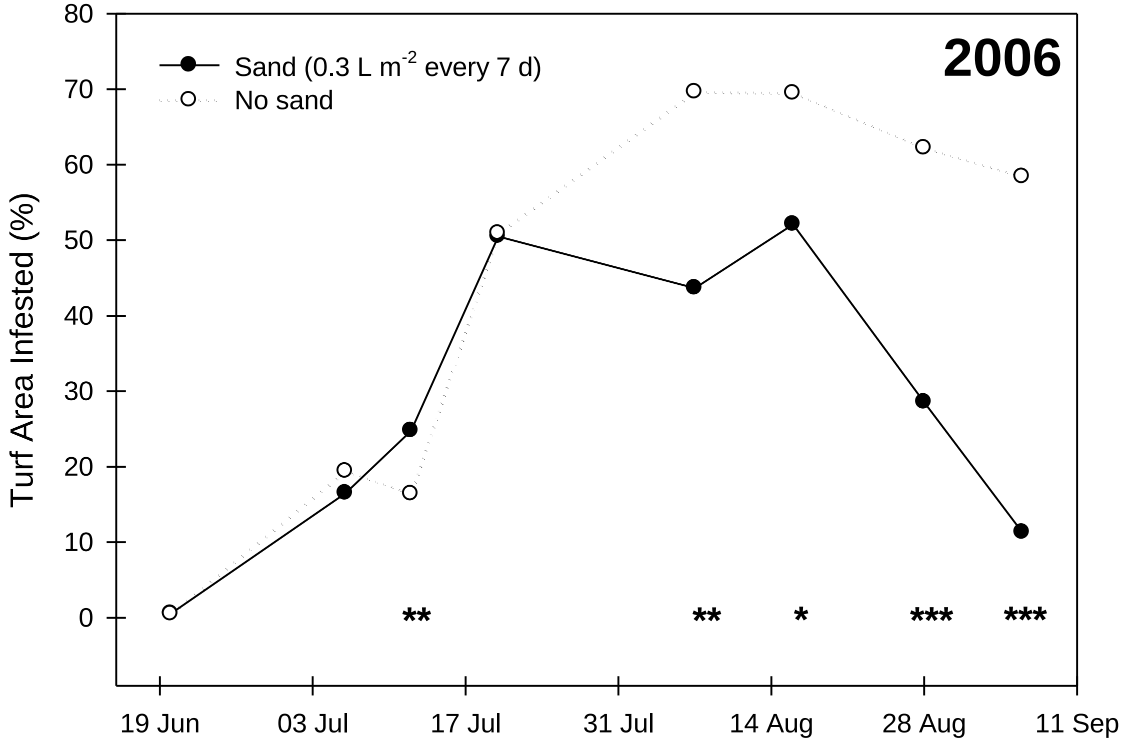

Figure 2. Anthracnose disease response to sand topdressing applied at 0.3 L m^{-2} every 7 d (pooled over with and without brushing treatments) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007. Topdressing was applied from 8 May to 2 Oct. 2007. Planned *F*-test indicates significant differences at the 0.05 (*), 0.01 (**) and 0.001 (***) probability levels.

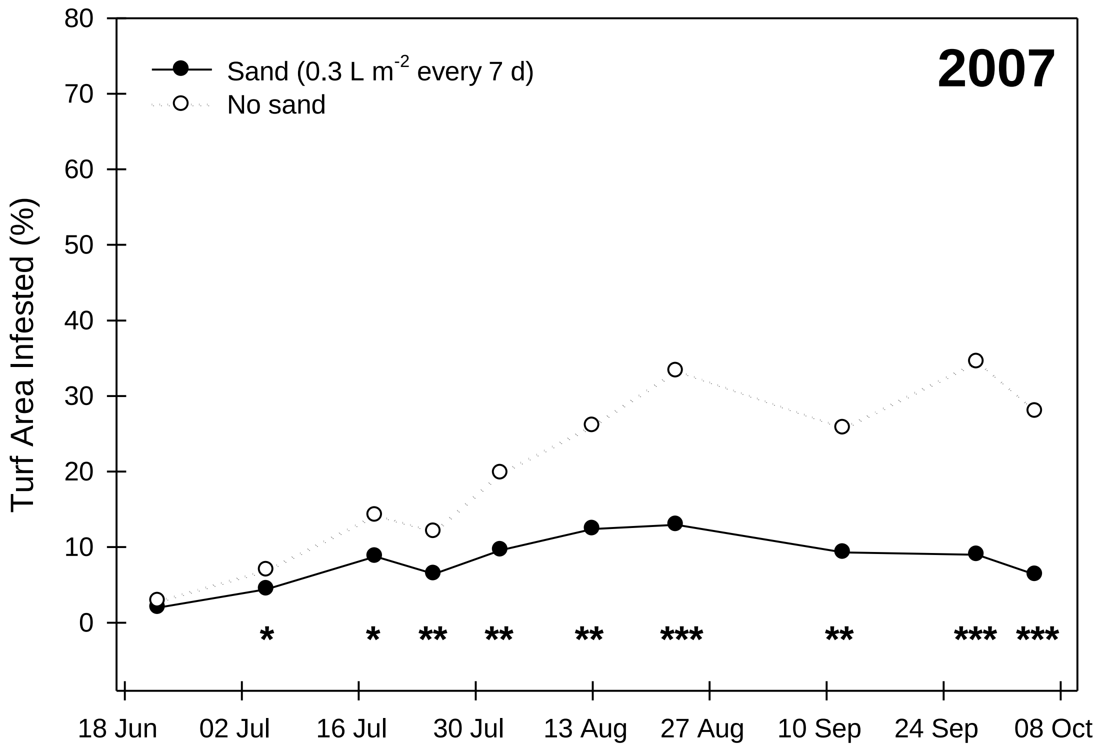

Table 2. Turf quality response to topdressing applied at 0.3 L m^{-2} every 7 d and brushing for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

		Turf quality							
		2006				2007			
Sand Rate†	Brush‡	6 June	7 July	9 Aug.	8 Sept.	13 June	19 July	15 Aug.	13 Sept.
L m^{-2}	days	1-9 scale§							
0.0	none	7.3	6.8	3.5	3.0	7.0	4.5	3.3	3.0
	7 d	7.3	6.0	2.5	2.0	7.8	5.0	3.8	3.8
0.3	none	7.0	6.0	5.5	5.3	8.0	7.0	4.5	5.5
	7 d	7.0	6.0	6.0	5.8	7.3	6.0	4.3	5.3
$LSD_{0.05}$						0.9#	1.0		
Planned *F*-test		*p* > *F*							
0.0 *vs.* 0.3 L m^{-2}		ns¶	ns	***	***	ns	***	ns	***
No brush *vs.* brush		ns	ns	ns	ns	ns	ns	ns	ns
Sand x brush		ns	ns	ns	ns	*	*	ns	ns
CV, %		11.2	19.9	27.5	36.9	8.2	9.1	16.2	14.7

*Significant at the 0.05 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007.
‡Brushing was conducted as four passes of a broom across individual plots every 7 d following topdressing.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
¶ns, not significant.
#Means separated using Fisher's protected least significant differences test at $\alpha = 0.05$.

Figure 3. Anthracnose disease response to sand topdressing applied at 1.2 L m^{-2} (pooled over 42 and 21 d intervals) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006. Topdressing was applied from 25 May to 31 Aug. 2006. Planned *F*-test indicates significant differences at the 0.1 (*) probability levels.

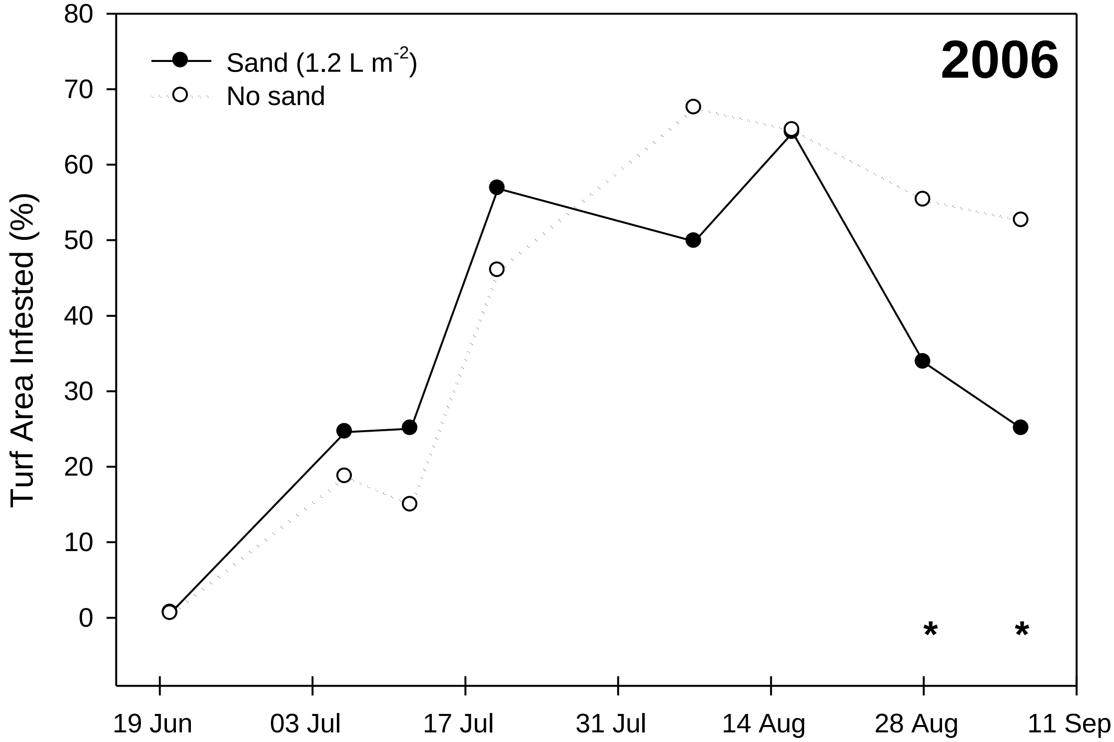

Figure 4. Anthracnose disease response to sand topdressing applied at 1.2 L m^{-2} (pooled over 42 and 21 d intervals) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007. Topdressing was applied from 8 May to 2 Oct. 2007. Planned *F*-test indicates significant differences at the 0.05 (*), 0.01 (**) and 0.001 (***) probability
levels.

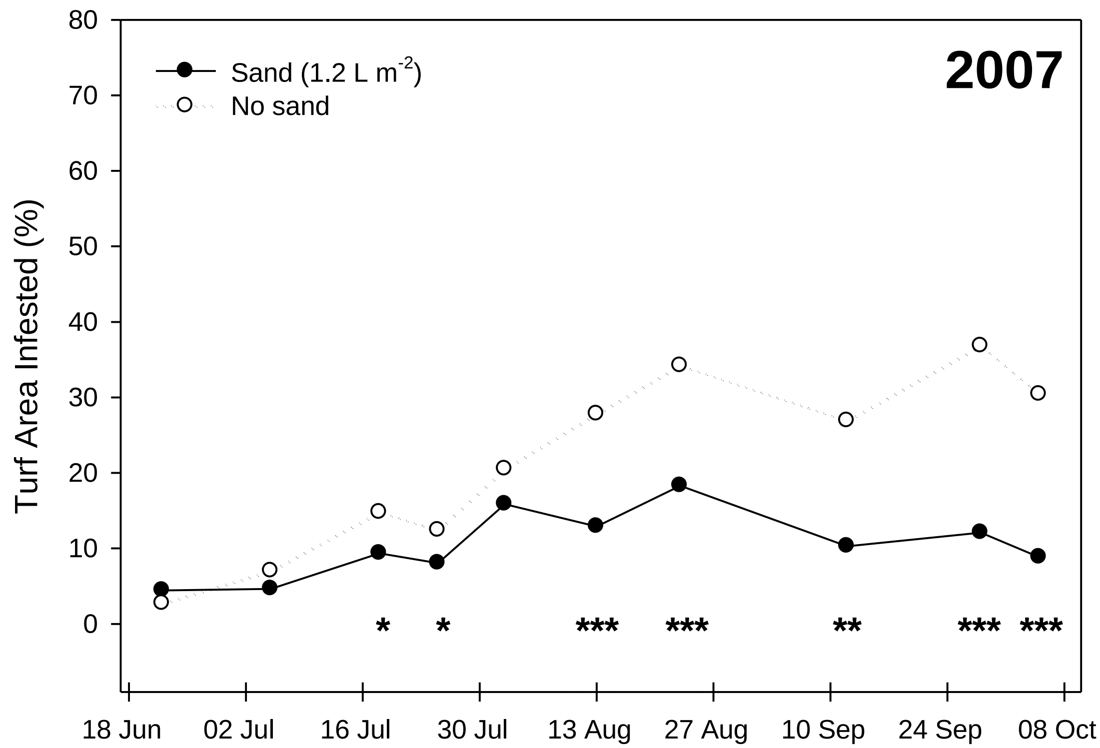

Figure 5. Anthracnose disease response to sand topdressing applied every 21 and 42 d at 1.2 L m^{-2} for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007. Topdressing was applied from 8 May to 2 Oct. 2007. Planned *F*-test indicates significant differences at the 0.05 (*), 0.01 (**) and 0.001 (***) probability levels.

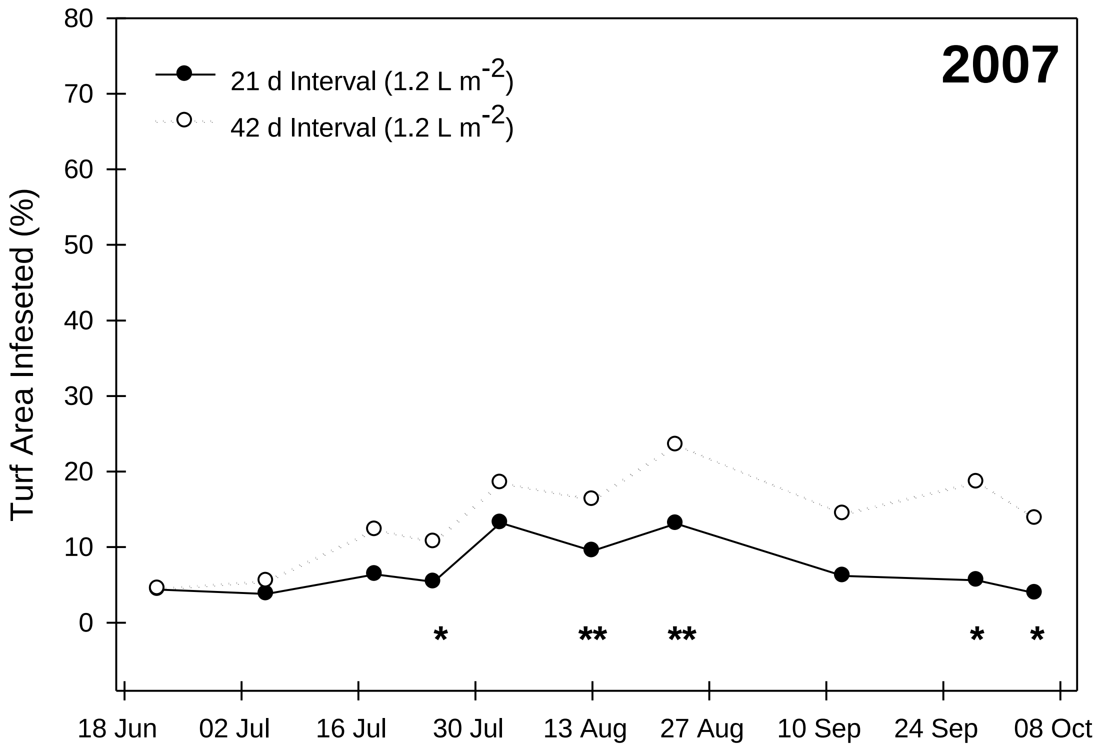

Table 3. Turf quality response to sand topdressing applied at 1.2 L m^{-2} (every 42 and 21 d) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

		Turf Quality							
		2006				2007			
Sand Rate†	Interval	6 June	7 July	9 Aug.	8 Sept.	13 June	19 July	15 Aug.	13 Sept.
L m^{-2}	days	---------- 1-9 scale‡ ----------							
0.0	0	7.3	6.8	3.5	3.0	7.0	4.5	3.3	3.0
1.2	42	7.3	3.5	4.8	3.8	7.3	5.3	4.0	4.0
1.2	21	7.0	3.8	4.8	4.5	7.8	6.8	5.5	4.3
Planned *F*-test		---------- $p > F$ ----------							
0.0 *vs.* 1.2 L m^{-2}		ns§	**	ns	ns	ns	**	**	*
21 *vs.* 42 d		ns	ns	ns	ns	ns	**	*	ns
CV, %		11.2	19.9	27.5	36.9	8.2	9.1	16.2	14.7

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§ns, not significant.

Table 4. Anthracnose disease severity analysis of variance summary for sand topdressing application rate and interval effects for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

		2006‡		2007¶	
Source	df	20 June – 20 July	7 Aug. – 6 Sept.	22 June – 18 July	25 July – 5 Oct.
Rate (R) †	2				
R_{Linear} (R_L)	1	ns§	***	ns	***
$R_{Quadratic}$ (R_Q)	1	ns	ns	ns	ns
Interval (I)	2				
I_{Linear} (I_L)	1	ns	***	ns	ns
$I_{Quadratic}$ (I_Q)	1	ns	*	ns	*
R x I	4				
R_L x I_L	1	ns	***	ns	ns
R_L x I_Q	1	ns	ns	ns	ns
R_Q x I_L	1	ns	ns	ns	**
R_Q x I_Q	1	ns	*	ns	ns
CV, %		21.0	17.5	27.6	32.0

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied every 7, 21 or 28 d at 0, 0.3 or 0.6 L m^{-2} from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007.
‡Data pooled since treatments did not interact with observation date from 20 June to 20 July (n = 4 observations) or 7 Aug. to 6 Sept. 2006 (n = 4 observations).
§ns, not significant.
¶ Data pooled since treatment did not interact with observation date from 22 June to 18 July (n = 3 observations) or 25 July to 5 Oct. 2007 (n = 7 observations).

Figure 6. Predicted anthracnose disease response surface of sand topdressing application rate and interval for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ from 7 Aug. to 6 Sept. 2006. Topdressing was applied from 25 May to 31 Aug. 2006. Turf area infested (%) = 78.18 – $1.40I_L$ + $0.03I_Q$ – $141.14R_L$ + $51.49R_Q$ + $15.25I_LR_L$ – $6.37I_LR_Q$ – $0.37I_QR_L$ + $0.16I_QR_Q$. $R^2 = 0.75$ ($P < 0.0001$).

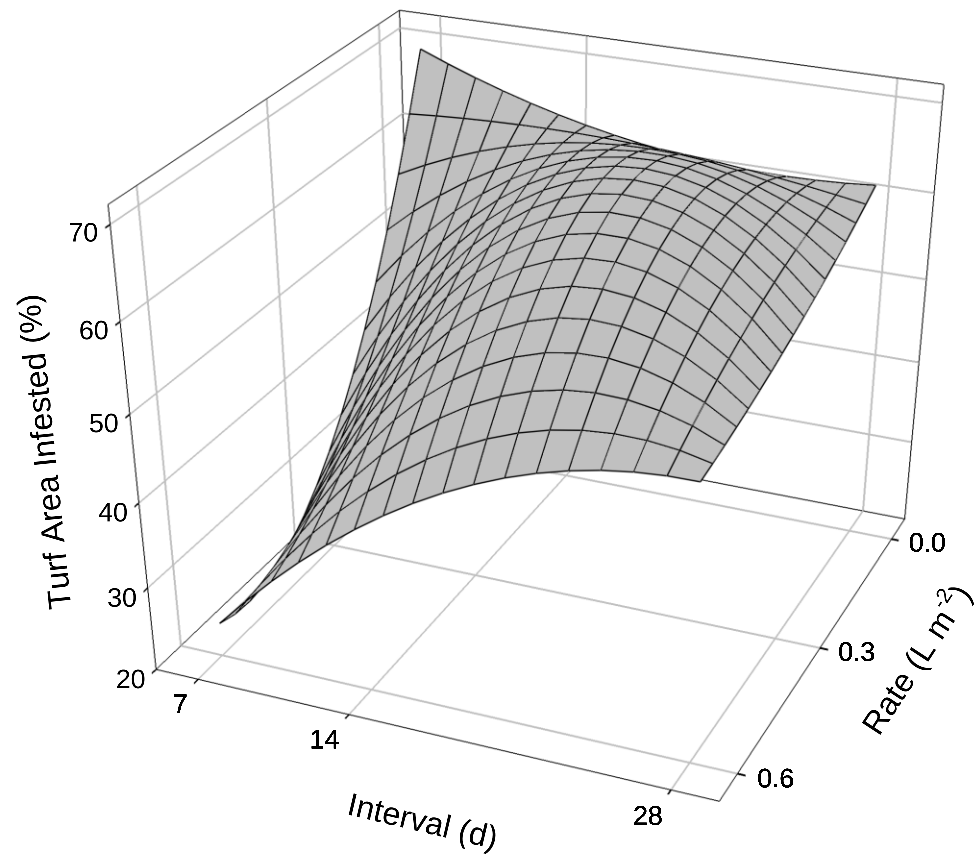

Figure 7. Predicted anthracnose disease response surface of sand topdressing application rate and interval for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ from 25 July to 5 Oct. 2007. Topdressing was applied from 8 May to 2 Oct. 2007. Turf area infested (%) = 29.17 – 0.30I_L – 28.98R_L + 8.87R_Q + 1.47I_LR_L – 0.59I_LR_Q. R^2 = 0.60 (P < 0.0001).

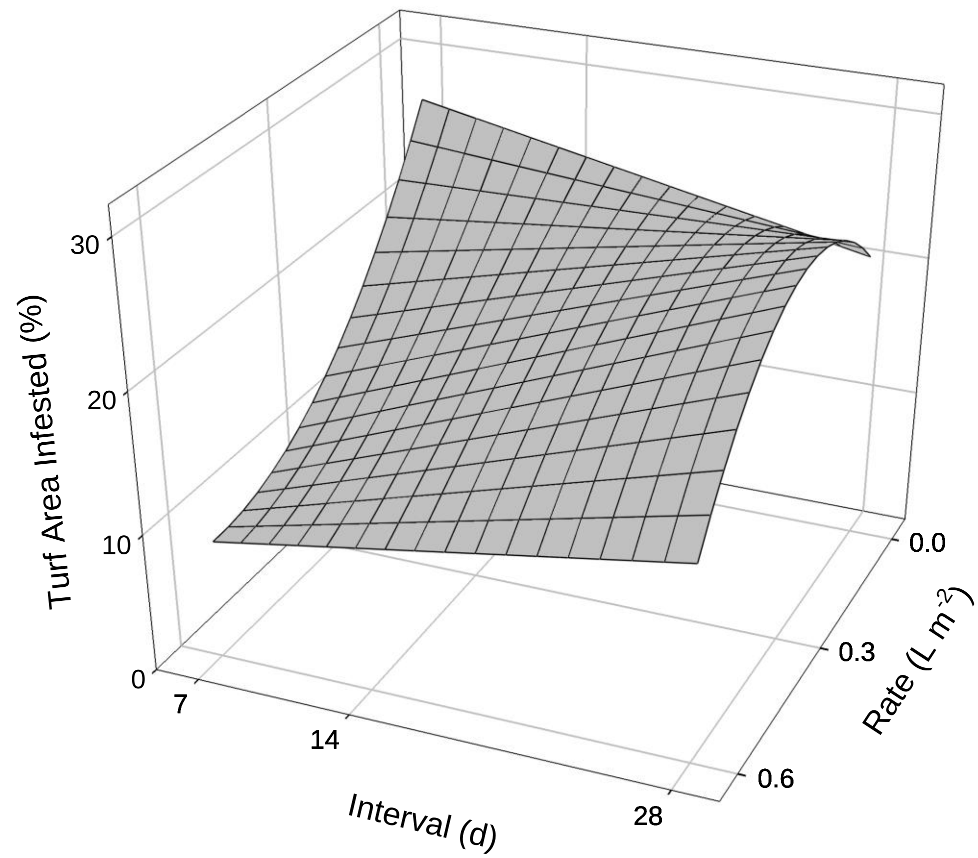

Table 5. Turf quality response to topdressing application rate and interval effects on anthracnose disease severity on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

		Turf Quality							
		2006				2007			
Rate†	Interval	6 June	7 July	9 Aug.	8 Sept.	13 June	19 July	15 Aug.	13 Sept.
L m^{-2}	days	1-9 scale‡							
0.0	28	6.8	4.5	2.0	3.3	7.8	5.0	4.0	3.5
	14	6.8	5.8	2.0	3.0	8.5	4.8	3.3	3.0
	7	7.3	5.3	2.0	2.3	7.8	5.0	3.8	3.8
0.3	28	7.3	4.5	3.0	3.8	8.3	4.0	3.5	3.0
	14	6.5	4.5	3.3	4.0	8.3	4.8	3.5	4.3
	7	7.0	5.5	5.8	7.0	7.3	6.0	4.3	5.3
0.6	28	7.0	5.5	4.0	5.3	7.5	6.3	4.8	4.8
	14	6.3	5.0	5.3	7.0	7.5	5.3	4.0	4.5
	7	6.8	5.5	6.3	6.5	7.3	5.8	4.0	4.5
$LSD_{0.05}$				1.3	1.5		1.1		0.9
Source		$p > F$							
Rate (R)		ns§	ns	***	***	ns	*	ns	***
Interval (I)		ns	ns	***	*	ns	ns	ns	*
R x I		ns	ns	*	**	ns	*	ns	**
CV, %		9.6	21.1	23.3	22.4	8.5	15.1	17.2	15.8

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§ns, not significant.

CHAPTER 6. Topdressing Sand Particle Shape and Incorporation Effects on Anthracnose Severity of an Annual Bluegrass Putting Green

ABSTRACT

Sand topdressing is a common practice on putting green turf and is suspected to enhance anthracnose disease caused by the fungus *Colletotrichum cereale* sensu lato Crouch, Clarke, and Hillman. A field trial was conducted to evaluate topdressing incorporation method (none, vibratory rolling, soft bristled brush and stiff bristled brush) and sand shape (none, round and sub-angular) for effects on anthracnose severity in 2006 and 2007. The trial used a split-plot design in a 4 x 3 factorial with incorporation method as the main plot factor and sand shape as the subplot factor, on an annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] turf mowed at 3.2 mm. Topdressing was applied at 0.3 L m^{-2} every 14 d from 27 June to 13 Sept. 2006 and 14 May to 27 Sept. 2007. The sand shape main effect was the only significant source of variation in both years. None of the topdressing incorporation methods affected anthracnose severity. Both sand shapes initially increased disease severity 4 to 14% compared to non-topdressed turf in July 2006; however, neither sand shape increased severity compared to non-topdressed turf throughout the remainder of the trial. Sub-angular and round sand reduced anthracnose 8 to 29% and 7 to 29%, respectively, compared to non-topdressed turf during August and September of 2006 and 2007. Anthracnose was less severe in plots topdressed with sub-angular sand than round sand in July 2006 and July through September 2007. This trial supports the findings of our other trials which indicate that

subtle wounding or bruising associated with routine cultural practices is not a significant factor affecting anthracnose severity.

INTRODUCTION

Anthracnose disease epiphytotoics, caused by the fungus *Colletotrichum cereale* Manns sensu lato Crouch, Clarke, and Hillman (Crouch et al., 2006), have become a common malady of putting green turf throughout the United States, the United Kingdom and Europe (Smiley et al., 2005) over the past 15 years. Annual bluegrass [*Poa annua* L. f. *reptans* (Hausskn) T. Koyama] (ABG) putting green turf is the primary host affected by this disease, although creeping bentgrass (*Agrostis stolonifera* L.) turf is also susceptible (Smiley et al., 2005).

Increased incidence and severity of anthracnose have encouraged speculation regarding factors that might contribute to disease outbreaks. Recent research has demonstrated resistance of the fungus to a number of fungicide classes previously known to be efficacious against *C. cereale* (Avila-Adame et al., 2003; Crouch et al., 2005; Wong and Midland, 2007; Wong et al., 2007; Wong et al., 2008). Attention also has focused on cultural practices of putting green turf that may enhance plant stress or wound plant tissue, thus potentially predisposing the host to anthracnose disease (Smiley et al., 2005). Recent investigations of reduced summer N fertility (Inguagiato et al., 2008a) and low mowing heights (Inguagiato et al., 2009b) support the hypothesis that reduced plant vigor and plant stress enhances anthracnose epiphytotics. However, the effect of abrasive cultural practices such as sand topdressing on anthracnose severity remains unclear.

Topdressing is a cultural practice that applies a thin soil layer to the turf canopy for the purposes of minimizing thatch accumulation, smoothing the surface, modifying soil and improving winter protection (Beard, 1973). During the past 30 years, sand has become the predominant topdressing media particularly for use on putting greens

(Cooper and Skogley, 1981). It has been suggested that topdressing sand may wound turfgrass crowns or leaves thereby providing an entry point for *C. cereale* (Smiley et al., 2005). While recent research conducted by the authors has shown that repeated sand applications during the growing season can reduce anthracnose severity on ABG putting green turf (Inguagiato et al., 2009b), the influence of sand particle shape and incorporation method on this disease is currently unknown.

Sand particle shape can range from very angular to well rounded (Beard, 2002). Distinction among sand particle shapes used for topdressing is uncommon since local availability often dictates the material used. However, round sands are favored as topdressing material over more angular sand (Green Section Staff, 1977) for reasons which are unclear. Angular sands may have a greater potential to wound turf and enhance anthracnose severity than round sands. Once applied to the turf surface, topdressing sand typically needs to be incorporated into the canopy. Brushes or drag mats are commonly used for this purpose; however this practice may contribute to detrimental wounding, which could possibly enhance anthracnose severity, particularly if done excessively. Alternative incorporation methods such as hand watering or vibratory rolling (Foy, 1999) may be less abrasive and could potentially minimize anthracnose outbreaks.

Topdressing is believed to enhance anthracnose severity due to the wounding associated with this practice; it is likely that more disease would result from the use of sub-angular sand and more abrasive incorporation methods. Therefore, the objectives of this trial were to determine the effects of sand particle shape and incorporation method used for topdressing on anthracnose severity and turf quality of ABG putting green turf.

MATERIALS AND METHODS

The trial was initiated in 2006 on ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludaults) with a pH of 6.4 in North Brunswick, NJ. The monostand of ABG was established in September 2002 as described by Inguagiato et al. (2009b). The site had been inoculated with *C. cereale* isolate HFIIA in August 2004 (Inguagiato et al., 2009b), after which disease developed each year as a natural infestation.

Mowing was performed seven times wk^{-1} with a walk-behind greens mower (model 220B, Deere & Company, Moline, IL) equipped with a grooved front roller (model AMT2979, Deere & Company, Moline, IL) at a bench setting of 3.2 mm. Nitrogen (water soluble sources) was applied to the trial 20 times from March to October 2006 totaling 188 kg ha^{-1} and 15 times from April to October 2007 totaling 107 kg ha^{-1}. Phosphorous and potassium were applied based on soil test results at 25.6 and 50.7 kg ha^{-1} as actual P and K, respectively, in 2006; P and K were not applied in 2007 until after the conclusion of the trial. Irrigation was applied only when wilt stress was evident and to wash-in fertilizer and topdressing to maintain relatively dry soil conditions. Trinexapac-ethyl [4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethylester] was applied at 0.05 kg a.i. ha^{-1} every 14 d from 22 May to 22 Sept. 2006 and 12 May to 19 Oct. 2007 to mimic growth regulation practices commonly employed on golf course putting greens. Anthracnose was suppressed on 6 and 26 June, 8 July 2006 and 12 May 2007 with chlorothalonil (tetrachloroisophthalonitrile) applied at 6.0, 11.0, 14.7 and 13.1 kg a.i. ha^{-1}, respectively, to permit collection of turf quality data on turf undamaged by this disease. The anthracnose epiphytotic was arrested between trial years with applications of chlorothalonil at 15.7 and 17.9 kg a.i. ha^{-1} on 4 and 26 Sept. 2006, respectively, to allow turf to recover. Renovation from disease damage included coring in late-September 2006, verticutting soil cores, topdressing with sand at 1.7 L m^{-2}, and incorporating these materials using a box-link drag, brush, and cocoa mat drags (Ace Equipment and Supply Co., Henderson, CO). Dollar spot disease was preventatively controlled in April and May 2006 and May through October 2007 with vinclozolin [3-(3, 5-dichlorophenyl)-5-ethenyl-5-methyl-2, 4-oxazolidinedione] at 1.5 to 1.8 kg a.i. ha^{-1} or boscalid {3-pyridinecarboxamide, 2-chloro-N-[4'-chloro(1,1'-biphenyl)-2-yl]} at 0.4 kg a.i. ha^{-1} every 14 d. Brown patch (caused by *Rhizoctonia solani* Kühn) was suppressed with bi-weeekly applications of flutolanil {N-[3-(1-methylethoxy) phenyl]-2-[trifluoromethyl] benzamide} at 3.2 to 4.7 kg a.i. ha^{-1} in July 2006 and May through July 2007and azoxystrobin [methyl (*E*)-2-{2-[6-(2-cyanophenoxy)pyrimidin-4-yloxy]phenyl}-3-methoxyacrylate] was applied monthly at 0.3 to 0.6 kg a.i. ha^{-1} in September 2006 and from July through August 2007. Thiophanate-methyl was applied at 9.3 kg a.i. ha^{-1} on 8 Sept. 2006 to control summer patch (*Magnaporthe poae* Landschoot and Jackson). Algal growth was suppressed with mancozeb (coordination of Mn^{2+}, Zn^{2+} and ethylene bisdithiocarbamate) at 21.4 kg a.i. ha^{-1} as necessary in June and July 2007. These fungicides were previously determined not to affect the development of anthracnose at this site. Annual bluegrass weevils [*Listronotus maculicollis* (Kirby)] were controlled with applications of bifenthrin {[2-methyl(1,1'-biphenyl)-3-yl]methyl 3-[2-chloro-3,3,3-trifluoro-1-propenyl]-2,2-dimethylcyclopropanecarboxylate} at 0.13 kg a.i. ha^{-1} in May 2006 and 2007. Creeping bentgrass was eliminated with applications of fluazifop-P-butyl [Butyl(*R*)-2-(4-{[5-(trifluoromethyl)-2-

pyridinyl]oxy}phenoxy)propanoate] at 0.2 kg a.i. ha^{-1} in May and September 2006 and August and September 2007, and pearlwort [*Sagina subulata* (Sw.) C. Presl] was controlled with MCPP [2-(2-methyl-4-chlorophenoxy) propionic acid] at 0.5 kg a.i. ha^{-1} in August and September 2007, respectively.

Treatment Design

The trial used a split plot design arranged as a 4 x 3 factorial with three and six experimental blocks in 2006 and 2007, respectively. Topdressing incorporation method was the main plot (1.8 by 7.2 m) factor and sand particle shape was the subplot (1.8 by 2.4 m) factor. Levels of each factor were randomly assigned within respective experimental units and repeated in the same location each year, except where treatments were applied within newly established blocks in 2007. The incorporation factor included no incorporation, vibratory rolling, soft bristled brushing and stiff bristled brushing. Vibratory rolling was conducted as one pass of the triplex attached rolling units (model UR3T, Turfline, Inc., Moscow Hills, MO) each afternoon for three consecutive days after sand topdressing was applied. Soft and stiff bristled brushes were constructed by mounting three broom heads (91 by 6.7 cm each) with fine, split-tip synthetic bristles (model 2336, Harper Brush Works, Inc. Fairfield, IA) or six broom heads (46 by 6.7 cm each) with stiff synthetic bristles (model 9418, Harper Brush Works, Inc. Fairfield, IA), respectively, to a plywood board with two extended handles. Individual plots were brushed by manually pulling the broom across each half of the plot eight times following sand application. The sand particle shape subplot factor included no sand, round sand or sub-angular sand. Round (“Crystal” U.S. Silica, Co., Ottawa, IL) and sub-angular (“310” U.S. Silica, Co., Mauricetown, NJ) sands were derived from silica parent material with a pH of 7.0, and conformed to the particle size distribution recommended for sand putting green root zones (Green Section Staff, 2004) (Table 1). Both sands were applied at 0.3 L m^{-2} every 14 d as dry sand using a drop spreader (The Scotts Company, Marysville, OH) calibrated to uniformly distribute the required volume in four passes. Treatments were applied when the turf canopy was dry (1300 and 1600 hr) every 14 d from 27 June to 5 Sept. 2006 and 14 May to 24 Sept. 2007. The entire experimental area was lightly irrigated after topdressing and incorporation treatments to further settle sand into the turf canopy.

Data Collection and Analysis

Anthracnose severity was assessed from July through September 2006 and June through October 2007 as the percent turf area infested with *C. cereale* using a line-intercept grid count method (Inguagiato et al., 2008a). Turf quality was visually assessed each month using a 1 to 9 scale (where 9 represented the best quality and 5 the minimum acceptable level) from July through September 2006 and June through October 2007 at least 7 d after topdressing was applied. Disease severity, sandiness (unincorporated sand), turf density, uniformity, color, algae and seedhead expression were considered when assessing turf quality.

All data were subjected to analysis of variance to identify significant ($p \leq 0.05$) main and interaction treatment effects using the General Linear Model procedure for a split plot design in the Statistical Analysis System software v. 9.1.3 (SAS Institute Inc., Cary, NC). Means of main effects and significant interactions were separated by Fisher's protected least significant difference test at the 0.05 probability level using the appropriate formulae described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Anthracnose Severity

Anthracnose basal rot developed on 6 June 2006 prior to the initiation of treatments, although assessment of pre-treatment disease severity indicated no significant differences (data not shown). Disease severity was low to moderate (7 to 22%) in July 2006, but increased rapidly during August resulting in maximum of 61 to 73% turf area infested (Table 2). Disease declined in September that year. Disease symptoms reoccurred on 24 June 2007 and increased slowly to peak levels (39 to 56%) in late-August (Table 3). Disease severity declined gradually during September and October 2007.

Sand particle shape was the only factor to influence anthracnose severity and no interaction with topdressing incorporation method was observed throughout the two year trial (Tables 2 and 3). Round and sub-angular sands initially increased disease severity 14 and 5%, respectively, compared to no topdressing on 7 July 2006 (Table 2) after one topdressing (27 June). Round sand continued to enhance anthracnose severity (6%) after the second topdressing treatment compared to non-topdressed turf on 14 July; however sub-angular sand did not increase disease on this date (Table 2). Neither sand type increased anthracnose severity for the remainder of 2006, or at any time in 2007 compared to non-topdressed turf (Table 3).

Sub-angular sand reduced disease severity 9 and 4% compared to round sand on 7 and 14 July 2006, respectively (Table 2). Continued topdressing with both round and sub-angular sands reduced disease 7 to 29% and 8 to 29%, respectively, compared to non-topdressed turf as the epidemic progressed in August and September 2006 (Table 2).

Similarly, disease was reduced 12 to 25% and 7 to 29% by round and sub-angular sands, respectively, compared to no topdressing throughout much of the epidemic in 2007 (Table 3). However, sub-angular topdressing reduced disease earlier in the epidemic (~ 3 wk) and had 5 to 6% less disease than round sand from 5 July to 19 September 2007 (Table 3).

These data suggest that anthracnose may be initially enhanced by sand topdressing, but this effect was only evident early in the epidemic of the first year (2006) of the trial. More importantly, the cumulative effect of sand topdressing (regardless of sand particle shape) was beneficial throughout most of the trial, reducing anthracnose severity by as much as 29%. The current trial supports results from two concurrent studies of topdressing rates and intervals (Inguagiato et al., 2009b) and sand topdressing and traffic (unpublished data), where topdressing initially increased anthracnose, but later reduced the disease after continued application. In these studies, the mat layer which results from sand topdressing was proposed to protect the plant sheaths and crowns enhancing plant vigor and reducing anthracnose severity. Possible benefits of mat formation include greater surface firmness that effectively raises the height of cut, and a more desirable substrate for turf growth (Inguagiato et al., 2009b). In the absence of a sufficient sand/mat layer just below the verdure, crowns and leaf sheaths exposed to sand topdressing may be damaged and anthracnose severity enhanced as has been suggested by some turf managers, and documented in the first year of this trial. However, this temporary increase in disease appears to be overcome once sufficient sand accumulates to cover and support these tissues. Thus, increased anthracnose severity associated with topdressing on golf course putting greens may be an indication that inadequate topdressing rates and/or intervals are being applied.

Sub-angular sand was slightly more effective at reducing anthracnose severity than round sand particularly during the second year (2007) of the trial. Angular sands are known to pack to a greater density and have more stability than more rounded sands (Yi et al., 2001). These characteristics of sub-angular sand may have enhanced the structure within the turf canopy and mat and improved the capacity of the surface to support the load of the mower, thus raising the effective height of cut; a factor known to reduce anthracnose severity (Inguagiato et al., 2009a). Conversely, round sand particles may not be as well suited to form an integrated structure since the stability of round sand is less than sub-angular sand.

Contrary to expectations, the methods used to incorporate sand in this two-year trial had no effect on anthracnose severity (Tables 2 and 3). Anthracnose has been reputed to be enhanced by wounding of host plant tissue (Smiley et al., 2005). However, data from this trial indicate that wounding or bruising of turf associated with topdressing incorporation methods do not contribute to anthracnose outbreaks. Investigations examining the infection process of *Colletotrichum spp.* indicate that wounds are not required for penetration of annual bluegrass (Smith, 1954) or maize (*Zea mays* L.) (Smith, 1954; Vernard and Vaillancourt, 2007). Moreover, Bruehl and Dickson (1950) observed that *C. graminicola* (Ces.) G.W. Wils. directly penetrates the cuticle of Sudan grass [*Sorghum bicolor* (L.) Moench subsp. *drummondii* (Steud.) de Wet ex Davidse] via a penetration peg, and noted that germ tubes did not enter the host through stomata or wounds. Recent work has also demonstrated that wounding caused by shallow verticutting (3 mm) every 14 d throughout the summer had little effect on anthracnose severity (Inguagiato et al., 2008). However, deeper verticutting (3 and 5 mm) every 7 d during a one month period, which cut crowns, and removed stolons, increased anthracnose severity (Uddin et al., 2008). These data suggest that cultural practices which produce low to moderate wounding do not increase anthracnose. Further research is needed to quantify the intensity of wounding as well as other cultural practices that damage plant tissue on anthracnose severity.

Turf Quality

Turf quality was acceptable (≥ 5) for both factors in June and July before anthracnose symptoms were apparent or when disease severity was low (Table 4). Turf quality of all treatments was reduced later in the season as disease severity increased (Table 4). Sand shape influenced turf quality on 88% of the observations during the two year trial. Topdressing with either sand type generally improved quality compared to non-topdressed turf, particularly from August to September 2006 and August to October 2007 when anthracnose damage was severe (Table 4). Reductions in disease severity associated with sand topdressing treatments (Tables 2 and 3) were largely responsible for improved turf quality during this time. Sub-angular sand improved turf quality compared to the remaining treatments on 3 July 2006 (Table 4) when disease severity was low. Sand shape had little effect on turf quality before disease initiated in 2007, although round sand slightly reduced turf quality compared to non-topdressed turf on 8 June (Table 4). This was apparently due to excess sand present at the turf surface, even though quality ratings were acceptable for both treatments.

The incorporation main effect had little impact on turf quality throughout the two year trial (Table 4). However, incorporation with the soft bristled brush did improve turf quality compared to all other treatments on 8 Sept. 2006 after the turf canopy had been severely thinned by disease. An interaction between incorporation method and sand shape was detected on 3 July 2006 (Table 4). However, comparison of interaction means revealed inconsistent treatment effects (data not shown); therefore this was considered to be a random effect.

CONCLUSIONS

Anthracnose disease is reputed to be enhanced by wounding and abrasion associated with topdressing and incorporation methods. However, these data indicate that wounding does not contribute to anthracnose outbreaks. Overall, the sand and topdressing incorporation treatments evaluated in this study did not enhance anthracnose severity contrary to initial expectations. In fact, routine topdressing with sub-angular and round shaped sands generally reduced anthracnose severity, although this effect appeared to be dependent upon sufficient accumulation of sand within the turf canopy and surface thatch-mat layer over time. Sub-angular sand topdressing was slightly more effective at reducing disease severity than round sand, possibly because of its better packing characteristics. Sand incorporation methods did not influence anthracnose severity; therefore sand should be thoroughly incorporated into the canopy to enhance mat layer development and minimize dulling of mower blades and bedknives.

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Table 1. Particle size distribution of sub-angular and round sands used for topdressing annual bluegrass turf.

	Sieve size opening						
Sand shape	2 mm	1 mm	500 µm	250 µm	149 µm	53 µm	pan
	% retained (by weight)						
Sub angular	0	0.2	20.7	69.0	9.8	0.4	0.3
Round	0	< 0.1	3.8	85.4	9.2	0.9	0.2

Table 2. Anthracnose disease response to topdressing incorporation method and sand particle shape of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

	Turf Area Infested					
Main Effects	7 July	14 July	7 Aug.	22 Aug.	7 Sept.	13 Sept.
Incorporation[†]	%					
no incorporation	17.7	22.1	51.3	68.2	64.1	47.9
vibratory rolling	10.5	18.7	44.2	66.7	59.1	42.9
soft brush	11.1	15.1	39.5	64.1	46.0	31.7
stiff brush	14.5	16.3	46.6	63.0	57.6	44.4
Sand shape[‡]						
no sand	7.3 c	15.3 b	50.3 a	72.8 a	65.6 a	61.0 a
round	20.8 a	21.6 a	43.5 b	61.1 b	52.0 b	31.8 b
sub-angular	12.3 b	17.2 b	42.4 b	62.6 b	52.5 b	32.4 b
Source	*p>F*					
Incorporation (I)	NS[§]	NS	NS	NS	NS	NS
Sand shape (S)	***	*	*	***	***	***
I x S	NS	NS	NS	NS	NS	NS
C.V. (%)	38.0	27.2	17.2	10.6	14.0	25.1

*Significant at the 0.05 probability level.
***Significant at the 0.001 probability level.
[†]Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
[‡] Topdressing was applied every 14 d at 0.3 L m^{-2} from 27 June to 5 Sept. 2006.
[§]NS, not significant.

Table 3. Anthracnose disease response to topdressing incorporation method and sand particle shape of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

	Turf Area Infested								
Main Effects	24 June	5 July	12 July	28 July	6 Aug.	19 Aug.	5 Sept.	19 Sept.	3 Oct.
Incorporation†	%								
no incorporation	9.8	12.4	24.5	36.3	42.6	50.7	45.3	38.8	38.3
vibratory rolling	8.5	11.9	25.5	35.5	39.8	46.8	40.3	34.6	32.2
soft brush	6.1	9.8	20.6	30.6	38.0	43.7	36.8	31.9	33.4
stiff brush	6.1	10.0	20.7	29.2	35.5	44.4	37.1	32.0	32.8
Sand shape‡									
no sand	7.1	10.9 ab	23.5 ab	36.1 a	44.2 a	56.0 a	52.2 a	48.8 a	52.2 a
round	8.9	13.5 a	25.3 a	34.0 a	39.1 a	44.4 b	36.1 b	30.3 b	27.3 b
sub-angular	6.9	8.7 b	19.7 b	28.7 b	33.5 b	38.8 c	31.4 c	23.9 c	23.1 b
Source	*p>F*								
Incorporation (I)	NS§	NS	NS	NS	NS	NS	NS	NS	NS
Sand shape (S)	NS	*	*	**	***	***	***	***	***
I x S	NS	NS	NS	NS	NS	NS	NS	NS	NS
C.V. (%)	60.2	54.3	28.8	25.1	22.8	17.1	19.0	19.5	20.8

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
‡ Topdressing was applied every 14 d at 0.3 L m^{-2} from 14 May to 24 Sept. 2007.
§NS, not significant.

Table 4. Turf quality response to topdressing incorporation method and sand particle shape of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ in 2006 and 2007.

	Turf Quality							
	2006			2007				
Main Effects	3 July	9 Aug.	8 Sept.	8 June	9 July	2 Aug.	22 Aug.	1 Oct.
Incorporation[†]	1 – 9 scale[§]							
no incorporation	6.1	3.3	4.1 b	6.9	5.5	3.1	3.1	4.0
vibratory rolling	7.1	3.3	4.4 b	7.1	5.6	3.2	3.2	4.1
soft brush	7.1	4.1	5.8 a	7.3	5.8	3.6	3.2	4.3
stiff brush	6.7	3.9	4.0 b	7.1	6.0	3.6	3.4	4.6
Sand shape[‡]								
no sand	6.7 b	2.1 b	3.0 b	7.4 a	5.4	2.9 b	2.5 b	3.3 c
round	6.4 b	4.5 a	5.7 a	6.9 b	5.8	3.4 a	3.4 a	4.4 b
sub-angular	7.2 a	4.4 a	5.1 a	7.0 ab	6.0	3.8 a	3.7 a	5.0 a
Source	*p>F*							
Incorporation (I)	NS[¶]	NS	*	NS	NS	NS	NS	NS
Sand shape (S)	*	***	***	*	NS	***	***	***
I x S	**	NS	NS	NS	NS	NS	NS	NS
C.V. (%)	6.2	28.6	21.1	8.5	16.1	22.6	21.3	16.5

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
[‡]Topdressing was applied every 14 d at 0.3 L m^{-2} from 27 June to 5 Sept. 2006 and 14 May to 24 Sept. 2007.
[§]9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
[¶]NS, not significant.

APPENDIX

Table 1. Seedhead response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

Main Effect	27 May 2003	25 June 2004	27 May 2005
		-------------------- % --------------------	
Nitrogen (N) †			
28 d	25.6	24.1	71.7
7 d	26.5	23.8	72.5
Mefluidide (ME) ‡			
0	36.8	26.4	83.5
0.106 kg a.i. ha^{-1}	15.3	21.4	60.7
Trinexapac-ethyl			
0	25.8	22.5	74.0
0.050 kg a.i. ha^{-1}	26.2	25.3	70.3
Verticutting (VC) ¶			
0	25.1	24.4	72.7
3.0 mm	27.1	23.4	71.6
		ANOVA	
Source of variation			
N	NS	NS	NS
ME	***	NS	***
TE	NS	**	*
VC	NS	NS	NS
N x ME	NS	NS	NS
N x TE	NS	NS	NS
N x VC	NS	NS	NS
ME x TE	NS	NS	NS
ME x VC	NS	NS	NS
TE x VC	NS	NS	NS
N x ME x TE	NS	NS	NS
N x ME x VC	NS	NS	NS
N x TE x VC	NS	NS	NS
ME x TE x VC	NS	NS	NS
N x ME x TE x VC	NS	NS	NS
CV, %	47.4	17.0	10.0

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 September 2003, 7 May to 9 October 2004, and 21 May to 3 August 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 April 2003, 7 and 21 April 2004, and 6 and 20 April 2005.

§ Trinexapac-ethyl was applied every 14-d from 14 April to 16 September 2003, 7 April to 22 September 2004, and 6 April to 10 August 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 April in 2004, and 20 April in 2005.

¶ Verticutting was conducted every 14-d from 30 May to 7 August 2003, 11 May to 25 August 2004, and 28 May to 5 August 2005.

Table 2. Turf quality response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003.

Main Effect	14 Apr.	12 May	27 May	10 Oct.
	------------------------- 1-9; 9 = best -------------------------			
Nitrogen (N) †				
28 d	5.2	6.2	5.5	3.3
7 d	5.5	6.0	6.4	6.2
Mefluidide (ME) ‡				
0	5.3	5.3	4.8	4.5
0.106 kg a.i. ha^{-1}	5.3	7.0	7.2	5.0
Trinexapac-ethyl (TE) §				
0	5.3	5.9	5.6	4.1
0.050 kg a.i. ha^{-1}	5.4	6.3	6.3	5.4
Verticutting (VC) ¶				
0	5.3	5.9	6.0	5.0
3.0 mm	5.4	6.3	6.0	4.4
		ANOVA		
Source of variation				
N	NS	NS	***	***
ME	NS	***	***	NS
TE	NS	*	***	***
VC	NS	*	NS	*
N x ME	NS	NS	NS	NS
N x TE	NS	NS	NS	NS
N x VC	NS	NS	NS	NS
ME x TE	NS	**	NS	*
ME x VC	NS	NS	NS	NS
TE x VC	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	NS
N x ME x VC	*	NS	NS	NS
N x TE x VC	NS	*	NS	NS
ME x TE x VC	NS	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS
CV, %	11.1	10.3	9.5	21.1

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 12 May to 22 September 2003.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 April 2003.

§ Trinexapac-ethyl was applied every 14-d from 14 April to 16 September 2003. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003.

¶ Verticutting was conducted every 14-d from 30 May to 7 August 2003.

Table 3. Turf quality response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2004.

Main Effect	21 Apr.	18 May	28 May	7 June	25 June	9 Aug.	3 Sept.
	---------------------------------- 1-9; 9 = best ----------------------------------						
Nitrogen (N) †							
28 d	6.7	4.9	4.9	6.3	4.9	4.3	3.8
7 d	7.1	6.1	6.5	8.2	7.1	6.3	6.2
Mefluidide (ME) ‡							
0	6.6	3.8	4.5	6.7	5.6	5.1	4.6
0.106 kg a.i. ha^{-1}	7.3	7.3	6.8	7.8	6.4	5.5	5.4
Trinexapac-ethyl							
0	6.7	5.3	5.5	7.2	5.7	5.1	4.3
0.050 kg a.i. ha^{-1}	7.1	5.8	5.8	7.3	6.3	5.5	5.7
Verticutting (VC) ¶							
0	6.9	5.6	5.7	7.3	6.1	5.1	4.9
3.0 mm	6.9	5.4	5.7	7.2	5.9	5.5	5.1
				ANOVA			
Source of variation							
N	**	***	***	***	***	***	***
ME	***	***	***	***	***	NS	***
TE	**	**	NS	NS	**	NS	***
VC	NS	NS	NS	NS	NS	NS	NS
N x ME	NS	NS	NS	*	NS	NS	*
N x TE	NS	NS	NS	NS	NS	NS	NS
N x VC	NS	NS	NS	NS	NS	NS	NS
ME x TE	NS	*	***	NS	**	NS	*
ME x VC	NS	NS	NS	NS	NS	NS	NS
TE x VC	NS	NS	NS	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	NS	NS	NS	NS
N x ME x VC	NS	NS	NS	NS	NS	NS	NS
N x TE x VC	NS	NS	NS	NS	NS	NS	NS
ME x TE x VC	NS	NS	**	NS	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS	NS	NS	NS
CV, %	7.9	11.4	13.0	10.3	14.3	19.3	19.7

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 7 May to 9 October 2004.
‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 7 and 21 April 2004.
§ Trinexapac-ethyl was applied every 14-d from 7 April to 22 September 2004. Initial TE application was delayed on turf previously treated with ME until 21 April in 2004.
¶ Verticutting was conducted every 14-d from 11 May to 25 August 2004.

Table 4. Turf quality response to N fertilization, mefluidide, trinexapac-ethyl, and verticutting of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005.

Main Effect	17 May	27 May	13 June	14 July
	------------------ 1-9; 9 = best -----------------			
Nitrogen (N) †				
28 d	4.0	4.6	5.6	4.0
7 d	4.1	5.2	6.9	6.9
Mefluidide (ME) ‡				
0	3.4	4.0	5.7	5.1
0.106 kg a.i. ha^{-1}	4.7	5.8	6.8	5.9
Trinexapac-ethyl				
0	3.8	4.8	6.3	5.5
0.050 kg a.i. ha^{-1}	4.3	4.9	6.3	5.5
Verticutting (VC) ¶				
0	4.0	4.8	6.3	5.7
3.0 mm	4.1	5.0	6.2	5.3
	ANOVA			
Source of variation				
N	NS	NS	***	***
ME	***	***	***	**
TE	**	NS	NS	NS
VC	NS	***	NS	NS
N x ME	NS	NS	NS	*
N x TE	NS	NS	NS	*
N x VC	NS	NS	NS	NS
ME x TE	NS	***	*	*
ME x VC	NS	*	NS	NS
TE x VC	NS	NS	NS	NS
N x ME x TE	NS	NS	NS	NS
N x ME x VC	*	NS	NS	NS
N x TE x VC	NS	*	NS	NS
ME x TE x VC	*	NS	NS	NS
N x ME x TE x VC	NS	NS	NS	NS
CV, %	13.8	10.5	9.2	18.3

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Nitrogen was applied as an NH_4NO_3 solution containing 4.9 kg ha^{-1} of N from 21 May to 3 August 2005.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 6 and 20 April 2005.

§ Trinexapac-ethyl was applied every 14-d from 6 April to 10 August 2005. Initial TE application was delayed on turf previously treated with ME until 20 April in 2005.

¶ Verticutting was conducted every 14-d from 28 May to 5 August 2005.

Table 5. Turf quality response to mefluidide and trinexapac-ethyl application on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2003, 2004 and 2005.

		2003		2004				2005		
Mefluidide†	Trinexapac-ethyl‡	12 May	10 Oct.	18 May	28 May	25 June	3 Sept.	27 May	13 June	14 July
---------- kg a.i. ha^{-1} ----------		---------- 1-9; 9= best ----------								
0	0	4.9	4.2	3.7	4.7	5.6	4.2	4.4	5.9	5.3
0	0.050	5.7	4.8	3.8	4.3	5.6	5.0	3.7	5.5	4.8
0.106	0	7.0	4.0	6.8	6.3	5.9	4.4	5.3	6.7	5.6
0.106	0.050	6.9	5.9	7.8	7.4	7.0	6.4	6.2	7.0	6.1
$LSD_{0.05}$		*0.50*	*0.80*	*0.45*	*0.52*	*0.61*	*0.70*	*0.37*	*0.41*	*0.71*

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 14 and 28 April 2003, 7 and 21 April 2004, and 6 and 20 April 2005.

‡ Trinexapac-ethyl was applied every 14-d from 14 April to 16 September 2003, 7 April to 22 September 2004, and 6 April to 10 August 2005. Initial TE application was delayed on turf previously treated with ME until 12 May in 2003, 21 April in 2004, and 20 April in 2005.

Table 6. Anthracnose disease recovery response to mowing height, mowing frequency, and lightweight vibratory rolling on annual bluegrass putting green turf in North Brunswick, NJ during 2004.

Main effects	2 Oct.	15 Oct.
	----------- % -----------	
Mowing height (MH)		
2.8 mm	39.8	44.6
3.2 mm	26.8	31.7
3.6 mm	15.7	22.0
$LSD_{(0.05)}$	*5.0*	*8.0*
Mowing frequency (MF)		
7 mowings wk^{-1}	26.1	32.8
14 mowings wk^{-1}	28.7	32.8
Lightweight rolling (R)		
none	29.5	34.9
every other day	25.4	30.6
$LSD_{(0.05)}$	*2.9*	*2.8*
	ANOVA	
Source of variation		
MH	***	***
MF	NS†	NS
R	**	**
MH x MF	*	*
MH x R	NS	NS
MF x R	NS	NS
MH x MF x R	NS	NS
CV, %	17.6	14.0

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 7. Anthracnose disease recovery response to mowing height and mowing frequency on annual bluegrass turf in North Brunswick, NJ during 2004.

	2 Oct.		15 Oct.	
	Mowing frequency, wk^{-1}			
Mowing height	7	14	7	14
mm	----------------------- % -----------------------			
2.8	33.9a†B‡	45.8aA	40.7aB	48.5aA
3.2	29.0aA	24.6bA	34.5aA	28.8bA
3.6	15.6bA	15.8cA	23.1bA	20.9bA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
‡Means within rows and date followed by the same upper case letter are not significantly different according to Fisher's protected LSD (p = 0.05).

Table 8. Ball roll distance response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004					2005			
	June					May			June
Main effects	7	17	18	23	30	7	19	23	6
	m								
Mowing height (MH)									
2.8 mm	2.93	3.26	3.44	3.20	3.29	2.42	2.78	3.09	3.29
3.2 mm	3.02	3.35	3.38	3.08	3.23	2.41	2.82	3.03	3.18
3.6 mm	2.90	3.05	3.23	2.99	3.08	2.38	2.59	2.88	3.03
$LSD_{(0.05)}$							*0.12*	*0.14*	
Mowing frequency (MF)									
7 mowings wk^{-1}	2.90	3.14	3.14	2.93	2.99	2.30	2.58	2.85	2.99
14 mowings wk^{-1}	2.99	3.29	3.57	3.23	3.41	2.51	2.88	3.15	3.34
Lightweight rolling (LR)									
none	2.93	3.14	3.29	3.02	3.20	2.40	2.74	2.99	3.08
every other day	2.99	3.29	3.41	3.14	3.20	2.41	2.72	3.01	3.25
					ANOVA				
Source of variation									
MH	NS†	NS	NS	NS	NS	NS	**	*	NS
MF	NS	NS	**	*	***	***	***	***	***
LR	NS	*	NS	NS	NS	NS	NS	NS	*
MH x MF	NS	NS	NS	NS	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS	*	NS	NS
MH x MF x LR	NS	NS	NS	NS	*	NS	NS	NS	NS
CV, %	7.5	4.5	3.8	4.8	2.1	2.9	2.7	3.6	4.3

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 9. Ball roll distance response to mowing height and lightweight rolling on annual bluegrass turf in North Brunswick, NJ on 19 July 2004.

	Lightweight rolling	
Mowing height	None	Every other day
mm	m	
2.8	3.07a†B‡	3.21aA
3.2	2.89bB	3.09abA
3.6	2.76cB	3.02bA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
‡Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected LSD (p = 0.05).

Table 10. Ball roll distance response to mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ on 19 May 2005.

	Lightweight rolling	
Mowing frequency	None	Every other day
wk^{-1}	----------------- m -----------------	
7	2.62b†A‡	2.54bB
14	2.86aA	2.90aA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).
‡Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).

Table 11. Ball roll distance and response to mowing height, mowing frequency and lightweight rolling of annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	14 June 2004		30 June 2004		1 July 2005	
	Mowing frequency, wk^{-1}					
Mowing height	7	14	7	14	7	14
mm	-- m --					
			No rolling			
2.8	3.07a†B‡	3.50aA	2.96abB	3.61aA	3.29aB	3.60aA
3.2	2.95abB	3.24bA	3.01aB	3.38bA	3.12abB	3.38aA
3.6	2.81bB	3.26bA	2.88bB	3.35bA	2.87bB	3.42aA
			Rolling every other day			
2.8	3.14aB	3.57aA	3.11aB	3.48aA	3.32aB	3.73aA
3.2	2.93bB	3.45aA	3.00abB	3.49aA	3.21aB	3.56aA
3.6	3.02abB	3.25bA	2.93bB	3.20bA	3.10aA	3.29bA
Roll $LSD_{(0.05)}$	*0.13*§		*0.17*		*0.17*	

†Means within columns and level of rolling followed by the same lower case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).
‡Means within rows and observation date followed by the same upper case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).
§Least significant difference for comparing rolling regimen for same mowing height and mowing frequency on each observation date according to Fisher's protected LSD (*p* = 0.05).

Table 12. Turf quality response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004.

Main effects	7 June	24 June	30 June	10 July	17 Aug.	7 Sept.	29 Sept.
	-------------------------------- 1-9; 9 = best --------------------------------						
Mowing height (MH)							
2.8 mm	7.2	7.1	7.8	7.1	5.4	3.0	3.6
3.2 mm	6.8	7.8	8.0	7.6	5.8	3.3	5.1
3.6 mm	6.4	8.1	7.1	6.4	6.6	4.6	6.8
$LSD_{(0.05)}$	*0.60*	*0.63*		*0.70*	*1.00*	*0.71*	*0.68*
Mowing frequency (MF)							
7 mowings wk^{-1}	6.5	7.8	7.4	7.0	5.7	3.5	5.3
14 mowings wk^{-1}	7.1	7.5	7.8	7.0	6.2	3.8	5.1
Lightweight rolling (LR)							
none	6.6	7.8	7.6	7.0	5.6	3.3	5.0
every other day	7.0	7.5	7.6	7.1	6.3	4.0	5.4
$LSD_{(0.05)}$					*0.31*	*0.53*	
				ANOVA			
Source of variation							
MH	*	*	NS	**	NS	**	***
MF	NS	NS	NS	NS	NS	NS	NS
LR	NS	NS	NS	NS	***	**	*
MH x MF	NS	NS	NS	NS	*	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	**	NS	NS
CV, %	10.8	8.8	10.7	11.6	8.7	24.1	13.3

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 13. Turf quality and algal cover response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2005.

Main effects	1 July	21 July	25 July
Mowing height (MH)	----- 1-9; 9 = best -----		1-9; 9= no algae
2.8 mm	7.3	2.4	5.0
3.2 mm	7.9	3.9	7.5
3.6 mm	7.4	4.6	7.9
$LSD_{(0.05)}$		*0.81*	*1.43*
Mowing frequency (MF)			
7 mowings wk^{-1}	7.6	3.8	7.3
14 mowings wk^{-1}	7.5	3.5	6.3
$LSD_{(0.05)}$			*0.63*
Lightweight rolling (LR)			
none	7.5	3.4	6.8
every other day	7.6	3.9	6.8
$LSD_{(0.05)}$		*0.40*	
Source of variation		ANOVA	
MH	NS	**	**
MF	NS	NS	**
LR	NS	*	NS
MH x MF	NS	**	NS
MH x LR	NS	NS	NS
MF x LR	NS	NS	NS
MH x MF x LR	NS	NS	*
CV, %	8.3	20.6	10.1

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 14. Turf quality response to mowing height and mowing frequency of annual bluegrass turf in North Brunswick, NJ on 17 Aug. 2004.

	Mowing frequency, wk^{-1}	
Mowing height	7	14
mm	------- 1-9; 9 = best -------	
2.8	5.8 a†A‡	5.1bA
3.2	5.3aB	6.3aA
3.6	6.0aB	7.1aA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).
‡Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected LSD (*p* = 0.05).

Table 15. Turf quality and algal cover response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	Turf Quality		Algal Cover	
	17 Aug. 2004		25 July 2005	
	Mowing frequency, wk^{-1}			
Mowing height	7	14	7	14
mm	----- 1-9; 9 = best -----		----- 1-9; 9 = no algae -----	
		No rolling		
2.8	5.3ab[†]A[‡]	5.3bA	6.0bA	4.5bB
3.2	4.8bB	5.8abA	7.5abA	7.3aA
3.6	6.0aA	6.5aA	9.0aA	6.8aB
		Rolling every other day		
2.8	6.3aA	5.0cB	5.5bA	4.0bA
3.2	5.8aB	6.8bA	8.0aA	7.3aA
3.6	6.0aB	7.8aA	8.0aA	7.8aA
Roll LSD$_{(0.05)}$	*0.76*[§]		*1.02*	

[†]Means within columns and level of rolling followed by the same lower case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
[‡]Means within rows and observation date followed by the same upper case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
[§]Least significant difference for comparing rolling regimen for same mowing height and mowing frequency on each observation date according to Fisher's protected LSD (p = 0.05).

Table 16. Soil bulk density (measured by a Troxler surface moisture-density gauge) response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004			2005		
Main effects	1 July	9 Aug.	13 Sept.	6 June	5 July	23 Aug.
	------------------------------ Mg m^{-3} ------------------------------					
Mowing height (MH)						
2.8 mm	1.40	1.39	1.41	1.30	1.32	1.40
3.2 mm	1.41	1.38	1.41	1.29	1.32	1.40
3.6 mm	1.40	1.36	1.39	1.25	1.29	1.37
$LSD_{(0.05)}$	*NS*	*NS*	*NS*	*0.03*	*NS*	*NS*
Mowing frequency (MF)						
7 mowings wk^{-1}	1.39	1.36	1.39	1.26	1.29	1.37
14 mowings wk^{-1}	1.42	1.39	1.41	1.29	1.32	1.40
Lightweight rolling (LR)						
none	1.40	1.37	1.40	1.28	1.30	1.38
every other day	1.40	1.38	1.40	1.28	1.31	1.40
Source of variation			ANOVA			
MH	NS†	NS	NS	**	NS	NS
MF	*	NS	NS	*	**	*
LR	NS	NS	NS	NS	NS	*
MH x MF	NS	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	NS	NS
CV, %	2.3	2.0	1.9	2.2	1.3	1.5

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 17. Surface hardness response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004		2005		
Main effects	9 Aug.	13 Sept.	6 June	5 July	23 Aug.
	------------------------- G_{max}† -------------------------				
Mowing height (MH)					
2.8 mm	88.2	94.2	75.9	85.4	77.2
3.2 mm	89.7	93.6	75.9	84.4	75.7
3.6 mm	90.9	93.5	73.9	82.4	72.1
Mowing frequency (MF)					
7 mowings wk^{-1}	89.4	92.5	73.6	82.4	71.7
14 mowings wk^{-1}	89.7	95.0	76.8	85.7	78.3
Lightweight rolling (LR)					
none	89.1	93.6	75.1	84.2	73.2
every other day	90.1	93.9	75.3	83.9	76.8
Source of variation			ANOVA		
MH	NS‡	NS	NS	NS	NS
MF	NS	NS	*	**	***
LR	NS	NS	NS	NS	***
MH x MF	NS	NS	NS	NS	NS
MH x LR	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	NS
CV, %	4.5	4.0	3.7	2.7	4.0

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
† G_{max} denotes the ratio of maximum deceleration of an object during impact to the acceleration due to gravity in units of gravities.
‡ NS, not significant.

Table 18. Soil water content (measured by a Troxler surface moisture-density gauge) response to mowing height, mowing frequency and lightweight rolling on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	2004				2005	
Main effects	1 July	9 Aug.	13 Sept.	6 June	5 July	23 Aug.
	---------------------------- $m^3\ m^{-3}$ ----------------------------					
Mowing height (MH)						
2.8 mm	0.215	0.351	0.303	0.351	0.295	0.308
3.2 mm	0.215	0.351	0.300	0.351	0.287	0.313
3.6 mm	0.221	0.341	0.300	0.362	0.295	0.328
$LSD_{(0.05)}$				*0.007*		*0.009*
Mowing frequency (MF)						
7 mowings wk^{-1}	0.216	0.341	0.301	0.355	0.292	0.322
14 mowings wk^{-1}	0.218	0.354	0.301	0.355	0.292	0.311
Lightweight rolling (LR)						
none	0.218	0.346	0.303	0.354	0.292	0.316
every other day	0.216	0.349	0.300	0.356	0.293	0.316
Source of variation			ANOVA			
MH	NS†	NS	NS	**	NS	**
MF	NS	**	NS	NS	NS	***
LR	NS	NS	NS	NS	NS	NS
MH x MF	NS	**	NS	NS	NS	**
MH x LR	NS	NS	NS	NS	NS	NS
MF x LR	NS	NS	NS	NS	NS	NS
MH x MF x LR	NS	NS	NS	NS	NS	NS
CV, %	5.0	3.9	3.3	3.4	2.1	3.4

* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.
*** Significant at the 0.001 probability level.
†NS, not significant.

Table 19. Soil water content (measured by a Troxler surface moisture-density gauge) response to mowing height and mowing frequency on annual bluegrass turf in North Brunswick, NJ during 2004 and 2005.

	9 Aug. 2004		23 Aug.2005	
	Mowing frequency, wk^{-1}			
Mowing height	7	14	7	14
mm	---------------------------- $m^3\ m^{-3}$ ----------------------------			
2.8	0.340a†B‡	0.360abA	0.311bA	0.306bA
3.2	0.337aB	0.366aA	0.325aA	0.301bB
3.6	0.345aA	0.338bA	0.330aA	0.326aA

†Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected LSD (p = 0.05).
‡Means within rows and observation date followed by the same upper case letter are not significantly different according to Fisher's protected LSD (p = 0.05).

Table 20. Seedhead production response to trinexapac-ethyl on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

Trinexapac-ethyl (TE)	2006	2007			
	2 June	1 May	14 May	5 June	9 July
	------------------------------ % ------------------------------				
untreated	35.0	42.5	81.3	28.8	11.3
0.04 kg a.i. ha^{-1}, 7 d	45.0	30.0	80.0	48.8	20.0
0.05 kg a.i. ha^{-1}, 14 d	41.3	32.5	72.5	36.3	16.3
0.05 kg a.i. ha^{-1}, 7 d	50.0	27.5	76.3	48.8	22.5
0.08 kg a.i. ha^{-1}, 14 d	43.8	25.0	72.5	37.5	17.5
0.08 kg a.i. ha^{-1}, 7 d	52.5	28.8	73.8	56.3	23.8
Planned *F*-tests	--------------------------- $P > F$ ---------------------------				
untreated *vs.* all TE[†]	***	**	NS	***	***
14 d *vs.* 7 d[‡]	***	NS	NS	***	***
0.05 *vs.* 0.08 kg a.i. ha^{-1}[§]	NS[#]	NS	NS	NS	NS
interval x rate interaction	NS	NS	NS	NS	NS
linear rate of TE,7 d[¶]	***	**	NS	***	***

**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Comparison of: untreated vs. 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 14 d; 0.05 kg a.i. ha^{-1}, 7 d; 0.08 kg a.i. ha^{-1}, 14 d; and 0.08 kg a.i. ha^{-1}, 7 d.
[‡]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 14 d vs. 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d.
[§]Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.05 kg a.i. ha^{-1}, 7 d vs. 0.08 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 7 d.
[¶]Coefficients to determine linear response of TE rates at 7 d interval on seedhead expression: -17, -1, 3 and 15 for untreated, 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d, respectively.
[#]NS, not significant.

Table 21. Turf quality and turf color response to trinexapac-ethyl on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005	2006						2007					
	Turf quality												Turf color
Trinexapac-ethyl (TE)	28 June	30 Apr.	25 May	2 June	9 June	28 June	8 Sept.	30 Mar.	2 May	22 May	5 June	9 July	18 Apr.
	1 – 9 (9 = best)												1 – 9
untreated	6.8	5.3	4.5	4.3	4.5	4.3	4.5	2.8	4.0	4.5	5.3	6.0	4.5
0.04 kg a.i. ha^{-1}, 7 d	5.8	4.8	3.5	3.5	4.3	4.8	6.0	3.0	4.0	3.8	5.0	5.0	2.8
0.05 kg a.i. ha^{-1}, 14 d	6.8	5.0	4.0	4.0	4.8	5.0	4.8	2.8	4.0	4.0	5.8	4.8	2.5
0.05 kg a.i. ha^{-1}, 7 d	5.3	4.5	3.0	3.5	4.3	5.3	6.0	2.8	4.0	4.0	4.5	4.5	3.3
0.08 kg a.i. ha^{-1}, 14 d	6.0	4.5	3.8	3.3	4.0	4.0	6.3	3.5	4.3	4.5	5.5	6.0	2.8
0.08 kg a.i. ha^{-1}, 7 d	5.0	4.5	3.0	2.3	4.0	4.5	6.5	3.0	3.3	3.8	3.8	4.3	1.5
Planned *F*-tests	*P* > *F*												
untreated *vs.* all TE†	*	NS	**	*	NS	NS	**	NS	NS	NS	NS	**	***
14 d *vs.* 7 d‡	**	NS	**	*	NS	NS	NS	NS	NS	NS	***	**	NS
0.05 *vs.* 0.08 kg a.i. ha^{-1}§	NS#	NS	NS	**	NS	**	*	NS	NS	NS	NS	NS	NS
interval x rate interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	**
linear rate of TE,7 d¶	**	NS	***	***	NS	NS	**	NS	NS	NS	***	***	***

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Comparison of: untreated vs. 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 14 d; 0.05 kg a.i. ha^{-1}, 7 d; 0.08 kg a.i. ha^{-1}, 14 d; and 0.08 kg a.i. ha^{-1}, 7 d.
‡Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 14 d vs. 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d.
§Comparison of: 0.05 kg a.i. ha^{-1}, 14 d and 0.05 kg a.i. ha^{-1}, 7 d vs. 0.08 kg a.i. ha^{-1}, 14 d and 0.08 kg a.i. ha^{-1}, 7 d.
¶Coefficients to determine linear response of TE rates at 7 d interval on seedhead expression: -17, -1, 3 and 15 for untreated, 0.04 kg a.i. ha^{-1}, 7 d; 0.05 kg a.i. ha^{-1}, 7 d and 0.08 kg a.i. ha^{-1}, 7 d, respectively.
#NS, not significant.

Table 22. Seedhead response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

	2006	2007			
Main effect	2 June	24 Apr.	1 May	14 May	9 July
	------------------------		%		------------------------
Mefluidide (ME) †					
0	40.0	17.9	31.7	82.9	15.0
0.106 kg a.i. ha^{-1}	39.8	17.1	22.9	65.0	12.5
$LSD_{0.05}$			*4.5*	*7.7*	*2.5*
Trinexapac-ethyl interval(TE) ‡					
none	35.0	19.4	32.5	69.4	10.0
14 d	41.6	18.8	23.8	76.9	14.4
7 d	43.1	14.4	25.6	75.6	16.9
$LSD_{0.05}$		*4.1*	*5.6*		*3.0*
Source of variation			ANOVA		
ME	NS§	NS	***	***	*
TE	NS	*	**	NS	***
ME x TE	NS	**	**	NS	NS
CV, %	17.7	21.9	19.1	12.0	20.6

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 31 March and 12 April 2006, and 28 March and 11 April 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 26 April to 20 September 2006 and 25 April to 29 August 2007, or every 7 days from 19 April to 20 September 2006 and 18 April to 29 August 2007.

§ NS, not significant.

Table 23. Seedhead response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2007.

	24 Apr.		1 May	
	Mefluidide‡			
Trinexapac-ethyl interval†	None	0.106 kg a.i. ha^{-1}	None	0.106 kg a.i. ha^{-1}
d	----------------------------	%		----------------------------
none	22.5a§A¶	16.3abA	42.5aA	22.5aB
14	15.0aB	22.5aA	25.0bA	22.5aA
7	16.3aA	12.5bA	27.5bA	23.8aA

† Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 25 April to 29 August 2007, or every 7 days from 18 April to 29 August 2007.

‡ Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 28 March and 11 April 2007.

§ Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

¶ Means within rows for each observation date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 24. Seedhead response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

	2006	2007			
Main effect	2 June	24 Apr.	1 May	14 May	9 July
	------------------------- % -------------------------				
Ethephon (EP) †					
0	42.1	20.8	34.2	76.7	16.7
3.8 kg a.i. ha^{-1}	17.3	10.0	17.1	52.9	5.1
$LSD_{0.05}$	*4.4*	*3.6*	*6.0*	*11.1*	*2.0*
Trinexapac-ethyl interval(TE) ‡					
none	24.1	15.0	30.0	66.9	7.8
14 d	31.9	16.3	25.0	61.9	10.3
7 d	33.1	15.0	21.9	65.6	14.6
$LSD_{0.05}$	*5.3*				*2.4*
Source of variation			ANOVA		
EP	***	***	***	***	***
TE	**	NS§	NS	NS	***
EP x TE	*	NS	NS	NS	**
CV, %	16.9	26.7	27.0	19.6	21.0

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.
† Ethephon was applied on 31 March and 12 April 2006, and 28 March and 11 April 2007.
‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 26 April to 20 September 2006 and 25 April to 29 August 2007, or every 7 days from 19 April to 20 September 2006 and 18 April to 29 August 2007.
§ NS, not significant.

Table 25. Seedhead response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2006 and 2007.

	2 June 2006		9 July 2007	
	Ethephon‡			
Trinexapac-ethyl interval†	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}
d	---------------------------- % ----------------------------			
none	35.0b§A¶	13.3bB	11.3cA	4.3aB
14	41.3bA	22.5aB	16.3bA	4.3aB
7	50.0aA	16.3abB	22.5aA	6.8aB

† Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 26 April to 20 September 2006 and 25 April to 29 August 2007, or every 7 days from 19 April to 20 September 2006 and 18 April to 29 August 2007.
‡ Ethephon was applied on 31 March and 12 April 2006, and 28 March and 11 April 2007.
§Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
¶ Means within rows for each observation date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 26. Turf quality and turf color response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005	2006					2007					
	Turf quality											Turf color
Main effect	28 June	30 Apr.	25 May	9 June	19 June	8 Sept.	30 Mar.	2 May	22 May	5 June	9 July	18 Apr.
	---------- 1 – 9 (9 = best) ----------											1 – 9
Mefluidide (ME) †												
0	6.4	5.0	3.9	4.3	4.1	5.0	3.3	4.4	4.4	4.9	5.6	4.3
0.106 kg a.i. ha^{-1}	6.9	5.0	4.8	4.9	4.8	5.5	3.5	3.9	5.8	5.6	5.7	3.3
$LSD_{0.05}$			*0.4*	*0.5*	*0.5*			*0.5*	*0.5*	*0.4*		*0.6*
Trinexapac-ethyl interval(TE) ‡												
none	6.5	5.3	4.9	4.9	4.9	4.9	3.1	4.0	5.1	5.9	5.8	4.0
14 d	7.1	5.1	4.6	4.9	4.8	5.0	3.5	4.8	5.0	5.8	5.8	3.6
7 d	6.4	4.6	3.6	4.1	3.8	5.9	3.6	3.8	5.1	4.1	5.4	3.9
$LSD_{0.05}$			*0.5*	*0.6*	*0.6*			*0.6*		*0.5*		
Source of variation						ANOVA						
ME	NS§	NS	***	*	**	NS	NS	*	***	*	NS	**
TE	NS	NS	***	*	***	NS	NS	**	NS	***	NS	NS
ME x TE	NS	NS	NS	NS	NS	NS	NS	*	NS	NS	NS	NS
CV, %	15.0	13.7	9.9	12.6	12.0	15.9	19.0	14.1	11.7	8.5	16.1	17.6

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 4 and 20 April 2005, 31 March and 12 April 2006, and 28 March and 11 April 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 4 May to 26 July 2005, 26 April to 20 September 2006, and 25 April to 29 August 2007, or every 7 days from 28 April to 26 July 2005, 19 April to 20 September 2006, and 18 April to 29 August 2007.

§ NS, not significant.

Table 27. Seedhead response to mefluidide rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ on 2 May 2007.

Trinexapac-ethyl interval†	Mefluidide‡ None	Mefluidide‡ 0.106 kg a.i. ha^{-1}
	------------- %	-------------
none	4.0b§A¶	4.0bA
14	4.8aA	4.8aA
7	4.5abA	3.0cB

† Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 25 April to 29 August 2007, or every 7 days from 18 April to 29 August 2007.
† Mefluidide was applied as a split application of 0.053 kg a.i. ha^{-1} on 28 March and 11 April 2007.
§Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
¶ Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 28. Turf quality and turf color response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2005, 2006 and 2007.

	2005	2006					2007					
	Turf quality											Turf color
Main effect	28 June	30 Apr.	25 May	9 June	19 June	8 Sept.	30 Mar.	2 May	22 May	5 June	9 July	18 Apr.
	1 – 9 (9 = best)											1 – 9
Ethephon (EP) †												
0	6.3	4.9	3.8	4.5	4.8	5.1	2.8	4.0	4.2	5.2	5.1	3.4
3.8 kg a.i. ha^{-1}	7.8	6.8	6.6	7.5	7.7	6.2	3.6	5.2	7.1	7.7	7.1	4.7
$LSD_{0.05}$	*0.8*	*0.4*	*0.4*	*0.6*	*0.6*	*1.0*	*0.5*	*0.6*	*0.5*	*0.5*	*0.9*	*0.6*
Trinexapac-ethyl interval(TE) ‡												
none	7.3	6.0	5.4	5.8	5.6	5.5	3.3	4.8	5.9	6.5	6.5	4.9
14 d	7.4	5.9	5.4	6.1	6.4	5.1	3.3	4.6	5.6	6.8	5.9	3.8
7 d	6.4	5.8	4.9	6.1	6.6	6.3	3.0	4.4	5.4	6.0	5.9	3.5
$LSD_{0.05}$					*0.7*					*0.6*		*0.7*
Source of variation						ANOVA						
EP	***	***	***	***	***	*	**	***	***	***	***	***
TE	NS§	NS	NS	NS	*	NS	NS	NS	NS	*	NS	***
EP x TE	NS	NS	**	NS	**	NS	NS	NS	NS	NS	NS	**
CV, %	12.6	8.6	9.2	11.5	10.8	20.8	16.6	14.0	10.4	8.5	17.2	15.8

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively. NS, not significant

† Ethephon was applied on 5 and 20 April 2005, 31 March and 12 April 2006, and 28 March and 11 April 2007.

‡ Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 4 May to 26 July 2005, 26 April to 20 September 2006, and 25 April to 29 August 2007, or every 7 days from 28 April to 26 July 2005, 19 April to 20 September 2006, and 18 April to 29 August 2007.

§ NS, not significant.

Table 29. Turf quality and turf color response to ethephon rate and trinexapac-ethyl application interval on annual bluegrass putting green turf in North Brunswick, NJ during 2006 and 2007.

	Turf quality				Turf color	
	25 May 2006		19 June 2006		18 Apr. 2007	
	Ethephon‡					
Trinexapac-ethyl interval†	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}	None	3.8 kg a.i. ha^{-1}
d	--------------------- 1 – 9 (9 = best) ---------------------				----------- 1 – 9 -----------	
none	4.5a§B¶	6.3aA	4.8aB	6.5bA	4.5aA	5.3aA
14	4.0aB	6.8aA	5.0aB	7.8abA	2.5bB	5.0aA
7	3.0bB	6.8aA	4.5aB	8.8aA	3.3bA	3.8bA

† Trinexapac-ethyl was applied at 0.050 kg a.i. ha^{-1} either every 14 days from 26 April to 20 September 2006 and 25 April to 29 August 2007, or every 7 days from 19 April to 20 September 2006 and 18 April to 29 August 2007.

‡ Ethephon was applied on 31 March and 12 April 2006, and 28 March and 11 April 2007.

§ Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

¶ Means within rows for each observation date followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 30. Anthracnose disease response to topdressing applied at 0.3 L m^{-2} every 7 d and brushing for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Sand Rate[†]	Brush[‡]	20 June	6 July	12 July	20 July	7 Aug.	16 Aug.	28 Aug.	6 Sept.
L m^{-2}	days	%							
0.0	none	0.5	18.7	14.9	46.0	67.5	64.6	55.3	52.6
	7	0.5	20.1	17.9	55.8	71.7	74.3	69.1	64.2
0.3	none	0.5	17.0	23.4	49.9	44.9	56.4	29.6	12.3
	7	0.6	16.0	26.1	51.1	42.4	47.8	27.5	10.3
Planned *F*-test		$p > F$							
0.0 *vs.* 0.3 L m^{-2}		NS[§]	NS	**	NS	**	*	***	***
No brush *vs.* brush		NS	NS	NS	NS	NS	NS	NS	NS
Sand x brush		NS	NS	NS	NS	NS	NS	NS	NS
CV, %		59.4	34.6	20.6	14.1	22.8	23.3	26.2	34.9

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006.
‡Brushing was conducted as four passes of a broom across individual plots every 7 d following topdressing.
§ NS, not significant.

Table 31. Anthracnose disease response to topdressing applied at 0.3 L m^{-2} every 7 d and brushing for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

Sand Rate[†]	Brush[‡]	22 June	5 July	18 July	25 July	2 Aug.	13 Aug.	23 Aug.	12 Sept.	28 Sept.	5 Oct.
L m^{-2}	days	------------	------------	------------	------------	------------ %	------------	------------	------------	------------	------------
0.0	none	2.7	7.0	14.8	12.4	20.5	27.8	34.2	26.9	36.8	30.4
	7 d	3.0	6.9	13.6	11.7	19.1	24.3	32.4	24.6	32.2	25.5
0.3	none	1.0	3.5	7.0	6.0	8.2	11.4	10.8	8.1	7.4	5.9
	7 d	3.0	5.4	10.5	6.9	11.0	13.4	15.1	10.5	10.6	6.8
Planned *F*-test		------------	------------	------------	------------	------------ $p > F$	------------	------------	------------	------------	------------
0.0 *vs.* 0.3 L m^{-2}		NS[§]	*	*	**	**	**	***	**	***	***
No brush *vs.* brush		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Sand x brush		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %		84.0	39.4	37.1	46.9	35.4	37.8	27.4	46.3	27.5	36.7

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Topdressing was applied from 8 May to 2 Oct. 2007.
[‡]Brushing was conducted as four passes of a broom across individual plots every 7 d following topdressing.
[§] NS, not significant.

Table 32. Turf quality response to topdressing applied at 0.3 L m^{-2} every 7 d and brushing for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Sand Rate[†]	Brush[‡]	31 May	16 June	22 June	29 June	30 June	12 July	17 July	21 July	31 July
L m^{-2}	days	----------	----------	----------	----------	1-9 scale[§]	----------	----------	----------	----------
0.0	none	7.0	6.8	6.5	6.8	6.0	5.0	5.3	3.8	3.3
	7 d	7.3	5.8	6.8	7.0	6.5	5.3	5.3	3.5	2.8
0.3	none	6.8	4.0	5.0	7.0	7.5	5.5	5.5	5.0	3.8
	7 d	6.8	4.3	7.3	7.3	6.3	5.5	5.0	4.8	4.0
<u>Planned *F*-test</u>		----------	----------	----------	----------	$p > F$	----------	----------	----------	----------
0.0 *vs.* 0.3 L m^{-2}		NS[¶]	***	NS	NS	NS	NS	NS	*	***
No brush *vs.* brush		NS	NS	*	NS	NS	NS	NS	NS	NS
Sand x brush		NS	NS	NS	NS	NS	NS	NS	NS	NS
CV, %		8.4	13.7	15.0	8.9	14.0	21.8	22.0	22.2	29.2

*Significant at the 0.05 probability level.
***Significant at the 0.001 probability level.
[†]Topdressing was applied from 25 May to 31 Aug. 2006.
[‡]Brushing was conducted as four passes of a broom across individual plots every 7 d following topdressing.
[§]9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
[¶]ns, not significant.

Table 33. Turf quality response to topdressing applied at 0.3 L m^{-2} every 7 d and brushing for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

Sand Rate†	Brush‡	25 May	8 June	21 June	6 July	2 Aug.	29 Aug.	29 Sept.
L m^{-2}	days	----------------	----------------	----------------	1-9 scale§	----------------	----------------	----------------
0.0	none	7.0	7.0	6.3	5.5	3.8	3.3	3.5
	7 d	7.3	7.3	7.0	5.5	4.0	4.0	4.0
0.3	none	7.3	7.3	7.8	7.5	6.0	5.3	6.8
	7 d	7.0	7.3	7.5	6.5	5.8	4.8	5.8
$LSD_{0.05}$								*1.1*#
<u>Planned *F*-test</u>		----------------	----------------	----------------	$p > F$	----------------	----------------	----------------
0.0 *vs.* 0.3 L m^{-2}		NS¶	NS	*	**	**	**	***
No brush *vs.* brush		NS	NS	NS	NS	NS	NS	NS
Sand x brush		NS	NS	NS	NS	NS	NS	*
CV, %		13.4	8.8	9.6	12.5	18.4	18.2	13.3

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied from 8 May to 2 Oct. 2007.
‡Brushing was conducted as four passes of a broom across individual plots every 7 d following topdressing.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
¶NS, not significant.
#Means separated using Fisher's protected least significant differences test at $\alpha = 0.05$.

Table 34. Turf quality response to sand topdressing applied at 1.2 L m^{-2} (every 42 and 21 d) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Sand Rate†	Interval	31 May	16 June	22 June	29 June	30 June	12 July	17 July	21 July	31 July
L m^{-2}	days	1-9 scale‡								
0.0	0	7.0	6.8	6.5	6.8	6.0	5.0	5.3	3.8	3.3
1.2	42	6.5	7.5	7.3	7.0	7.3	5.0	5.8	4.0	3.0
1.2	21	7.3	4.3	5.3	6.8	7.0	4.5	4.8	4.3	3.0
Planned *F*-test		$p > F$								
0.0 *vs.* 1.2 L m^{-2}		NS§	NS	NS	NS	NS	NS	NS	NS	NS
21 *vs.* 42 d		NS	**	*	NS	NS	NS	NS	NS	NS
CV, %		7.2	15.5	18.0	17.4	18.3	16.9	26.2	30.3	38.6

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§NS, not significant.

Table 35. Turf quality response to sand topdressing applied at 1.2 L m^{-2} (every 42 and 21 d) for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

Sand Rate†	Interval	25 May	8 June	21 June	6 July	2 Aug.	29 Aug.	29 Sept.
L m^{-2}	days	1-9 scale‡						
0.0	0	7.0	7.0	6.3	5.5	3.8	3.3	3.5
1.2	42	7.5	7.5	7.3	7.0	4.3	4.3	5.3
1.2	21	5.5	7.5	7.3	7.0	4.8	5.5	7.0
Planned *F*-test		*p* > *F*						
0.0 *vs.* 1.2 L m^{-2}		NS§	NS	**	**	NS	**	***
21 *vs.* 42 d		**	NS	NS	NS	NS	*	*
CV, %		11.2	10.2	6.8	7.3	13.6	12.8	14.5

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
†Topdressing was applied from 8 May to 2 Oct. 2007.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§NS, not significant.

Table 36. Anthracnose disease severity analysis of variance summary for sand topdressing application rate and interval effects for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Source	df	20 June	6 July	12 July	20 July	7 Aug.	16 Aug.	28 Aug.	6 Sept.
Rep	3	NS‡	NS	NS	NS	***	**	NS	**
Rate (R)†	2	NS	NS	**	NS	****	****	****	****
R_{Linear} (R_L)	1	NS	NS	NS	NS	****	****	****	****
$R_{Quadratic}$ (R_Q)	1	NS	NS	**	NS	NS	NS	NS	**
Interval (I)	2	NS	NS	NS	NS	***	****	***	***
I_{Linear} (I_L)	1	NS	NS	NS	NS	***	****	***	***
$I_{Quadratic}$ (I_Q)	1	**	NS	NS	NS	NS	**	**	NS
R x I	4	NS	NS	NS	*	**	***	****	***
R_L x I_L	1	NS	NS	NS	NS	***	****	****	***
R_L x I_Q	1	NS	NS	NS	NS	NS	NS	**	NS
R_Q x I_L	1	NS	NS	NS	NS	NS	NS	NS	NS
R_Q x I_Q	1	NS	NS	NS	**	NS	**	**	**

*Significant at the 0.10 probability level.
**Significant at the 0.05 probability level.
***Significant at the 0.01 probability level.
****Significant at the 0.001 probability level.
†Topdressing was applied every 7, 21 or 28 d at 0, 0.3 or 0.6 L m^{-2} from 25 May to 31 Aug. 2006.
‡NS, not significant.

Table 37. Anthracnose disease severity response to topdressing application rate and interval effects on anthracnose disease severity on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Effect	20 June	6 July	12 July	20 July	7 Aug.	16 Aug.	28 Aug.	6 Sept.	20 June - 20 July[§]	7 Aug. - 6 Sept. [§]
					%					
Rate (L m^{-2})[†]										
0.0	0.5	17.1	15.9	52.8	67.6	71.5	61.3	61.1	21.6	65.4
0.3	0.9	20.4	26.0	54.7	55.0	62.5	44.8	31.6	25.5	48.5
0.6	0.8	18.2	22.0	56.9	47.3	55.5	31.8	19.5	24.5	38.5
$LSD_{0.05}$			*7.7*[‡]		*7.7*	*7.6*	*8.0*	*9.9*		*7.5*
Interval (d)										
28	0.5	17.8	16.7	55.8	60.7	69.5	50.3	45.4	22.7	56.5
14	1.3	21.3	24.2	55.2	59.6	66.4	50.4	39.2	25.5	53.9
7	0.5	16.5	23.0	53.4	49.5	53.6	37.1	27.5	23.4	41.9
$LSD_{0.05}$					*7.7*	*7.6*	*8.0*	*9.9*		*7.5*
Rate x Interval										
0.0 – 28	0.3	14.8	12.7	54.9	64.4	68.7	56.6	58.2	20.7	62.0
0.0 – 14	0.8	16.5	17.1	47.7	66.8	71.6	58.2	60.8	20.5	64.4
0.0 – 7	0.5	20.1	17.9	55.8	71.7	74.3	69.1	64.2	23.5	69.8
0.3 – 28	0.7	20.3	20.2	52.3	60.1	67.3	51.9	43.4	23.4	55.7
0.3 – 14	1.5	24.7	31.7	60.8	62.5	72.2	55.1	40.9	29.7	57.7
0.3 – 7	0.6	16.0	26.1	51.1	42.4	47.8	27.5	10.3	23.5	32.0
0.6 – 28	0.4	18.1	17.0	60.2	57.8	72.4	42.5	34.5	23.9	51.8
0.6 – 14	1.6	22.8	23.9	57.1	49.5	55.3	38.0	15.9	26.4	39.7
0.6 – 7	0.5	13.6	25.2	53.4	34.4	38.7	14.8	8.0	23.2	24.0
$LSD_{0.05}$				*9.8*	*13.4*	*13.1*	*13.9*	*17.2*		*13.0*

[†]Topdressing was applied every 7, 21 or 28 d at 0, 0.3 or 0.6 L m^{-2} from 25 May to 31 Aug. 2006.
[‡]Means separated using Fisher's protected least significant differences test at $\alpha = 0.05$.
[§]Data pooled since treatments did not interact with observation date from 20 June to 20 July (n = 4 observations) or 7 Aug. to 6 Sept. (n = 4 observations).

Table 38. Anthracnose disease severity analysis of variance summary for sand topdressing application rate and interval effects for an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

Source	df	22 June	5 July	18 July	25 July	2 Aug.	13 Aug.	23 Aug.	12 Sept.	28 Sept.	5 Oct.
Rep	3	NS‡	NS	**	NS	NS	NS	NS	NS	NS	NS
Rate (R)†	2	NS	NS	NS	**	**	***	****	****	****	****
R_{Linear} (R_L)	1	NS	NS	NS	***	**	***	****	****	****	****
$R_{Quadratic}$ (R_Q)	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interval (I)	2	NS	NS	NS	NS	NS	*	**	NS	**	*
I_{Linear} (I_L)	1	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
$I_{Quadratic}$ (I_Q)	1	NS	NS	NS	NS	**	**	**	NS	NS	NS
R x I	4	NS	NS	NS	*	*	NS	*	NS	**	**
R_L x I_L	1	NS	NS	NS	NS	NS	NS	NS	NS	**	**
R_L x I_Q	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
R_Q x I_L	1	NS	NS	**	**	**	*	**	*	**	NS
R_Q x I_Q	1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

*Significant at the 0.10 probability level.
**Significant at the 0.05 probability level.
***Significant at the 0.01 probability level.
****Significant at the 0.001 probability level.
†Topdressing was applied every 7, 21 or 28 d at 0, 0.3 or 0.6 L m^{-2} from 8 May to 2 Oct. 2007.
‡NS, not significant.

Table 39. Anthracnose disease severity response to topdressing application rate and interval effects on anthracnose disease severity on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

Effect	22 June	5 July	18 July	25 July	2 Aug.	13 Aug.	23 Aug.	12 Sept.	28 Sept.	5 Oct.	22 June - 18 July[§]	25 July - 5 Oct.[§]
	%											
Rate (L m^{-2})[†]												
0.0	2.4	5.4	12.4	11.4	19.1	24.1	32.9	24.9	31.8	25.9	18.4	24.3
0.3	2.6	5.6	12.5	10.0	17.0	21.0	26.3	20.5	20.3	14.5	18.9	18.5
0.6	2.4	5.6	10.4	7.1	13.8	13.4	14.5	11.4	10.3	6.9	16.7	11.1
$LSD_{0.05}$				*3.2*[‡]	*4.3*	*6.6*	*6.9*	*6.6*	*5.9*	*6.3*		*4.8*
Interval (d)												
28	2.5	5.3	11.5	10.4	17.4	18.5	26.3	20.0	23.3	18.0	17.6	19.1
14	1.8	5.3	12.4	10.0	18.7	23.6	28.1	21.7	22.9	17.7	17.7	20.4
7	3.1	6.1	11.4	8.1	13.8	16.5	19.3	15.0	16.1	11.5	18.8	14.3
$LSD_{0.05}$							*6.9*		*5.9*	*6.3*		*4.8*
Rate x Interval												
0.0 – 28	2.2	5.2	10.3	8.6	15.3	17.7	27.6	20.4	26.6	19.9	16.2	19.4
0.0 – 14	1.8	4.2	13.3	13.8	22.8	30.5	38.8	29.7	36.7	32.1	17.6	29.2
0.0 – 7	3.0	6.9	13.6	11.7	19.1	24.3	32.4	24.6	32.2	25.5	21.3	24.3
0.3 – 28	3.2	5.9	15.0	13.9	21.4	24.4	33.8	25.3	27.8	21.3	21.9	24.0
0.3 – 14	1.6	5.7	12.0	9.2	18.6	25.4	29.9	25.5	22.3	15.3	17.6	20.9
0.3 – 7	3.0	5.4	10.5	6.9	11.0	13.4	15.1	10.5	10.6	6.8	17.3	10.6
0.6 – 28	2.2	4.8	9.1	8.8	15.4	13.5	17.6	14.2	15.6	12.7	14.6	14.0
0.6 – 14	1.8	5.9	11.9	6.9	14.7	14.9	15.7	10.0	9.6	5.8	17.8	11.1
0.6 – 7	3.2	6.1	10.2	5.8	11.3	11.9	10.3	9.9	5.6	2.2	17.6	8.1
$LSD_{0.05}$				*5.5*	*7.4*		*11.4*		*10.3*	*11*		*8.3*

[†]Topdressing was applied every 7, 21 or 28 d at 0, 0.3 or 0.6 L m^{-2} from 8 May to 2 Oct. 2007.
[‡]Means separated using Fisher's protected least significant differences test at $\alpha = 0.05$.
[§]Data pooled since treatment did not interact with observation date from 22 June to 18 July (n = 3 observations) or 25 July to 5 Oct. (n = 7 observations).

Table 40. Turf quality response to topdressing application rate and interval effects on anthracnose disease severity on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Main effect	31 May	16 June	22 June	29 June	30 June	12 July	17 July	21 July	31 July
Rate (L m^{-2}) †	-- 1-9 scale ‡ --								
0.0	7.1	6.8	6.9	6.7	6.8	5.5	3.8	2.9	2.7
0.3	6.8	6.5	6.8	6.3	5.8	5.1	4.3	3.8	4.8
0.6	6.8	4.6	6.3	6.8	5.8	5.3	4.9	3.6	5.2
$LSD_{0.05}$		*0.8*			*0.9*		*0.7*		*0.9*
Interval (d)									
28	6.8	6.3	6.8	7.3	7.3	5.7	4.3	3.3	3.8
14	6.9	5.7	6.3	6.2	5.3	5.1	4.0	3.5	4.1
7	6.9	6.0	6.8	6.3	5.8	5.2	4.7	3.6	4.8
$LSD_{0.05}$					*0.9*				*0.9*
Source	-- $p > F$ --								
Rate (R)	NS§	***	NS	NS	*	NS	***	NS	****
Interval (I)	NS	NS	NS	NS	****	NS	NS	NS	*
R x I	NS	**	NS	NS	NS	NS	NS	NS	NS
CV, %	8.0	15.2	14.9	18.7	17.5	19.0	19.1	32.0	24.5

*Significant at the 0.10 probability level.
**Significant at the 0.05 probability level.
***Significant at the 0.01 probability level.
****Significant at the 0.001 probability level.
†Topdressing was applied from 25 May to 31 Aug. 2006.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§NS, not significant.

Table 41. Turf quality and sandiness response to topdressing application rate and interval effects on anthracnose disease severity on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2007.

	Turf quality							Sandiness
Main effect	25 May	8 June	21 June	6 July	2 Aug.	29 Aug.	29 Sept.	13 Sept.
Rate ($L\ m^{-2}$)[†]	------------------------------------ 1-9 scale[‡] ------------------------------------							1-9 scale[¶]
0.0	7.3	7.4	7.1	6.0	4.0	3.6	3.8	9.0
0.3	7.0	7.3	7.2	6.3	4.9	4.1	5.1	6.2
0.6	6.6	7.0	7.1	6.6	4.6	4.2	5.7	3.9
$LSD_{0.05}$					*0.7*	*0.5*	*0.5*	*0.6*
Interval (d)								
28	7.2	7.4	6.8	6.3	4.2	3.8	4.8	8.4
14	6.9	7.2	7.3	6.4	4.7	3.8	5.0	5.7
7	6.8	7.1	7.3	6.3	4.7	4.3	4.8	5.0
$LSD_{0.05}$						*0.5*		*0.6*
Source	--- $p > F$ --							
Rate (R)	NS[§]	NS	NS	NS	*	**	****	****
Interval (I)	NS	NS	NS	NS	NS	*	NS	****
R x I	NS	NS	NS	NS	*	***	***	****
CV, %	10.9	7.6	10.3	12.7	19.7	14.5	16.3	10.6

*Significant at the 0.10 probability level.
**Significant at the 0.05 probability level.
***Significant at the 0.01 probability level.
****Significant at the 0.001 probability level.
[†]Topdressing was applied from 8 May to 2 Oct. 2007.
[‡]9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
[§]NS, not significant.
[¶]9 represents no sand apparent at turf surface, and 5 represents the minimally acceptable rating.

Table 42. Turf quality and sandiness means for interaction of topdressing application rate and interval on an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006 and 2007.

		Turf Quality				Sandiness
		2006	2007			
Rate†	Interval	16 June	2 Aug.	29 Aug.	29 Sept.	13 Sept.
L m^{-2}	d	-------------------- 1 – 9 scale‡			--------------------	1 – 9 scale§
0.0	28	6.8	4.3	3.8	4.3	9.0
	14	7.0	3.8	3.0	3.3	9.0
	7	6.8	4.0	4.0	4.0	9.0
0.3	28	6.3	3.8	3.3	4.3	9.0
	14	6.0	5.3	4.3	5.3	5.5
	7	7.3	5.8	4.8	5.8	4.0
0.6	28	5.8	4.5	4.5	5.8	7.3
	14	4.0	5.0	4.0	6.5	2.5
	7	4.0	4.3	4.0	4.8	2.0
	$LSD_{0.05}$	*1.3*	*1.3*	*0.8*	*1.2*	*1.0*

†Topdressing was applied from 25 May to 31 Aug. 2006 and 8 May to 2 Oct. 2007.
‡9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
§9 represents no sand apparent at turf surface, and 5 represents the minimally acceptable rating.

Table 43. Turf quality response to topdressing incorporation method and sand particle shape of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ in 2006 and 2007.

	2006					2007		
Main Effects	23 June	12 July	17 July	31 July	25 Aug.	25 May	21 June	20 July
Incorporation[†]	-- 1 – 9 scale[§] --							
no incorporation	6.3	4.6	3.2	2.8	3.2	7.4	6.7	4.8
vibratory rolling	6.3	4.8	3.4	3.4	3.6	7.5	6.7	4.6
soft brush	6.8	5.6	4.3	3.8	4.4	7.1	7.1	4.8
stiff brush	6.3	5.2	3.9	3.2	3.7	7.1	6.8	5.0
$LSD_{0.05}$			*0.7*					
Sand shape[‡]								
no sand	7.9	5.3	3.7	2.7	2.8	7.2	6.3	4.4
round	5.3	4.8	3.5	3.5	4.5	7.3	6.9	4.9
sub-angular	6.2	5.1	4.0	3.8	3.8	7.3	7.3	5.1
$LSD_{0.05}$	*0.6*			*0.6*	*0.6*		*0.5*	*0.5*
Source	-- $p>F$ --							
Incorporation (I)	NS[¶]	NS	*	NS	NS	NS	NS	NS
Sand shape (S)	***	NS	NS	**	***	NS	***	**
I x S	NS	**	NS	NS	NS	NS	NS	NS
C.V. (%)	10.2	7.9	16.0	20.6	17.6	7.7	11.4	17.2

*Significant at the 0.05 probability level.
**Significant at the 0.01 probability level.
***Significant at the 0.001 probability level.
[†]Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
[‡]Topdressing was applied every 14 d at 0.3 L m^{-2} from 27 June to 5 Sept. 2006 and 14 May to 24 Sept. 2007.
[§]9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
[¶]NS, not significant.

Table 44. Turf quality and sandiness means for interaction of topdressing incorporation and sand particle shape of an annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ on 3 July 2007.

Incorporation†	Sand particle shape§		
	none	round	sub-angular
	------------------- 1 – 9 scale§ --------------------		
no incorporation	6.0b¶B#	5.3bB	7.0aA
vibratory rolling	6.7abB	7.0aAB	7.7aA
soft brush	7.7aA	6.3abB	6.7aB
stiff brush	6.3abA	7.0aA	6.7aA

†Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
‡Topdressing was applied every 14 d at 0.3 L m^{-2} from 14 May to 24 Sept. 2007.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
¶Means within columns followed by the same lower case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.
#Means within rows followed by the same upper case letter are not significantly different according to Fisher's protected $LSD_{0.05}$.

Table 45. Turf color response to topdressing incorporation method and sand particle shape of annual bluegrass turf mowed at 3.2 mm in North Brunswick, NJ during 2006.

Main Effects	31 July	9 Aug.	25 Aug.
Incorporation†	---------- 1 – 9 scale§ ----------		
no incorporation	3.3	2.1	4.2
vibratory rolling	4.8	3.1	4.7
soft brush	5.4	3.9	6.0
stiff brush	4.0	3.0	4.7
$LSD_{0.05}$		*1.4*	
Sand shape‡			
no sand	3.3	2.2	2.8
round	4.7	3.4	6.4
sub-angular	5.2	3.5	5.5
$LSD_{0.05}$	*1.1*	*1.1*	*1.1*
Source	-------------- *p>F* --------------		
Incorporation (I)	NS¶	*	NS
Sand shape (S)	*	*	***
I x S	NS	NS	NS
C.V. (%)	29.1	39.6	26.2

*Significant at the 0.05 probability level.
***Significant at the 0.001 probability level.
†Incorporation of sand was conducted every 14 d immediately after topdressing was applied.
‡Topdressing was applied every 14 d at 0.3 L m^{-2} from 27 June to 5 Sept. 2006.
§9 represents the best turf characteristic, and 5 represents the minimally acceptable rating.
¶NS, not significant.

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PUBLICATIONS

Refereed Journal Articles

Inguagiato, J.C., Murphy, J.A., and Clarke, B.B. 2008. Anthracnose severity on annual bluegrass influenced by nitrogen fertilization, growth regulators, and verticutting. Crop Sci. 48:1595-1607.

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