Supplement to Journal of Nematology 28(4S):687–694. 1996.

Avermectin B_1, Isazofos, and Fenamiphos for Control of *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* Infesting *Poa annua*[1]

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Abstract: Avermectin B_1, isazofos, and fenamiphos were evaluated in greenhouse experiments for efficacy against two common turfgrass parasites, *Hoplolaimus galeatus* and *Tylenchorhynchus dubius*. Treatments in all experiments were arranged in a completely randomized design and replicated four times. In the first experiment, avermectin B_1 at rates of 0.2 and 0.4 kg a.i./ha and isazofos at rates of 2.3 and 23 kg a.i./ha significantly reduced populations of both species of parasitic nematodes compared to controls at 14 and 28 days after treatment ($P \leq 0.01$). In the second experiment, the greatest reductions in both nematode populations occurred at 28 and 56 days after treatment, where 23 kg a.i./ha of isazofos was applied ($P \leq 0.01$). These reductions, however, were not different from reductions of *H. galeatus* at 28 and 56 days after treatment ($P \leq 0.01$) or *T. dubius* at 56 days after treatment ($P \leq 0.01$), where 0.2- and 0.4-kg a.i./ha rates of avermectin B_1 were mixed throughout the soil. In the third experiment, the greatest population reduction of *H. galeatus* was observed with a 0.4-kg a.i./ha treatment of avermectin B_1 at 56 days after treatment ($P \leq 0.05$). *T. dubius* populations were reduced by the 0.4-kg a.i./ha rate of avermectin B_1 at 28 ($P \leq 0.01$), 56 ($P \leq 0.05$), and 70 ($P \leq 0.01$) days after treatment. In the fourth and fifth experiments, avermectin B_1 at rates of 7.5 and 15.2 kg a.i./ha consistently reduced nematode populations compared to controls and performed as well or better than fenamiphos ($P \leq 0.01$).

Key words: avermectin, chemical control, fenamiphos, *Hoplolaimus galeatus*, isazofos, nematode, *Poa annua*, turfgrass, *Tylenchorhynchus dubius*.

Avermectins, derived from the mycelia of *Streptomyces avermitilis*, are macrocyclic lactones that have nematicidal activity (3). Fermentation of *S. avermitilis* produces four closely related compounds: avermectin A_1, A_2, B_1, and B_2. In terms of nematicidal efficacy, the B series has been found to be more biologically active than the A series (12). In nematodes, avermectins function as γ-aminobutyric acid (GABA) antagonists or stimulators of GABA release from presynaptic inhibitory terminals (25). At concentrations of 5 μg/ml, avermectin B_1 prevented the response of the dorsal excitatory motorneuron from being stimulated indirectly by the ventral nerve cord in *Ascaris suum* (L.), a nematode parasite of swine (4).

Where avermectin B_1 was incorporated into the soil at rates of 0.3, 1.1, and 3.3 kg/ha, it was 10 to 30 times more potent than several organophosphate and carbamate nematicides against *Meloidogyne incognita* (20). Residual activity of avermectin also can be increased from 30 to 60 days by the rapid addition of ketones by microbes (20). Increasing the organic matter fraction of the soil, however, decreased the nematicidal activity (19). Granulated formulations incorporated into the soil inhibit root galls and reproduction of *Meloidogyne incognita* on tobacco at application rates of 0.17 to 1.52 kg a.i./ha (22). At these rates, avermectin B_1 was as effective as ethoprop, fenamiphos, aldicarb, oxamyl, and carbofuran at 6.7 kg a.i./ha (22). Other field studies using drip irrigation on tomato confirmed that 0.093–0.34 kg a.i./ha as a single drench and 0.08 kg a.i./ha of avermectin B_1 applied three times were equally effective as oxamyl and aldicarb at 3.36 kg a.i./ha against *M. incognita* (8). Additionally, citrus treated with 1.1 kg a.i./ha/month of avermectin B_1 for 4 months had significant reductions in the numbers and damage from *Tylenchulus semipenetrans* (8).

Avermectin B_1 may be a good candidate for biochemical control of plant-parasitic

Received for publication 15 April 1996.

[1] Contribution no. 3346 from the Rhode Island Agricultural Experiment Station, Kingston.

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The authors thank G. Perry for supply of nematode-infested soil and C. Dawson, W. Lemus, C. Stroble, and J. McCutcheon for technical assistance.

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nematodes infesting turfgrasses since it has been shown to be highly potent against other nematodes at low doses and has little adverse impact on the environment (11). Soil binding studies with ^{3}H-labeled avermectin confirm that it is tightly bound to soils, which would minimize its potential to contaminate groundwater (5). Avermectins have no antifungal or antibacterial effects at concentrations as high as 2,000 ppm, and they appear to have no effect on soil respiration and nitrification (11). The results of testing these compounds on nontarget terrestrial organisms showed no effects on nitrogen-fixing bacteria or earthworms (12).

Isazofos is a broad-spectrum organophosphate insecticide-nematicide that controls numerous pests of turf (15). Currently, isazofos is being used for sting (*Belonolaimus* spp.) and lance (*Hoplolaimus* spp.) nematode suppression in turfgrasses under section 2ee of the Federal Insecticide Fungicide and Rodenticide Act. When applied as either 5% or 10% granules, isazofos sold commercially as Miral gave good control of the nematode *Radopholus similis* on banana and in turfgrass (10). Unfortunately, a study using a 2-kg/ha rate of Miral demonstrated phytotoxic effects to *Lolium penenne* cv. Ellett seedlings (2). The relatively short soil persistence of isazofos (half-life 0.5 to 5.0 weeks) minimizes the potential for leaching, but it is highly toxic to fish (rainbow trout = LC_{50} 6.36 ppb; bluegill sunfish = LC_{50} 3.83 ppb) and to aquatic invertebrates (*Daphnia magna* LC_{50} = 1.40 ppb) if it enters aquatic environments (1). Somasundaram et al. (23) showed that, in soils not previously exposed to isazofos, more than 90% of the material applied was degraded with 3 weeks. Soil pH values of 6.9 or greater may also increase the degradation of isazofos by bacteria, possibly rendering the chemical ineffective and (or) uneconomical for soil pest control (23).

Fenamiphos is a systemic organophosphate compound that controls the major genera of nematodes attacking turf (21). The estimated soil half-life is 30 days where fenamiphos has not been previously applied (27). Fenamiphos has demonstrated effective control of plant-parasitic nematodes and also helped to increase by four times the dry root weight of 'Ormond' bermudagrass infested with *Belonolaimus longicaudatus* (9). Despite the effectiveness of fenamiphos, microbial degradation can evolve as a result of continuous exposure to the point of rendering the material ineffective (24). After 20 years of continuous annual applications of fenamiphos to a golf course green, the soil half-life was reduced to a range of 0.9 to 1.6 days, which resulted in a loss of control (18). It also was determined that a mixed bacterial consortium mineralized fenamiphos, suggesting that soluble organic components in soil induce bacteria to produce enzymes that mineralize fenamiphos (17). Fenamiphos also was used as a standard treatment for 20 years in Bowen, Queensland, Australia, to control *Meloidogyne* spp. on tomato, during which time growers reported a gradual decrease in the residual life and efficacy of fenamiphos (24).

Hoplolaimus galeatus Cobb and *Tylenchorhynchus dubius* (Bütschli) Filipjev are two species of parasitic nematodes infecting turfgrasses. *H. galeatus* causes root swelling and stunting of top growth on bermudagrass, annual bluegrass, and zoysiagrass (26). *T. dubius* causes wilting and stunting of the top growth and roots of bermudagrass, annual bluegrass, Kentucky bluegrass, and zoysiagrass (26). The purpose of this investigation was to compare the efficacy of avermectin B_1 to the chemical nematicides isazofos and fenamiphos for control of *H. galeatus* and *T. dubius*.

Materials and Methods

Soil (78.5% sand, 19% silt, 2.5% clay; 4.1% OM) primarily infested with *Hoplolaimus galeatus* was collected from a golf course fairway. Soil (80.5% sand, 15% silt, 4.5% clay; 4.0% OM) primarily infested with *Tylenchorhynchus dubius* was collected from a second fairway. Soil from the two fairways was kept separate for all experi-

ments. Soil was seived and thoroughly mixed to ensure a uniform distribution of each nematode species. Two sets of either 140-cm^3 specimen cups (Superior Corp., Cumberland, RI) or 7.5-cm-diam. plastic pots (Dillen Products, Middlefield, OH) were used in each experiment to test chemicals against *H. galeatus* and *T. dubius* simultaneously in a greenhouse. All treatments were arranged in a completely randomized design and replicated four times.

Experiment 1: The bottoms of all specimen cups were removed and replaced with YardTek weed fabric (American Agrifabrics, Alpharetta, GA) to allow drainage. Cups were filled with 140 cm^3 of soil. Avermectin B_1 (Merck & Co. Rahway, NJ) was applied to soil in each set of specimen cups at rates of 0.2 and 0.4 kg a.i./ha. Isazofos (Ciba-Geigy, Greensboro, NC) was applied at rates of 2.3 and 23.0 kg a.i./ha. The chemicals were added into the soil in 50 ml of water. An additional square of weed fabric was applied to the top of the cup to prevent desiccation. Controls were treated with 50 ml of water. Nematodes were counted at 14 and 28 days after treatment by means of centrifugal flotation (28) of the entire sample.

Experiment 2: Avermectin B_1 at rates of 0.2 and 0.4 kg a.i./ha were compared to isazofos at rates of 2.3 and 23.0 kg a.i./ha. Each avermectin B_1 treatment was either mixed thoroughly with a stirring rod following application or applied and left undisturbed. Isazofos was applied and left undisturbed, as were controls. Specimen cups were seeded with *Poa annua* at a rate of 146.5 kg/ha and irrigated with 50 ml of water two to three times per week. Controls were treated with 50 ml of water and seeded in an identical manner. Nematodes were extracted in the manner previously described and counted at 14, 28, and 56 days.

Experiment 3: Avermectin B_1 was tested at concentrations of 0.2 and 0.4 kg a.i./ha. Treatments were applied in 50-ml aliquots and thoroughly mixed in 140 cm^3 of soil. *Poa annua* seed was applied to the treated specimen cups as in the previous experiment. Controls were treated with 50 ml of water and seeded in an identical manner. Cups were irrigated with 50 ml of water two to three times per week. Treatments were evaluated at 28, 56, and 70 days, as previously described.

Experiment 4: Avermectin B_1 was assayed at rates of 0.02, 0.2, 0.4, 0.8, 1.6, 7.5, and 15.2 kg a.i./ha. Fenamiphos (Bayer, Kansas City, MO) was applied at a rate of 112.1 kg a.i./ha. Treatments were applied to 100 cm^3 of soil in plastic pots with drainage holes rather than specimen cups. Pots were treated using the protocol of the third experiment. Evaluation was made at 28 days in the manner previously described.

Experiment 5: Treatments of the fourth experiment were applied to 140 cm^3 of soil. Experimental protocol was identical to the previous experiment, and evaluation of nematode survival was made at 28 days.

Data were analyzed by ANOVA followed by mean separation by LSD (SAS Institute, Cary, NC).

Results

Experiment 1: All treatments demonstrated lower *H. galeatus* populations compared to controls at 14 and 28 days after treatment ($P \leq 0.01$) (Table 1). At 14 days after treatment, the lowest population occurred with the 23.0-kg a.i./ha rate of isazofos. At 28 days after treatment, the greatest nematode reductions were observed in isazofos-treated cups. The reduction caused by the 2.3-kg a.i./ha rate of isazofos, however, was not significantly different from that caused by the 0.4-kg a.i./ha rate of avermectin B_1.

A decrease in *T. dubius* populations also was seen in all treatments compared to controls at 14 and 28 days after treatment ($P \leq 0.01$). At 28 days, the 0.4-kg a.i./ha rate of avermectin B_1 and the 2.3- and 23.0-kg a.i./ha rates of isazofos were not significantly different in comparison to each other.

Experiment 2: Hoplolaimus galeatus populations were reduced compared to controls at 14 days by the 2.3- and 23.0-kg

TABLE 1. Evaluation of avermectin B_1 and isazofos against *Hoplolaimus galeatus* and *Tylenchorhynchus dubius*.

		Mean ± SEM live nematodes/140 cm^3 soil			
		H. galeatus		*T. dubius*	
Treatment	Kg a.i./ha	14 Dat[a]	28 Dat[b]	14 Dat[c]	28 Dat[d]
Avermectin B_1	0.2	993 ± 48bc	581 ± 53b	1,490 ± 76b	573 ± 53b
Avermectin B_1	0.4	1,124 ± 92b	481 ± 108bc	1,475 ± 56b	324 ± 44c
Isazofos	2.3	1,098 ± 101b	285 ± 45cd	1,411 ± 90b	279 ± 19c
Isazofos	23.0	682 ± 80c	210 ± 38d	1,516 ± 67b	304 ± 16c
Control	—	1,699 ± 66a	847 ± 58a	2,213 ± 75a	730 ± 38a

[a]$F = 21.39$; df 4,15; $P < 0.01$; [b]$F = 15.02$; df 4,15; $P < 0.01$; [c]$F = 20.60$; df 4,15; $P < 0.01$; [d]$F = 29.47$; df 4,15; $P < 0.01$.
Means in the same column followed by the same letter are not significantly different (LSD test).
Dat = days after treatment.
Each treatment replicated four times.

a.i./ha rates of isazofos and by the 0.2-kg a.i./ha rate of avermectin B_1 mixed throughout the soil (Table 2). At 28 days, only populations treated with the 23.0-kg a.i./ha rate of isazofos and the mixed treatments of avermectin B_1 were lower than the controls ($P \leq 0.01$). At 56 days, all treated populations were lower than the controls, with greatest mortality in the 23.0-kg a.i./ha rate of isazofos ($P \leq 0.01$).

At 14 days after treatment, *T. dubius* populations were reduced from the control by the 2.3- and 23.0-kg a.i./ha rates of isazofos and by both of the 0.4-kg a.i./ha rates of avermectin B_1 ($P \leq 0.01$). At 28 and 56 days, all treatments reduced populations compared to controls ($P \leq 0.01$). At 28 days after treatment, greater mortality occurred in both rates of isazofos ($P \leq 0.01$). At 56 days after treatment, the greatest mortality occurred in the 23.0-kg a.i./ha rate of isazofos, but population reductions by this treatment were not significantly greater than those made by the 0.4-kg a.i./ha rate of avermectin B_1 mixed throughout the soil or either of the 0.2-kg a.i./ha rates of avermectin B_1.

Experiment 3: Hoplolaimus galeatus populations were reduced by the 0.2-kg a.i./ha rate of avermectin B_1 at 28 days and by the 0.2- and 0.4-kg a.i./ha rates at 56 days after treatment ($P \leq 0.01$) (Table 3). Nematode populations were not reduced by any of the treatments at 70 days after treatment ($P \leq 0.1$).

Populations of *T. dubius* were reduced compared to controls by the 0.4-kg a.i./ha rate of avermectin B_1 at 28 and 56 days ($P \leq 0.01$) and also were suppressed by both the 0.2- and 0.4-kg a.i./ha rates at 70 days after treatment ($P \leq 0.01$).

Experiment 4: Hoplolaimus galeatus populations were reduced compared to controls by the 0.2-, 1.6-, 7.5-, and 15.2-kg a.i./ha applications of avermectin B_1 and by 112.1 kg a.i./ha of fenamiphos ($P \leq 0.01$) (100 cm^3 soil column, Table 4). Numerically, the greatest mortality was caused by application of avermectin B_1 at the 15.2-kg a.i./ha rate, although this mortality was not significantly different from that caused by fenamiphos or by avermectin B_1 at a rate of 7.5 kg a.i./ha.

Reductions of *T. dubius* compared to controls were found in all treatments with greatest mortality occurring in the 0.8-, 1.6-, and 15.2-kg a.i./ha rates of avermectin, as well as with the 112.1-kg a.i./ha fenamiphos treatment ($P \leq 0.01$) (100 cm^3 soil column, Table 4).

Experiment 5: Reduction of populations of *H. galeatus* compared to controls occurred with 0.02, 0.4, 7.5, and 15.2 kg a.i./ha of avermectin B_1 and with 112.1 kg a.i./ha of fenamiphos ($P \leq 0.01$) (140 cm^3 soil column, Table 4). The greatest suppression occurred with 0.4, 7.5, and 15.2 kg a.i./ha of avermectin B_1, as well as with fenamiphos.

Reductions of *T. dubius* populations compared to controls were found in fenamiphos (112.1 kg a.i./ha) and aver-

TABLE 2. Evaluation of avermectin B_1 and isazofos against *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting *Poa annua*.

		Mean ± SEM live nematodes/140 cm^3 soil					
		H. galeatus			*T. dubius*		
Treatment	Kg a.i./ha	14 Dat[a]	28 Dat[b]	56 Dat[c]	14 Dat[d]	28 Dat[e]	56 Dat[f]
Avermectin B_1	0.2	529 ± 67 ab	525 ± 28 bc	210 ± 38 bc	520 ± 35 abc	443 ± 46 b	90 ± 19 c
Avermectin B_1 (Mixed)	0.2	278 ± 27 c	420 ± 109 c	171 ± 66 bc	606 ± 82 ab	381 ± 10 b	70 ± 14 c
Avermectin B_1	0.4	556 ± 29 a	805 ± 54 a	159 ± 23 c	349 ± 29 d	374 ± 7 b	223 ± 46 b
Avermectin B_1 (Mixed)	0.4	460 ± 76 ab	430 ± 50 c	146 ± 32 c	484 ± 32 bc	409 ± 24 b	95 ± 13 c
Isazafos	2.3	388 ± 49 bc	496 ± 45 bc	294 ± 44 b	474 ± 31 bcd	241 ± 19 c	178 ± 21 b
Isazofos	23.0	375 ± 15 bc	381 ± 13 c	93 ± 32 c	413 ± 53 cd	231 ± 35 c	38 ± 15 c
Control	—	604 ± 71 a	621 ± 59 b	458 ± 48 a	648 ± 35 a	683 ± 40 a	598 ± 31 a

[a]$F = 4.75$; df 6,21; $P < 0.01$; [b]$F = 6.31$; df 6,21; $P < 0.01$; [c]$F = 8.22$; df 6,21; $P < 0.01$; [d]$F = 5.13$; df 6,21; $P < 0.01$; [e]$F = 26.45$; df 6,21; $P < 0.01$; [f]$F = 58.93$; df 6,21; $P < 0.01$.

Means in the same column followed by the same letter are not significantly different (LSD test).

Dat = days after treatment.

Each treatment replicated four times.

TABLE 3. Evaluation of avermectin B_1 against *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting *Poa annua*.

		Mean ± SEM live nematodes/140 cm^3 soil					
		H. galeatus			*T. dubius*		
Treatment	Kg a.i./ha	28 Dat[a]	56 Dat[b]	70 Dat[c]	28 Dat[d]	56 Dat[e]	70 Dat[f]
Avermectin B_1	0.2	525 ± 42 b	501 ± 55 b	433 ± 69	755 ± 84 ab	788 ± 79 a	500 ± 47 b
Avermectin B_1	0.4	755 ± 61 a	454 ± 56 b	313 ± 19	511 ± 56 b	470 ± 46 b	336 ± 29 b
Control	—	829 ± 32 a	839 ± 111 a	278 ± 48	1,038 ± 123 a	709 ± 69 a	830 ± 92 a

[a]$F = 11.74$; df 2,9; $P < 0.05$; [b]$F = 7.17$; df 2,9; $P < 0.05$; [c]$F = 2.66$; df 2,9; $P = 0.1$; [d]$F = 8.26$; df 2,9; $P < 0.01$; [e]$F = 6.22$; df 2,0; $P < 0.05$; [f]$F = 16.59$; df 2,9; $P < 0.01$.

Means in the same column followed by the same letter are not significantly different (LSD test).

Dat = days after treatment.

Each treatment replicated four times.

TABLE 4. Evaluation of avermectin B_1 and fenamiphos against *Hoplolaimus galeatus* and *Tylenchorhynchus dubius* infesting *Poa annua*.

		Mean ± SEM live nematodes			
		H. galeatus		*T. dubius*	
		100 cm^3	140 cm^3	100 cm^3	140 cm^3
Treatment	Kg a.i./ha	28 Dat[a]	28 Dat[b]	28 Dat[c]	28 Dat[d]
Avermectin B_1	0.02	789 ± 76 a	343 ± 64 bc	573 ± 68 bc	830 ± 53 b
Avermectin B_1	0.2	241 ± 43 d	394 ± 32 ab	601 ± 103 b	1,074 ± 39 a
Avermectin B_1	0.4	405 ± 85 bc	218 ± 20 cd	588 ± 34 bc	1,041 ± 55 a
Avermectin B_1	0.8	428 ± 39 bc	379 ± 71 abc	458 ± 27 bcd	528 ± 75 de
Avermectin B_1	1.6	289 ± 44 cd	365 ± 78 abc	429 ± 69 bcd	643 ± 39 cd
Avermectin B_1	7.5	161 ± 39 de	73 ± 4 d	584 ± 40 bc	453 ± 110 e
Avermectin B_1	15.2	75 ± 25 e	63 ± 13 d	289 ± 40 d	250 ± 47 e
Fenamiphos	112.1	145 ± 37 de	113 ± 6 d	421 ± 65 cd	411 ± 20 ef
Control	—	495 ± 68 b	516 ± 94 a	814 ± 31 a	729 ± 80 bc

[a]$F = 16.62$; df 8,27; $P < 0.01$; [b]$F = 9.30$; df 8,27; $P < 0.01$; [c]$F = 6.63$; df 8,27; $P < 0.01$; [d]$F = 20.25$; df 8,27; $P < 0.01$.
Means in the same column followed by the same letter are not significantly different (LSD test).
Dat = days after treatment.
Each treatment replicated four times.

mectin B_1 (0.8, 7.5, and 15.2 kg a.i./ha) treatments ($P \leq 0.01$) (140 cm^3 soil column, Table 4). The greatest mortality was caused by application of avermectin B_1 at the 15.2-kg a.i./ha rate. This mortality was not significantly different from that caused by fenamiphos.

DISCUSSION

Avermectin B_1 has potential to control *H. galeatus* and *T. dubius* as well as the currently registered nematicides, fenamiphos and isazofos. The acute toxicity of fenamiphos (rat oral LD_{50} of 3 mg/kg) makes it potentially dangerous to humans, birds, and wildlife (14), and the high rate of isazofos used in this study (which demonstrated significant control for these nematodes) is greater than the current labeled rate. Avermectin B_1, therefore, may be a good control alternative, particularly at the consistently successful suppression rates of 7.5 and 15.2 kg a.i./ha. These rates, however, are not economical at this time.

Nwadinobi et al. (16) observed a reduction in the number of galls produced by *Meloidogyne* spp. when dipping roots of 14-day-old tomato seedlings in 1 mg/liter of avermectin B_1. The treatment delayed nematode invasion and development for up to 20 days (16). In our studies, consistent nematode reduction was observed at much higher rates. Avermectin has some systemic or translaminar movement into plant tissue (7), and, if it were applied to established turf, it may be more effective against *H. galeatus* and *T. dubius* at lower rates.

Reducing nematode populations in soils is difficult with chemicals due to problems associated with nematicide damage to the host plant, nematicide distribution, and release of the active ingredient in the soil (13). Isazofos (as Miral) applied at a rate of 2 kg/ha to *Lolium perenne* cv. Ellett seedlings reduced nematode numbers in pot trials, but phytotoxic effects such as low seedling emergence and delayed growth were observed (2). In turfgrass environments, chemical control is also difficult since thatch hinders penetration and many chemicals adsorb to thatch (13). As a result, higher rates of chemicals may be required to obtain effective control against plant-parasitic nematodes. A test was done on an established bluegrass site applying 6 kg of fenamiphos/ha, which usually provides excellent control of nematodes in the field. This rate, however, had no significant effect on *T. dubius* or *Criconemoides lobatum* and instead required 25 kg/ha to obtain 85% control of these two species (13).

Biological degradation of organophosphorus pesticides is well documented in the literature (24). Increased degradation of nematicidal metabolites by microbes has been shown to decrease the efficacy of fenamiphos. Davis et al. (6) found that the formation of fenamiphos sulfoxide (a nematicidal metabolite of fenamiphos) was faster in nonautoclaved versus autoclaved soil, which indicated that the breakdown is biologically mediated.

If avermectin B_1 were to become more economically feasible for practical field use against plant-parasitic nematodes, it would provide a lower (non-target) toxicity control alternative. It has little adverse effect on the environment, and the ability of avermectin B_1 to bind to soil particles should prevent groundwater contamination. Safe, effective, and expanded labels of nematicidal compounds are needed for commercial turfgrass (9). Currently available nematicides such as isazofos and fenamiphos may be hazardous to humans and the environment and, in some cases, phytotoxic. In time, their use also may become economically impractical since repeated applications are needed to obtain effective nematode suppression.

Although these studies are promising, these experiments relied on incorporating treatments into the soil without a thatch barrier. In order to avoid a loss of activity due to thatch and soil binding of the chemical when applied as a drench to turf, high-pressure injection could be a useful method of application if the higher rates used in these studies were to become more economical. Further research should concentrate on improving application rates and procedures as well as finding information on the effects of soil type and biota on nematicides.

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