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

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ABSTRACT

Frequency and severity of anthracnose epiphytotics, caused by *Colletotrichum cereale* Manns Manns sensu lato 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 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. Nitrogen 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 yr 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. Verticutting had little effect on anthracnose severity.

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Abbreviations: ABG, annual bluegrass; ME, mefluidide; N, nitrogen; PGR, plant growth regulator; PIGE, post-inhibition growth enhancement; TE, trinexapac-ethyl; VC, verticutting; WAT, weeks after treatment.

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 annual bluegrass (ABG) [*Poa annua* L. f. *reptans* (Hauskins) T. Koyama]. Crouch et al. (2006) recently redesignated the pathogen causing anthracnose on turfgrasses as *Colletotrichum cereale* Manns Manns sensu lato Crouch, Clarke, and Hillman [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 6- 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, 2002; Landschoot and Hoyland, 1995; Mann and Newell, 2005; 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

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increase ball roll distance may be partly responsible (Vermeulen, 2003; Zontek, 2004). 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, 1985; Zontek, 2004). 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 range 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 (caused by *Sclerotinia homoeocarpa* F.T. Bennett) and red thread [caused by *Laetisaria fuciformis* (McAlpine) Burdsall] (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., 2004). 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 (Dernoeden, 2002; Danneberger, 2003). Mefluidide {ME; *N*-[2,4-dimethyl-5-[[(trifluoromethyl)sulfonyl]amino] phenyl]acetamide} 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 [TE; 4-(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethylester] 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. (2004) observed that TE applied to ABG putting green turf at the same rate every 14 d reduced the severity of this disease.

Verticutting (VC) is commonly used to reduce irregular shoot growth, puffiness, excessive thatch, and nonuniform 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 and creeping bentgrass green compared to a 3-mm depth or no VC, 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 on 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 3-yr field study was initiated in 2003 on an ABG turf grown on a Nixon sandy loam (fine-loamy, mixed, mesic Typic Hapludult) 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 Aug. 2001, and the remaining half on 8 Aug. 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 Mar. 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 (caused by *Rhizoctonia solani* Kühn) 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., 2002). Annual bluegrass weevils [*Listronotus maculicollis* (Kirby)] were controlled with applications of chlorpyrifos [*O*,*O*-diethyl *O*-(3,5,6-trichloro-2-pyridinyl) phosphorothioate] at 1.1 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 Aug., 22 Sept., and 7 Nov. 2003; 18.3 kg a.i. ha^{-1} and 9.5 kg a.i. ha^{-1} on 15 and 27 Sept. 2004, respectively; and 13.4 kg a.i. ha^{-1} on 18 Aug. and 7 and 18 Sept. 2005.

Treatment Design

The study used a 2 by 2 by 2 by 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. Nitrogen 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 Sept. 2003, 7 May to 9 Oct. 2004, and 21 May to 3 Aug. 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. Mefluidide levels were either none or a split application of ME at 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 levels were either none or TE applied at 0.050 kg a.i. ha^{-1} every 14 d. Trinexapac-ethyl applications on non–ME-treated plots were made from 14 Apr. to 16 Sept. 2003, 7 Apr. to 22 Sept. 2004, and 6 Apr. to 10 Aug. 2005. When TE was applied to turf previously treated with ME, the initial TE application dates were 12 May 2003, 21 Apr. 2004, and 20 Apr. 2005. Verticutting 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 Aug. 2003, 11 May to 25 Aug. 2004, and 28 May to 5 Aug. 2005. Nitrogen 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

Before 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. *Colletotrichum cereale* was grown on full-strength potato dextrose agar (Difco, Sparks, MD) at 25°C for 20 d under fluorescent light (46.3 to 87.3 μmol m^{-2} s^{-1}). 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) per liter of inoculum. The site was lightly irrigated to wet the foliage before 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 h for three consecutive evenings when the minimum air temperature was ≥21°C and relative humidity ≥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 h the day after each inoculation. *Colletotrichum 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: $(n/546) \times 100$; 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, Cary, NC). 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 d 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 3 yr, 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). Nitrogen 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 3-yr study compared to the same rate applied every 28 d (Tables 1–3).

Mefluidide-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-

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.

Main effects	Turf area infested			
	18 June	30 June	25 July	22 Aug.
	%			
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 × ME	NS	NS	NS	NS
N × TE	NS	NS	NS	NS
N × VC	NS	*	NS	NS
ME × TE	NS	NS	NS	NS
ME × VC	NS	*	NS	NS
TE × VC	NS	**	NS	NS
N × ME × TE	NS	NS	NS	NS
N × ME × VC	NS	*	NS	NS
N × TE × VC	NS	*	NS	NS
ME × TE × VC	NS	***	NS	NS
N × ME × TE × VC	NS	**	NS	NS
CV, %	52.9	19.0	13.2	32.4

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†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. (or 12 May if previously treated with ME) to 16 Sept. 2003.

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

#NS, not significant.

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.

Main effects	Turf area infested				
	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 × ME	NS	NS	NS	NS	NS
N × TE	NS	NS	NS	NS	NS
N × VC	NS	NS	NS	NS	NS
ME × TE	*	**	*	**	NS
ME × VC	NS	NS	NS	NS	NS
TE × VC	NS	NS	NS	NS	NS
N × ME × TE	NS	NS	NS	NS	***
N × ME × VC	NS	NS	NS	NS	NS
N × TE × VC	NS	NS	NS	NS	NS
ME × TE × VC	NS	NS	NS	NS	NS
N × ME × TE × VC	NS	NS	NS	NS	NS
CV, %	45.1	34.7	34.6	18.4	13.7

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†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.

#NS, not significant.

treated plots; however ME treatment sustained 3 to 6% less severe disease on 20 June and 17 and 30 Aug. 2004 (Table 2). Turf treated with ME reduced disease severity 3 to 6% on all observation dates in 2005 (Table 3).

Trinexapac-ethyl 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 Aug. 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 1–3).

Interaction Effects

The ME × TE interaction was significant on seven of nine dates during 2004 and 2005 (Tables 2 and 3). Mefluidide slightly increased disease severity 3% on 11 June 2004 in

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.

Main effects	Turf area infested			
	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 × ME	*	NS	NS	NS
N × TE	NS	NS	NS	**
N × VC	NS	NS	NS	NS
ME × TE	NS	*	*	*
ME × VC	NS	NS	NS	NS
TE × VC	NS	NS	NS	NS
N × ME × TE	NS	NS	NS	**
N × ME × VC	NS	NS	NS	NS
N × TE × VC	NS	NS	NS	NS
ME × TE × VC	NS	NS	NS	NS
N × ME × TE × VC	NS	NS	NS	NS
CV, %	57.9	47.5	44.0	12.8

*Significant at the 0.05 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†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.

#NS, not significant.

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 Aug. 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).

Nitrogen 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 Aug. 2004 and 30 July 2005, N fertilization interacted with both ME and TE (Tables 2 and 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 nonregulated 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). Seven-day N fertilization had 2% more seedheads on 13 and 28 June 2005 when seedhead production was very low (2 to 19%) (Table 8).

Trinexapac-ethyl reduced the initial appearance of seedheads only once in 3 yr (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 × TE interaction was observed on four of nine dates over the 3-yr study (Table 8). Mefluidide reduced seedheads

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.

Mefluidide†	Trinexapac-ethyl‡	Turf area infested					
		2004				2005	
		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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide 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.

Nitrogen†	Mefluidide‡	Turf area infested
		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.

Nitrogen†	Mefluidide‡	Trinexapac-ethyl§	Turf area infested	
			2004	2005
			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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide until 21 Apr. in 2004 and 20 Apr. in 2005.

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.

An N × ME interaction was observed during peak seedhead production on 12 May 2003 (Table 8). Nitrogen 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

Nitrogen applied every 7 d improved turf quality compared to 28-d applications of N on each assessment date during the 3-yr study (Table 11). Nitrogen fertilization every 7 d maintained acceptable, albeit sometimes marginal, turf quality (i.e., ≥5, on a 1–9 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 (Table 11). Trinexapac-ethyl enhanced quality of turf on all rating dates in 2003 (Table 11), 17 June and 26 Aug. 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 3-yr study (Table 11). On 2 July 2003, the TE × 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 Aug. 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 × TE interaction on 21 July 2005 indicated that TE improved quality only when applied to turf that received 7-d N fertilization (Table 15).

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 depth¶	Turf area infested 30 June 2003
Interval (d)	kg a.i. ha^{-1}	kg a.i. ha^{-1}	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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide until 12 May 2003.

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

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} mo^{-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 et al., 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 Tanaka, 2001).

Danneberger et al. (1983) found that overstimulating 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 3-yr 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

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.

Main effects	Seedhead expression								
	2003			2004			2005		
	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 × ME	*	NS	NS	NS	NS	NS	NS	NS	NS
N × TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME × TE	NS	***	NS	NS	**	NS	**	**	NS
ME × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
TE × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × ME × TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × ME × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × TE × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME × TE × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × ME × TE × 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 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†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.

#NS, not significant.

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 labrusca* L. cv. Concord which act as sensor molecules inducing pathogenesis-related proteins that reduced growth of *Botrytis cinerea* Pers.:Fr. and *Guignardia bidwellii* (Ellis) Viala and 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, 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.

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.

Mefluidide†	Trinexapac-ethyl‡	Seedhead expression			
		2003	2004	2005	
		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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide until 12 May in 2003, 21 Apr. in 2004, and 20 Apr. in 2005.

Trinexapac-ethyl application can also improve physiological characteristics that could enhance plant vigor including increased chlorophyll content (Ervin and Koski, 2001b), photochemical efficiency and superoxide dismutase activity (Zhang and Schmidt, 2000), and photosynthesis (Qian and Engelke, 1999; McCann and Huang, 2007). A loss of photosynthetic capacity through defoliation of maize increases stalk rot incidence (Mortimore and Ward, 1964; Dodd, 1980). Plant growth regulators such as TE and ME induce morphological changes in turfgrasses including reduced elongation of internodes (Ervin and Koski, 1998, 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 wk 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

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.

Nitrogen†	Mefluidide‡	Seedhead expression
		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.

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 regarding TE used alone on annual bluegrass turf. 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.

Trinexapac-ethyl 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.

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.

Main effects	Turf quality†								
	2003			2004			2005		
	9 June	2 July	28 July	17 June	2 July	26 Aug.	6 June	28 June	21 July
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 × ME	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × TE	NS	NS	NS	NS	NS	NS	NS	NS	*
N × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME × TE	NS	*	NS	NS	**	NS	***	*	*
ME × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
TE × VC	NS	*	NS	NS	NS	**	NS	NS	NS
N × ME × TE	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × ME × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
N × TE × VC	NS	NS	NS	NS	NS	NS	NS	NS	NS
ME × TE × VC	NS	NS	NS	NS	NS	*	NS	NS	NS
N × ME × TE × 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 probability level.

**Significant at the 0.01 probability level.

***Significant at the 0.001 probability level.

†Turf quality was rated on a 1 to 9 scale, with 9 = best.

‡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. 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.

††NS, not significant.

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 2 wk also had little effect

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.

Mefluidide†	Trinexapac-ethyl‡	Turf quality§				
		2003	2004	2005		
		2 July	2 July	6 June	28 June	21 July
kg a.i. ha^{-1}	kg a.i. ha^{-1}					
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.

§Turf quality was rated on a 1 to 9 scale, with 9 = best.

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 2 wk during the growing season had little effect on anthracnose severity.

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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.

Trinexapac-ethyl†	Verticutting depth‡	Turf quality§
		2 July 2003
kg a.i. ha^{-1}	mm	
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.

§Turf quality was rated on a 1 to 9 scale, with 9 = best.

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.

Mefluidide†	Trinexapac-ethyl‡	Verticutting depth§	Turf quality¶
			26 Aug. 2004
kg a.i. ha^{-1}	kg a.i. ha^{-1}	mm	
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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide until 21 Apr. 2004.

§Verticutting was conducted every 14 d from 11 May to 25 Aug. 2004.

¶Turf quality was rated on a 1 to 9 scale, with 9 = best.

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.

Nitrogen†	Trinexapac-ethyl‡	Turf quality§
		21 July 2005
Interval (d)	kg a.i. ha^{-1}	
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 trinexapac-ethyl application was delayed on turf previously treated with mefluidide until 20 Apr. 2005.

§Turf quality was rated on a 1 to 9 scale, with 9 = best.

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