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Entomopathogenic Nematodes Are Not an Alternative to Fenamiphos for Management of Plant-Parasitic Nematodes on Golf Courses in Florida

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Abstract: With the cancellation of fenamiphos in the near future, alternative nematode management tactics for plant-parasitic nematodes (PPN) on golf courses need to be identified. The use of entomopathogenic nematodes (EPN) has been suggested as one possible alternative. This paper presents the results of 10 experiments evaluating the efficacy of EPN at managing PPN on turfgrasses and improving turf performance. These experiments were conducted at various locations throughout Florida over the course of a decade. In different experiments, different EPN species were tested against different species of PPN. Separate experiments evaluated multiple rates and applications of EPN, compared different EPN species, and compared single EPN species against multiple species of PPN. In a few trials, EPN were associated with reductions in certain plant-parasite species, but in other trials were associated with increases. In most trials, EPN had no effect on plant parasites. Because EPN were so inconsistent in their results, we conclude that EPN are not acceptable alternatives to fenamiphos by most turf managers in Florida at this time.

Key words: Belonolaimus longicaudatus, bermudagrass, biological control, *Cynodon dactylon*, entomopathogenic nematode, *Helicotylenchus microlobus*, *Hemicriconemoides annulatus*, *Heterorhabditis* spp., *Hoplolaimus galeatus*, lance nematode, *Mesocriconema ornata*, ring nematode, sheathoid nematode, spiral nematode, *Steinernema* spp., sting nematode, stubby-root nematode, *Trichodorus obtusus*, turf.

Plant-parasitic nematodes (PPN) are considered to be important turfgrass pests by golf course superintendents in Florida. A recent survey of pesticide use in Florida found that 87% of golf course superintendents used nematicides (E. A. Buss, pers. comm.). A field survey of 196 fairways and 193 putting greens on 62 golf courses throughout the state found potentially damaging numbers of PPN on 87% of the golf courses surveyed (Crow, 2005). The PPN that are considered most important on golf courses in Florida are *Belonolaimus longicaudatus* (sting nematode) and *Hoplolaimus* spp. (lance nematodes). Other nematodes that are known to damage turf in Florida are *Trichodorus obtusus* (stubby-root nematode), *Mesocriconema* and *Criconemoides* spp. (ring nematodes), *Meloidogyne* spp. (root-knot nematodes), *Peltamigratus christiei* and *Helicotylenchus* spp. (spiral nematodes), *Dolichodorus* spp. (awl nematodes), *Hemicycliophora* spp. (sheath nematodes), and *Hemicriconemoides annulatus* (sheathoid nematode). Root damage to turf caused by PPN causes decline of turf in affected areas that reduces the aesthetic appeal and function of the turf and can increase water requirements (Trenholm et al., 2005), herbicide use (Busey, 2003), and the potential for nitrate leeching (Luc and Crow, 2004).

The nematicide most commonly used on golf courses during the past 25 yr is fenamiphos. However, enhanced microbial degradation of fenamiphos has been documented in Florida golf courses (Ou et al., 1994), and on many golf courses in the state fenamiphos has little, if any, benefit. Additionally, the manufacturer of fenamiphos (Bayer Corp.) has agreed to a voluntary cancellation of fenamiphos production in 2007 (Anonymous, 2002). This has generated great concern from the golf course industry that new nematode management options be identified. Recently, the fumigant nematicide 1,3-dichloropropene (1,3-D) has received supplemental labeling for use on turfgrasses in Florida and several other states in the southeastern United States. While 1,3-D is very effective against *B. longicaudatus* (Crow et al., 2003, 2005), its use is limited by buffer and topography restrictions, and it is not suited to treating small areas or around irrigation heads, trees, etc. Therefore, a great need still exists for management tactics that fit better into an integrated pest management approach.

Entomopathogenic nematodes (EPN) are used on turfgrass for biological control of insect pests. Some research has indicated that they may be useful for suppression of PPN as well. Suppression of PPN by EPN was first reported by Bird and Bird (1986), who found that *Steinernema glaseri* suppressed *Meloidogyne javanica* on tomato seedlings in agar. In several field trials, EPN have shown promise as a management tactic for PPN on turf. *Heterorhabditis bacteriophora* reduced populations of *Tylenchorhynchus* spp. and *Pratylenchus pratensis* on turfgrasses under irrigated conditions in the field (Smitley et al., 1992). *Steinernema riobrave* reduced populations of *Meloidogyne* sp., *B. longicaudatus*, and *Criconemoides* sp. on turfgrass in coastal South Carolina and Georgia (Grewal et al., 1997). In Ohio, *Heterorhabditis* spp. reduced the number of total PPN in a turfgrass system (Somasekhar et al., 2002).

Since 1994 there have been 10 experiments conducted by University of Florida faculty evaluating the effectiveness of EPN as a nematode management tactic on turf and trying to optimize their efficacy using different EPN species, application rates, application fre-

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quency, and target plant-parasite species. This paper presents the results of these experiments. Our objective was to determine if EPN could be used as a valid alternative to fenamiphos for management of PPN on turf in Florida.

Materials and Methods

Multiple rate experiment: This experiment evaluated the effects of three rates of *S. carpocapsae* and *S. riobrave* on several genera of PPN on turfgrass. The experimental site was fairway-managed 'Tifway 419' bermudagrass grown at the University of Florida Research and Education Center in Fort Lauderdale, FL. This site is naturally infested *with B. longicaudatus, M. ornata, T. obtusus, H. microlobus,* and *H. annulatus.* Treatments were *S. carpocapsae* and *S. riobrave* at 2.5, 7.4, and 14.8 billion nematodes/ha, fenamiphos 10G at 11.2 kg a.i./ha, and nontreated control. The experimental design was randomized block with six replications. Population densities of PPN were assayed 3 wk before treatment, and treatments were assigned to blocks based on population densities of *B. longicaudatus.* Because *B. longicaudatus* was the primary nematode of interest, this ensured that each treatment in a block started with similar population densities and helped reduce experimental error. Each plot was 1 m^2, and there were 15-cm nontreated borders between adjacent plots.

Nematode treatments were applied with water cans in 1 liter water per plot. Fenamiphos was applied topically with a drop-spreader. After treatment applications, all plots were watered with 5 liters water from water cans. Treatments were applied on 11 October 1994.

Treatments were compared based on population densities of PPN and turf-quality ratings. Plant-parasitic nematode samples consisted of five 1.9-cm-diam. × 10-cm-deep cores taken from each plot. The samples were mixed thoroughly, and then nematodes were extracted into water from a 100-cm^3 subsample using a centrifugal-flotation method (Jenkins, 1964) for identification and counting (×25 magnification). Turf-quality ratings were based on a 1-to-9 scale with 9 being optimum turf visual quality.

Nematode samples and turf-quality measurements were collected before treatment and at 4 and 8 wk after treatment. All data were subjected to one-way analysis of covariance (Ott, 1993) with the initial measurement being the covariant, and individual treatment means were compared to the nontreated control using SAS software (SAS Institute, Cary, NC).

Multiple application experiment: This experiment studied the effects of multiple applications of *S. scapterisci* on populations of *H. galeatus* and *T. obtusus.* The experimental site was located at the G. C. Horne Turfgrass Research Unit in Gainesville, FL, on a naturally infested putting green planted to "Floradwarf' bermudagrass. The experimental design was randomized block with four replications. Blocks were stratified based on population densities of *H. galeatus* assayed 2 wk before treatment. Plots were 1.5 m^2 with 0.7-m nontreated borders between plots.

Treatments were *S. scapterisci*, fenamiphos, and nontreated control. *Steinernema scapterisci* was applied at 5 billion nematodes/ha every 4 wk, beginning 23 April 2004 and ending 10 September 2004, and fenamiphos was applied only once. The *S. scapterisci* were mixed in 7.5 liters water and applied to each plot using watering cans. Fenamiphos 10G was applied topically at 11.2 kg/ha and watered in with 7.5 liters water at the same time as the first *S. scapterisci* application.

Each plot was sampled for population densities of PPN 2 wk prior to the first treatment and subsequently 2 wk after each application of *S. scapterisci.* Nematode samples consisted of nine soil cores, 1.9-cm-diam. × 7.5-cm-deep, taken from each plot. The samples were mixed thoroughly, and then nematodes were extracted into water from a 100-cm^3 subsample using a centrifugal-flotation method (Jenkins, 1964) for identification and counting (×25 magnification). On each sampling date, the turf was evaluated visually for turf color and density. Turf color was rated on a 1-to-9 scale, with 1 being no green grass present and 9 being bright green. Turf density was based on percent cover by healthy turf (0–100%). Nematode data were subjected to one-way analysis of covariance with the initial measurement being the covariant, and individual treatment means were compared to the nontreated control. Turf color and density data were subjected to analysis of variance and individual treatments were compared to the nontreated control using the contrast procedure.

Multiple species experiment: This experiment compared the effects of several species of EPN on several species of PPN. Two trials were conducted, one in spring 2003 and a second in spring 2004. Both trials were conducted on a "Tifway 419' bermudagrass fairway site at the University of Florida Fort Lauderdale Research and Education Center in Fort Lauderdale, FL. The site was naturally infested with *B. longicaudatus, H. galeatus, T. obtusus, M. ornata, H. microlobus,* and *Hemicriconemoides annulatus.* Plots were 1 m^2 with 20-cm nontreated borders between adjacent plots. In both trials, population densities of PPN were assayed 3 wk before treatment and treatments were assigned to blocks based on population densities of *B. longicaudatus.*

In the first trial, there were five nematode species treatments (*H. bacteriophora, H. indica, H. zealandica, S. scapterisci,* and *S. carpocapsae*), fenamiphos, and nontreated control. All of the nematode treatments were applied at the rate of 2.5 billion nematodes/ha. The nematodes were applied in 1 liter water per plot. Fenamiphos was an EC formulation applied at 11.2 kg a.i./ha in 1 liter water. All treatments were applied on 17 February 2003 and were followed by 1.2 cm of irrigation.

In the second trial there were three nematode species treatments (*H. bacteriophora*, *H. indica*, and *S. carpocapsae*), fenamiphos, and nontreated control. All the nematode treatments were applied at the rate of 2.5 billion nematodes/ha. The nematodes were applied in 1 liter of water per plot. Fenamiphos was an EC formulation applied at 11.2 kg a.i./ha in 1 liter of water. All treatments were applied on 11 March 2004 and were followed by 1.2 cm of irrigation.

In both trials, PPN samples were collected from each plot 3 wk before treatment and 3 and 12 wk after treatment. Nematode samples consisted of five soil cores, 1.9-cm-diam. × 10-cm-deep, taken from each plot. Turf was evaluated for quality ratings (1 to 9) at treatment and 3 and 12 wk after treatment. All data were subjected to one-way analysis of covariance with the initial measurement being the covariant, and individual treatment means were compared to the untreated control.

Steinernema scapterisci experiments: Six field trials were conducted to determine the effects of single applications of *S. scapterici* on populations of either *B. longicaudatus* (sting nematode) or *H. galeatus* (lance nematode). Sting nematode trial 1 was conducted on a 'Tifway 419' bermudagrass golf course fairway at Meadow Oaks Golf and Country Club in Hudson, FL, in 2003. Sting nematode trial 2 was conducted on a 'Tifway 419' bermudagrass polo field at The Saddlebrook Club in The Villages, FL, in 2003. Sting nematode trial 3 was conducted on a 'Tifdwarf' bermudagrass putting green at the Jupiter Island Club in Hobe Sound, FL, in 2004. All three sites had potentially damaging populations of *B. longicaudatus.* Lance nematode trial 1 was conducted on a 'Tifdwarf' bermudagrass putting green at Meadow Oaks Golf and Country Club in Hudson, FL, in 2004. Lance nematode trial 2 was conducted on a 'Champion' bermudagrass putting green at the Royal Poinciana Club in Naples, FL, in 2004. Lance nematode trial 3 was conducted on a "Tifdwarf' bermudagrass putting green at the South Fork High School in Stuart, FL, in 2004. All three sites had potentially damaging populations of *H. galeatus.*

All six trials used a completely randomized design, but the number of replications varied among trials. Three replications were used in sting nematode trials 1 and 3 and lance nematode trials 1 and 2. Four replications were used in sting nematode trial 1 and lance nematode trial 3. Plots were 9.5 m^2 for sting nematode trial 1 and 3.4 m^2 for all other trials. Adjacent plots in all trials were separated by 0.7-m nontreated borders. All trials had the following treatments: *S. scapterisci* at 2.5 billion nematodes/ha, nontreated control, and a standard nematicide treatment. Sting nematode trial 3 had two different standard nematicide treatments. The industry standards used were 1,3-D for sting nematode trials 1 and 2, both 1,3-D and fenamiphos 10G for sting trial 2, and fenamiphos 10G for all other trials. The 1,3-D was applied by slit-injection (Crow et al., 2003, 2005) at 55 kg a.i./ha, fenamiphos 10G was applied topically at 11.2 kg a.i./ha, and *S. scapterisci* was mixed in 7.57 liters water and applied with a sprinkling can. Following application, each plot was irrigated with 1.3 cm of water.

Treatments were compared according to population

TABLE 1. Effects of three rates of *Steinernena carpocapsae*, *S. riobrave*, and fenamiphos on population densities of *Belonolaimus longicaudatus*, *Mesocriconema ornata*, *Trichodorus obtusus*, and *Hemicriconemoides annulatus*, and turf quality of 'Tifway 419' bermudagrass. Data were collected before treatment and 4 and 8 wk after treatment and are means of six replications. Individual treatment means are compared to the nontreated using analysis of covariance.

Treatment	Before treatment	4 WAT[a]	8 WAT
		B. longicaudatus/100 cm^3 soil	
Nontreated	119	258	184
Fenamiphos[b]	126	282	165
S. carpocapsae 1X[c]	127	220	136
S. carpocapsae 3X	133	279	207
S. carpocapsae 6X	114	180	134
S. riobrave 1X	124	210	142
S. riobrave 3X	133	267	152
S. riobrave 6X	131	250	193
		M. ornata/100 cm^3 soil	
Nontreated	212	277	242
Fenamiphos	127	233	190
S. carpocapsae 1X	154	255	198
S. carpocapsae 3X	138	208	229
S. carpocapsae 6X	126	202	176
S. riobrave 1X	119	169	155
S. riobrave 3X	89	174	159
S. riobrave 6X	103	166	208
		T. obtusus/100 cm^3 soil	
Nontreated	107	214	253
Fenamiphos	86	143	175
S. carpocapsae 1X	87	221	218
S. carpocapsae 3X	35	36	88
S. carpocapsae 6X	67	130	154
S. riobrave 1X	66	98	178
S. riobrave 3X	133	225	227
S. riobrave 6X	51	74	98
		H. annulatus/100 cm^3 soil	
Nontreated	88	147	136
Fenamiphos	83	134	149
S. carpocapsae 1X	41	111	104
S. carpocapsae 3X	87	117	115
S. carpocapsae 6X	105	115	161
S. riobrave 1X	86	150	122
S. riobrave 3X	35	74	71
S. riobrave 6X	65	88	118
		Turf quality[d]	
Nontreated	6.6[d]	5.5	5.5
Fenamiphos	7.1	6.7*	6.0
S. carpocapsae 1X	7.1	6.2	6.1
S. carpocapsae 3X	6.5	5.4	5.3
S. carpocapsae 6X	6.8	5.8	5.9
S. riobrave 1X	7.0	6.0	5.6
S. riobrave 3X	6.6	5.8	5.6
S. riobrave 6X	6.8	5.8	6.0

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.

[a] Weeks after treatment.

[b] Fenamiphos 10G was applied at the rate of 112 kg/ha.

[c] *Steinernema carpocapsae* and *S. riobrave* were each applied at rates of 2.5 (1X), 7.4 (3X), and 14.8 (6X) billion nematodes/ha.

[d] Turf quality is rated on a 1-to-9 scale, with 9 being optimum turf quality.

Table 2. Effects of *Steinernema scapterisci* and fenamiphos on population densities of *Hoplolaimus galeatus* and turf density of bermudagrass putting greens in three trials. Trials 1 and 3 were conducted on 'Tifdwarf' bermudagrass sites, and trial 2 was conducted on a 'Champion' bermudagrass site. Data are means of three replications in trials 1 and 2 and four replications in trial 3. Treatment means for *H. galeatus* are compared to the nontreated using analysis of covariance; treatment means for turf density are compared to the nontreated using the contrast procedure.

Treatment	*H. galeatus* before treatment	*H. galeatus* 2 WAT[a]	Density 2 WAT	Density 6 WAT
		Trial 1		
Nontreated	246[b]	190	59[c]	57
Fenamiphos[d]	179	100	81	47
S. scapterisci[e]	124	103	81	47
		Trial 2		
Nontreated	174	110	80	99
Fenamiphos	179	109	75	100
S. scapterisci	254	136	85	99
		Trial 3		
Nontreated	162	232	85	81
Fenamiphos	136	216	83	84
S. scapterisci	111	209	90	84

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.
[a] Weeks after treatment.
[b] Number of nematodes/100 cm^3 soil.
[c] Turf density is the percent cover by live turf (0–100%).
[d] Fenamiphos applied at the rate of 11.2 kg a.i./ha.
[e] *Steinernema scapterisci* applied at the rate of 2.5 billion nematodes/ha.

densities of either *B. longicaudatus* or *H. galeatus* and turf density. Nematode samples were collected 2 wk before application and at 2 and 6 wk after application in sting nematode trials 1 and 2. Nematode samples were collected immediately before treatment and at 2 wk after treatment for sting nematode trial 3 and all lance nematode trials. Each nematode sample consisted of nine soil cores, 1.9-cm-diam. × 7.5-cm-deep, taken from each plot. Turf density was measured 2 and 6 wk after treatment in all trials except sting nematode trial 2, where turf density was measured at 6 wk after treatment only. Nematode data were subjected to one-way analysis of covariance with the initial measurement being the covariant, and individual treatment means were compared to the untreated control. Turf density data were subjected to analysis of variance, and individual treatments were compared to the nontreated using the contrast procedure.

Results

Application of EPN had no effect ($P \leq 0.1$) on population densities of PPN in the multiple rate experiment and in the *S. scapterisci* experiments on lance nematode (Tables 1, 2). In the multiple application experiment and the multiple species experiments, EPN occasionally affected PPN ($P \leq 0.1$) but, depending on PPN species, these effects varied (Tables 3, 4, 5). *Steinernema scapterisci* reduced populations of *B. longicaudatus* ($P \leq 0.05$) in one out of the three *S. scapterisci* experiments on sting nematode (Table 6). Fenamiphos reduced ($P \leq 0.1$) population densities of PPN in some instances (Tables 4, 5, 6), but had no effect in others (Tables 1, 2, 6). In the two trials where it was used as the standard nematicide, 1,3-D reduced ($P \leq 0.01$) population densities of *B. longicaudatus* (Table 5).

Application of EPN improved ($P \leq 0.1$) turf visual parameters in two instances (Tables 3, 6). Fenamiphos improved ($P \leq 0.1$) turf visual parameters in most in-

Table 3. Effects of multiple applications of *Steinernema scapterisci* and a single application of fenamiphos on population densities of *Hoplolaimus galeatus*, and *Trichodorus obtusus*, and color and density of 'Floradwarf' bermudagrass. Data were collected 2 wk folling each *S. scapterisci* application and are means of four replications. Treatment means for *H. galeatus* and *T. obtusus* are compared to the nontreated using analysis of covariance. Treatment means for turf color and density are compared to the nontreated using the contrast procedure.

Treatment	Initial	App. 1	App. 2	App. 3	App. 4	App. 5	App. 6
				H. galeatus			
Nontreated	348[a]	294	305	288	381	327	153
Fenamiphos[b]	328	279	293	349	328	293	169
S. scapterisci[c]	316	371	359	496**	361	213	173
				T. obtusus			
Nontreated	122	69	95	257	190	330	247
Fenamiphos	107	43	71	175	225	272	234
S. scapterisci	145	87	72	229	213	377	324
				Color[d]			
Nontreated	—	6.0	5.9	6.8	5.0	6.4	—
Fenamiphos	—	6.3	7.1***	7.3	5.1	6.5	—
S. scapterisci	—	6.5	6.5*	6.9	4.6	6.5	—
				Density[e]			
Nontreated	—	60	69	68	43	65	—
Fenamiphos	—	70	74	71	46	65	—
S. scapterisci	—	63	69	70	43	64	—

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.
[a] Number of nematodes/100 cm^3 soil.
[b] Fenemiphos 10G was applied at the same time as the first *S. scapterisci* application at the rate of 11.2 kg a.i./ha.
[c] *Steinernema scapterisci* was applied every 4 wk at the rate of 5 billion nematodes/ha.
[d] Turf color is rated on a 1-to-9 scale, with 9 being optimum turf color.
[e] Turf density is the percent cover by live turf (0 to 100%).

TABLE 4. Effects of *Heterorhabditis bacteriophora*, *H. indica*, *H. zealandica*, *Steinernema scapterisci*, *S. carpocapsae*, and fenamiphos on population densities of *Belonolaimus longicaudatus*, *Hoplolaimus galeatus*, *Trichodorus obtusus*, *Mesocriconema ornata*, *Helicotylenchus microlobus*, and *Hemicriconemoides annulatus*, and turf quality of 'Tifway 419' bermudagrass in 2003. All data are means of eight replications. Individual treatment means are compared to the nontreated using analysis of covariance.

Treatment	Initial	3 WAT[a]	6 WAT	12 WAT
		B. longicaudatus/100 cm^3 soil		
Nontreated	103	97	98	173
Fenamiphos[b]	102	54*	21*	27***
H. bacteriophora[c]	95	69	120	85**
H. indica	98	74	100	110*
H. zealandica	102	100	145	165
S. scapterisci	96	71	101	109*
S. carpocapsae	98	84	90	119
		H. galeatus/100 cm^3 soil		
Nontreated	215	230	115	309
Fenamiphos	162	172	119	104**
H. bacteriophora	145	175	95	139
H. indica	129	134	73	172
H. zealandica	173	161	118	235
S. scapterisci	191	182	142	295
S. carpocapsae	188	205	163	218
		T. obtusus/100 cm^3 soil		
Nontreated	276	100	133	60
Fenamiphos	246	89	125	99**
H. bacteriophora	329	113	82*	35*
H. indica	316	118	89	40
H. zealandica	337	129	84	59
S. scapterisci	379	166	148	76
S. carpocapsae	283	182	142	56
		M. ornata/100 cm^3 soil		
Nontreated	219	208	158	283
Fenamiphos	165	141	174	295
H. bacteriophora	325	240	262	256
H. indica	265	172	179	191*
H. zealandica	253	217	175	266
S. scapterisci	179	149	183	268
S. carpocapsae	204	212	258	232
		H. microlobus/100 cm^3 soil		
Nontreated	380	254	239	600
Fenamiphos	312	163	105	82
H. bacteriophora	509	431	343	548
H. indica	630	424	553*	1,074
H. zealandica	588	383	378	821
S. scapterisci	371	222	335	1,165*
S. carpocapsae	381	301	323	563
		H. annulatus/100 cm^3 soil		
Nontreated	141	133	122	241
Fenamiphos	54	78	44	81
H. bacteriophora	201	165	140	224
H. indica	35	119	152*	160
H. zealandica	93	78	126	167
S. scapterisci	83	136	134	305
S. carpocapsae	143	125	179	101*
		Turf quality[d]		
Nontreated	6.0[b]	6.4	5.6	6.1
Fenamiphos	5.4	6.7**	6.2***	6.5
H. bacteriophora	6.7	7.0	6.7	6.4
H. indica	6.6	7.0	6.6	6.4
H. zealandica	6.3	6.7	6.0	6.1
S. scapterisci	5.8	6.1	5.7	6.0
S. carpocapsae	6.0	6.3	6.0	6.1

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.
[a] Weeks after treatment.
[b] Fenamiphos was applied at the rate of 11.2 kg a.i./ha.
[c] Nematode treatments were applied at the rate of 2.5 billion nematodes/ha.
[d] Turf quality is rated on a 1-to-9 scale, with 9 being optimum turf quality.

TABLE 5. Effects of *Heterorhabditis bacteriophora*, *H. indica*, *Steinernema carpocapsae*, and fenamiphos on population densities of *Belonolaimus longicaudatus*, *Hoplolaimus galeatus*, *Trichodorus obtusus*, *Mesocriconema ornata*, *Helicotylenchus microlobus*, and *Hemicriconemoides annulatus*, and turf quality of 'Tifway 419' bermudagrass in 2004. All data are means of eight replications. Individual treatment means are compared to the nontreated using analysis of covariance.

Treatment	Initial	3 WAT[a]	6 WAT	12 WAT
		B. longicaudatus		
Nontreated	14	13	7	8
Fenamiphos[b]	18	8	3	10
H. bacteriophora[c]	15	23	24**	22*
H. indica	18	20	15	12
S. carpocapsae	15	6	14	20
		H. galeatus		
Nontreated	62	29	32	30
Fenamiphos	29	36	23**	22***
H. bacteriophor	17	13	13	8***
H. indica	28	30	19	12***
S. carpocapsae	29	13*	22	14***
		T. obtusus		
Nontreated	89	137	153	116
Fenamiphos	114	73**	117	126
H. bacteriophora	94	156	195*	145
H. indica	109	189	219*	121
S. carpocapsae	131	156	238**	103
		M. ornata		
Nontreated	64	26	53	23
Fenamiphos	81	38	43	57*
H. bacteriophora	71	51*	69	46
H. indica	54	20	42	28
S. carpocapsae	38	20	24	8
		H. microlobus		
Nontreated	207	197	161	200
Fenamiphos	415	191***	47***	56***
H. bacteriophora	394	234*	215	193
H. indica	229	177	167	154
S. carpocapsae	231	190	179	127
		H. annulatus		
Nontreated	26	26	18	26
Fenamiphos	61	44	19*	35
H. bacteriophora	44	17	31	33
H. indica	25	14	14	18
S. carpocapsae	26	17	36	11
		Turf quality[d]		
Nontreated	4.7[b]	6.3	5.8	7.1
Fenamiphos	4.7	7.0	6.5*	7.2
H. bacteriophora	5.0	7.0	6.1	7.1
H. indica	4.8	6.6	5.7	7.0
S. carpocapsae	5.3	6.3	6.6	6.8

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.
[a] Weeks after treatment.
[b] Fenamiphos was applied at the rate of 11.2 kg a.i./ha.
[c] Nematode treatments were applied at the rate of 2.5 billion nematodes/ha.
[d] Turf quality is rated on a 1-to-9 scale, with 9 being optimum turf quality.

stances (Tables 1–4,6). In the two trials where it was used as the standard nematicide, 1,3-D had no effect ($P \leq 0.01$) on turf visual parameters (Table 6).

DISCUSSION

In Florida, the most common use of EPN on turf is for management of the tawny and southern molecrickets *Scapteriscus vicinus* and *S. borellii*, respectively. *Steinernema scapterisci* is the EPN species normally used

TABLE 6. Effects of *Steinernema scapteriski* and standard nematicide (fenamiphos and/or 1,3-dichloropropene) treatments on population densities of *Belonolaimus longicaudatus* and turf density of hybrid bermudagrass in three trials. Trial 1 was conducted on a 'Tifway 419' bermudagrass fairway, trial 2 on a 'Tifway 419' bermudagrass polo field, and trial 3 on a 'Tifdwarf' putting green. Data are means of three replications in trials 1 and 3 and four replications in trial 2. Treatment means for *B. longicaudatus* are compared to the nontreated using analysis of covariance; treatment means for turf density are compared to the nontreated using the contrast procedure.

Treatment	*B. longicaudatus* before treatment	*B. longicaudatus* 2 WAT[a]	*B. longicaudatus* 6 WAT	Turf density 2 WAT	Turf density 6 WAT
			Trial 1		
Nontreated	114[b]	108	94	54[c]	52
1,3-D[d]	110	15***	50	63	59
S. scapterisci[e]	110	117	118	60	55
			Trial 2		
Nontreated	212	324	111	—	83
Fenamiphos[f]	184	122***	84	—	73
S. scapterisci	119	210**	61**	—	80
			Trial 3		
Nontreated	42	198	—	68	63
Fenamiphos	32	125	—	75	77*
1,3-D	24	36***	—	73	68
S. scapterisci	48	209	—	80**	68

*, **, *** Treatment mean is different from nontreated at $P < 0.10$, $P < 0.05$, and $P < 0.01$, respectively.
[a] Weeks after treatment.
[b] Number of nematodes/100 cm^3 soil.
[c] Turf density is the percent cover by live turf (0–100%).
[d] 1,3-dichloropropene applied at 55 kg a.i./ha.
[e] *Steinernema scapterisci* applied at the rate of 2.5 billion nematodes/ha.
[f] Fenamiphos applied at the rate of 11.2 kg a.i./ha.

for management of mole-crickets in Florida, and it is typically applied at the rate of at 2.5 billion nematodes/ha. In these studies, there was no indication that any species of EPN was more or less effective at reducing population densities of PPN or improving turf performance than any other species. There also was no indication that increasing rates or application frequency improved efficacy against plant parasites or turf performance. Therefore, from the results of these experiments, using *S. scapterisci* according to the normal use pattern for mole-cricket management is just as likely to affect PPN on turf as any other EPN species, use rate, or application frequency.

The results of EPN in these experiments were variable. In most cases, applications of EPN had no effect on PPN. In a few cases, numbers of a particular species of plant-parasitic nematode were reduced following EPN application, but increases in numbers of plant parasites were just as common. For example, in the first multiple-species experiment *H. bacteriophora* reduced population densities of *B. longicaudatus* 12 wk after treatment but increased *B. longicaudatus* in the second multiple-species experiment. In only two instances was there a turf visual response associated with EPN application. Turf color was improved following the second application in the multiple-application experiment. However, as there were no differences following subsequent applications, this appears to be due to natural variability among plots rather than treatment affects. In sting nematode trial 3, there was an increase in turf density following application of *S. scapterisci*, but no reduction in *B. longicaudatus* was associated with the treatment.

Often the effects of fenamiphos are nematostatic, paralyzing nematodes rather than killing them (Opperman and Chang, 1991). Therefore, it is common to have a positive turf response following fenamiphos application, even when no nematode reductions are observed. This occurred in the multiple-rate and multiple-application experiments. Visual benefits from fenamiphos were observed in all four of the experiments conducted on research centers but in only one of six trials conducted on commercial turf sites. Turf maintained on commercial sites tends to be much more intensively managed than on research centers, receiving more frequent irrigation and fertilization, helping to mask nematode damage and thereby reducing visual responses. Also, fenamiphos is used frequently on the commercial sites for nematode management; therefore, these sites may experience enhanced microbial degradation of fenamiphos, reducing its efficacy. The nematicide 1,3-dichloropropene was very effective at reducing population densities of *B. longicaudatus* in the two trials where it was used (sting nematode trials 1 and 3). These results are similar to those reported previously (Crow et al., 2003, 2005).

Analysis of covariance was used to analyze all the nematode data and much of the turf visual data. This analysis was used because it takes into account variability in the initial measurements. The treatments are compared based on how the measurements in individual plots after treatment change relative to their measurements before treatments were imposed. While this is an excellent method for analyzing highly variable data, the results may seem strange if an individual is only considering the treatment means at a given date.

For example, in Table 3 the turf quality measurements at 3 wk after treatment were 6.4, 6.7, and 7.0 for non-treated control, fenamiphos, and *H. bacteriophora*, respectively. The fenamiphos treatment was different from the control, but the *H. bacteriophora* treatment was not. This occurs because the initial values before treatment were 5.4 for the fenamiphos treatment and 6.7 for the *H. bacteriophora* treatment. Therefore, at 3 wk after treatment, the fenamiphos treatment had improved by 1.3 points but *H. bacteriophora* treatment had improved only by 0.3 points.

Our results show that, while EPN may occasionally reduce population densities of PPN on turf in Florida, they are not consistent enough to be relied on as a nematode management tactic. Therefore, EPN are not an acceptable alternative to fenamiphos on turf in Florida at this time. Perhaps future research will find ways to improve their performance and make them more practical and consistent.

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