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Slit Injection of 1,3-Dichloropropene for Management of *Belonolaimus longicaudatus* on Established Bermudagrass[1]

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Abstract: Belonolaimus longicaudatus is a serious problem on bermudagrass, a common warm-season turfgrass, in Florida. The cancellation of organophosphate nematicides necessitates that new management tools be identified for use on sports turf. Postplant application of 1,3-dichloropropene (1,3-D) on bermudagrass was evaluated for management of *B. longicaudatus* on golf course fairways and driving ranges. A series of 10 experiments were conducted to evaluate the effectiveness of 1,3-D in reducing population densities of *B. longicaudatus* and enhancing bermudagrass recovery from nematode damage. In 5 of 10 experiments, 1,3-D injected at 46.8 liters/ha was effective in reducing population densities of *B. longicaudatus* ($P < 0.05$) compared to untreated plots 2 to 4 weeks after treatment. One month after treatment, population densities of *B. longicaudatus* ranged from 59% to 97% of those in untreated plots. Nematode suppression generally lasted 2 months or less. Turf visual performance was improved following injection with 1,3-D ($P < 0.05$) over untreated plots when other factors were not limiting. Turf root development also was enhanced following injection with 1,3-D. Postplant injection of 1,3-D could be a useful nematode management tool for certain sports turf applications.

Key words: Belonolaimus longicaudatus, bermudagrass, *Cynodon dactylon, Cynodon* hybrids, 1,3-dichloropropene, nematicide, nematode, nematode management, soil fumigation, sting nematode, turf.

Belonolaimus longicaudatus (sting nematode) is an important pest of bermudagrass (*Cynodon dactylon* L. and *Cynodon* hybrids) and other crops in the southeastern United States (Perry and Rhoades, 1982). On bermudagrass, *B. longicaudatus* can cause severe root reductions (Camarena, 1963; Giblin-Davis et al., 1992; Johnson, 1970) that lead to water and nutrient stress, and decline of the grass.

Belonolaimus longicaudatus is found primarily in soils with >80% sand content (Robbins and Barker, 1974). Most golf course fairways are constructed of native materials, unlike greens that are usually constructed of a sand mix that is brought to the site. Hence, *B. longicaudatus* is normally damaging on fairways only in areas with native soil composed of high sand content. Due to the sandy conditions in much of Florida, *B. longicaudatus* is the most destructive nematode on bermudagrass and is considered a major pest by the golf course industry in that state. *Belonolaimus longicaudatus* also causes damage to bermudagrass in sandy areas in other states in the southeastern United States, and parts of the Midwest. It has been spread in infested planting material to golf courses in California (Mundo-Ocampo et al., 1994) and internationally to some islands in the Caribbean (Perry and Rhoades, 1982).

For the past 20 years, the golf course industry has depended on the organophosphate nematicides fenamiphos and ethoprop for nematode management. A review of organophosphates by the U.S. Environmental Protection Agency has been ongoing as mandated by the Food Quality Protection Act of 1996. The manufacturer of ethoprop withdrew its registration for turf uses in 2001. Additionally, the manufacturer of fenamiphos, the most frequently used nematicide on golf courses in the United States, has requested a voluntary cancellation of all product registrations of fenamiphos effective 31 May 2007 (Anonymous, 2002). The loss of organophosphates has led to great interest in developing new ways to manage nematodes on golf courses.

1,3-Dichloropropene (1,3-D), one of the oldest fumigant nematicides, is the active ingredient in the Telone products that have been widely used for nematode management in agricultural crops over the past 50 years. 1,3-D was tested experimentally for nematode management on turf with good results in the 1950s (Perry, pers. comm.) but never was used commercially. Recently, Dow AgroSciences LLC has developed a new product concept, Curfew Soil Fumigant. Curfew Soil Fumigant is a water-soluble formulation of 1,3-D (97.5% a.i. by weight) that is being evaluated for management of plant-parasitic nematodes on golf course fairways, driving ranges, roughs, and tees. Curfew Soil Fumigant had an experimental use permit for use on turf in Florida in 2001 and 2002 and received a 24(c) label for Florida in 2003. Curfew Soil Fumigant is applied by custom applicators using slit-injection technology, where a coulter slices through the thatch and soil to a depth of 15 cm. A knife with a dispensing tube places the undiluted fumigant 14 cm deep. This is followed by a roller, which seals the injection slit. Irrigation with 1.2 cm of water is recommended immediately following injection. The objectives of this study were to evaluate the efficacy of 1,3-D applied by slit injection in reducing population counts of *B. longicaudatus,* and promoting turf recovery from damage caused by *B. longicaudatus* on established bermudagrass.

Materials and Methods

Experiments 1 to 7: Experiments 1 to 3 were conducted at site 1, a fairway at the Orange County National Panther Lake Golf Course in Winter Garden, Florida. Ex-

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periments 4 to 7 were conducted at site 2, the driving range of the Mayfair Golf and Country Club in Lake Mary, Florida. Both sites had damaging population densities of *B. longicaudatus* and were planted to 'Tifway 419' bermudagrass (*Cynodon dactylon X C. transvaalensis*). The mowing height was 1.25 cm on site 1 and 1.9 cm on site 2. Water was applied by the golf course staff according to their standard cultural practices as needed. No other nematicides or insecticides were used on the experimental areas. Site 2 was not fertilized, and site 1 was fertilized at approximately 2-week intervals with 0.56 kg N/ha by the golf course staff.

These experiments used a randomized complete block design with three replications. Comparisons were made between plots treated with 1,3-D applied at 55 kg a.i./ha and untreated plots. Plots measured 6.4 m × 23 m with 1.5-m borders between plots. Nematode population densities were assayed 2 weeks before treatment, and no pre-treatment differences ($P < 0.05$) in nematode populations were found between treatments (data not shown). 1,3-D was injected 15 cm deep using pressurized-nitrogen slit-injection equipment (Southern Soils Turf Management, Lake Mary, FL) with 30 cm between slits. A third treatment was included in experiments 1 to 7 to determine if benefits resulting from 1,3-D injection might be attributed to the slit-injection process rather than the fumigant. This treatment involved slitting the plots using the injection equipment but without adding 1,3-D. Experiment 4 was treated on 15 May 2001, experiments 1 and 5 were treated on 22 June 2001, experiments 2 and 6 were treated on 20 July 2001, and experiments 3 and 7 were treated on 21 August 2001.

Nematode populations and turf quality were evaluated 1 month after application. Nematode samples consisted of 2.5-cm-diam. cores taken 8 to 10 cm deep from 15 arbitrary locations in each plot. The nematodes were extracted from a 100-cm^3 subsample using centrifugal-flotation (Jenkins, 1964) and counted using an inverted light microscope. Turf quality was evaluated visually on a 1- to 9-scale, with 9 being the optimal turf performance (Lucas, 1982).

Treatment means were subjected to analysis of variance, and treatment means were separated at $P < 0.05$ according to Duncan's multiple-range test. The plots that were treated by mechanical slitting without 1,3-D were never different ($P < 0.05$) from the untreated (data not shown). Therefore, treatment means of the 1,3-D treated plots and the untreated plots were compared using the contrast procedure ($P < 0.05$).

Experiments 8 and 9: Experiments 8 and 9 were conducted on two fairways at the Palatka Municipal Golf Club in Palatka, Florida. The site was planted to 'Common' bermudagrass (*C. dactylon*) with damaging populations of *B. longicaudatus*. The turf was mowed at 1.25-cm height. Fertilizer was applied approximately every 2 weeks at 0.56 kg N/ha by the golf course staff during their routine maintenance. Irrigation was applied as needed. The experimental design for these experiments was a randomized complete block design with four replications. Nematode population densities were assayed 2 weeks before treatment, and no pre-treatment differences ($P < 0.05$) in nematode populations were found between treatments (data not shown). Treatments were 1,3-D at 55 and 110 kg a.i./ha, fenamiphos (Nemacur 10G) at 11.2 kg a.i./ha, and untreated. Plots were 6.4 m wide × 15 m long with 1.5-m borders between plots. 1,3-Dichloropropene was applied using the same equipment used in experiments 1 to 7. Fenamiphos was surface-applied using a drop-spreader. Nematicides were applied on 28 June 2001.

Nematode samples were collected 2, 4, 8, and 12 weeks after treatment. Each sample was composed of 2.5-cm-diam. cores taken 8 to 10 cm deep from 12 random locations in each plot. In these experiments, instead of using one visual parameter (turf quality), two separate visual parameters were used. Each parameter, turf color, and turf density measured a separate turf health component. Turf color and density were evaluated visually 2, 4, 8, and 12 weeks after treatment. Turf color was rated on a 1- to 9-scale, with 1 being brown turf and 9 being brilliant green turf. Turf density was based on the percentage of ground coverage and density of the bermudagrass. In experiment 8, root depth was measured visually 10 weeks after treatment from soil profiles taken 15 cm deep with a 1.25-cm × 10-cm soil profile probe from two arbitrary locations in each plot. All data were subjected to analysis of variance, and at $P < 0.05$ treatment means were separated according to Duncan's multiple-range test.

Experiment 10: Test plots were established on 'Tifgreen' bermudagrass (F1 hybrid of *Cynodon dactylon X C. transvaalensis*) naturally infested with *B. longicaudatus* at the Fort Lauderdale Research and Education Center, University of Florida. Experimental design was a split plot with randomization of main plots (with or without 1,3-D at 55 kg a.i./ha) and four subplot treatments that were randomized within each main plot. Main plots were 1.83 m wide, with 0.91-m untreated borders between plots. The 1,3-D injection was made on 14 October 1998 using the injection rig described previously. The following treatments were applied 24 hours later to 2.25 m^2 demarcated subplots: no treatment, or fenamiphos at 11.2 kg a.i./ha. There were eight replications for this experiment. Nematode populations in each plot were assayed prior to treatment, and no differences ($P < 0.05$) in nematode populations were found (data not shown). Because there were no main plot × subplot interactions, only the main plot effects are discussed in this paper. Turf density, root core dry weights, root visual ratings of dried root cores (root volume and a nematode damage ratings), and nematode assays were taken several days prior to treatment and at 28 days and 56 days post-treatment.

TABLE 1. Effects of postplant injection with 1,3-dichloropropene at 55 kg a.i./ha on population densities of *Belonolaimus longicaudatus* and on turf quality of 'Tifway 419' bermudagrass at 4 weeks after treatment.

	B. longicaudatus/100 cm^3 soil		Turf quality rating[a]	
	Untreated	Treated	Untreated	Treated
	Site 1			
Experiment 1	147	4*	5.7	9.0*
Experiment 2	118	22	6.8	8.5*
Experiment 3	50	17	7.2	9.0*
	Site 2			
Experiment 4	31	4*	4.0	4.3
Experiment 5	13	4	4.0	4.0
Experiment 6	18	4*	5.0	4.3
Experiment 7	17	5	5.7	6.0

Data are means of 3 replicates. Means followed by an asterisk are different from untreated ($P < 0.05$).
[a] Turf quality was rated on a subjective 1- to 9-scale, with 9 equaling maximum turf quality, 1 as completely dead turf, and 6 as the threshold for acceptability.

Turf density was rated based on percentage of ground coverage and density of the bermudagrass. To measure root dry weight, single 10-cm-diam. cores were randomly taken to a depth of 7.75 cm from one corner of each subplot at 48 hours before (pre-) and 28 and 56 days post-treatment from each subplot treatment. The top 1.25 cm of soil was removed and discarded (grass + thatch + upper rhizomes) before the soil core was washed on a No. 20 sieve to remove soil and most of the non-root debris. Samples were dried at 55 to 60 °C for 24 hours before they were handpicked free of contaminating debris and then weighed. Dry root samples from the previous step were retained until the end of the experiment and then rated side by side for root volume and nematode damage. The root volume assessment was done by comparing the total apparent volume of each dried sample on a 0- to 10-scale (0 = no volume of roots to 10 = a high and compact volume of dried roots [the highest volume observed in this experiment]). The root damage assessment used a 0- to 5-scale where 0 = no root damage (white to light-tan colored roots with abundant root hairs) to 5 = 100% of roots (dark colored and "stubby" in appearance with no root hairs). Because the scale in the root damage scores used a 0 for high-quality roots and a 5 for low-quality roots, a lower rating is preferable for that parameter.

All data were subjected to analysis of variance using the general linear model procedure for split-plot design. The block × main-plot interaction was used as the error term for the main-plots. Treatment means were separated according to Duncan's multiple-range test.

RESULTS

Experiments 1 to 7: Population densities of *B. longicaudatus* decreased ($P < 0.05$) at 4 weeks after treatment in response to application of 1,3-D in experiments 1, 4, and 6 (Table 1). Visual quality of treated plots improved ($P < 0.05$) in experiments 1, 2, and 3. The mechanically slit treatments were never different from the untreated (data not shown).

Experiments 8 and 9: In experiment 8, population densities of *B. longicaudatus* decreased ($P < 0.05$) in plots treated with 1,3-D at both 55 and 110 kg a.i./ha 2 weeks after treatment compared with untreated and fenamiphos treated plots (Table 2). Turf color and density were improved ($P < 0.05$) by application of 1,3-D at both rates compared with untreated at 8 and 12 weeks after treatment (Table 2). Turf color was improved ($P < 0.05$) by application of 1,3-D at only the 110-kg a.i./ha rate 4 weeks after treatment. Density of turf treated with 1,3-D was greater than that of turf treated with fenamiphos at 8 weeks after treatment at both rates, and at 4 and 12 weeks after treatment only at the 110 kg a.i./ha rate. Root depth increased ($P < 0.05$) at 10 weeks after treatment in plots treated with 1,3-D at 55 kg a.i./ha compared with untreated plots (Table 3).

TABLE 2. Effects of injection with two rates of 1,3-dichloropropene, and fenamiphos at 11.2 kg a.i./ha, on population counts of *Belonolaimus longicaudatus,* and on turf color rating (1 to 9) and turf density (0% to 100%) of 'Common' bermudagrass.

	2 Weeks after treatment			4 Weeks after treatment			8 Weeks after treatment			12 Weeks after treatment		
	Nemas[a]	Color[b]	Density[c]	Nemas	Color	Density	Nemas	Color	Density	Nemas	Color	Density
					Experiment 8							
Untreated	37 a	6.25 ab	65	21	6.00 bc	63 b	32	3.50 b	48 b	7	4.50 b	30 c
Fenamiphos	30 a	5.25 b	57	19	5.75 c	63 b	46	4.75 a	50 b	7	4.75 ab	43 b
1,3-D 55 kg a.i./ha	15 b	7.75 a	70	6	6.50 ab	73 ab	43	5.50 a	65 a	17	5.25 ab	50 b
1,3-D 110 kg a.i./ha	15 b	7.25 a	68	7	7.00 a	75 a	45	6.00 a	70 a	15	5.50 a	63 a
					Experiment 9							
Untreated	24	5.75	48	24	5.75 b	53	19 ab	3.50	46 b	7 b	3.00 b	23 c
Fenamiphos	20	6.50	53	53	6.25 ab	53	30 a	4.25	60 a	28 a	4.25 ab	38 bc
1,3-D 55 kg a.i./ha	12	6.50	50	2	6.75 a	53	23 a	5.00	55 a	11 b	4.25 ab	48 ba
1,3-D 110 kg a.i./ha	9	6.00	50	8	6.50 ab	48	10 b	5.00	60 a	11 b	5.25 a	53 a

Data are means of 4 replicates. Means within the same experiment followed by common letters are not different ($P < 0.05$) according to Duncan's Multiple-Range Test.
[a] *Belonolaimus longicaudatus*/100 cm^3 of soil.
[b] Turf color was rated on a subjective 1- to 9-scale, with 9 equaling maximum turf quality, 1 as completely dead turf, and 6 as the threshold for acceptability.
[c] Turf density was rated as a percentage of complete ground cover with 0 as bare soil and 100 as maximum possible density.

TABLE 3. Effects of nematicide application on root depth of 'Common' bermudagrass at 10 weeks after treatment application.

Treatment	Root depth (mm)
Untreated	2.75
Fenamiphos 11.2 kg a.i./ha	3.31
1,3-D 55 kg a.i./ha	4.75*
1,3-D 110 kg a.i./ha	3.72

Data are means of 4 replicates. Means followed by an asterisk are different from untreated ($P < 0.05$).

In experiment 9, none of the nematicide treatments reduced ($P < 0.05$) population counts of *B. longicaudatus* (Table 2). Turf color was improved ($P < 0.05$) in plots treated with 1,3-D at 55 kg a.i./ha at 4 weeks after treatment, and in plots treated with 110 kg a.i./ha at 12 weeks after treatment, compared with untreated plots (Table 2). Turf density was improved in plots treated with either rate of 1,3-D at 8 and 12 weeks after treatment (Table 2).

In experiment 10, population densities of *B. longicaudatus* and root damage ratings were reduced ($P < 0.05$) by treatment with 1,3-D at both 4 and 8 weeks after treatment (Table 4). Root volume increased ($P < 0.05$) in plots treated with 1,3-D (Table 4). Turf density improved ($P < 0.05$) following application of 1,3-D by 8 weeks after treatment (Table 4).

Discussion

Postplant application of 1,3-D at 55 kg a.i./ha resulted in lower population densities of *B. longicaudatus* in 5 of 10 tests, with similar trends observed in the remaining tests. In the tests where differences in nematode population densities were not observed, it may have been due to uneven distribution of nematode populations in the untreated plots. The suppression of population densities appeared to last only up to 8 weeks. However, this appears to allow enough time for the bermudagrass to establish a healthier root system.

The lack of visual improvement ($P < 0.05$) in turf treated with 1,3-D at site 2 (experiments 4 to 7) could be attributed to low fertility conditions or lower nematode population counts. The golf course staff at that location applied no fertilizer to the driving range throughout the summer. The other sites received fertilizer routinely. The bermudagrass at site 2 may have been unable to take advantage of reduction in nematode pressure because of nutrient deprivation.

Overall, postplant application of 1,3-D appears to be effective for seasonal management of *B. longicaudatus* on established bermudagrass. However, many areas on golf courses cannot be treated with 1,3-D using slit-injection technology. Areas near trees, irrigation heads, and other structures that can be damaged during injection need to be avoided. Areas within 30.4 m of occupied structures cannot be treated according to the label restrictions. Reentry into treated areas is not allowed within 24 hours after treatment unless full personal protective equipment is used. Putting greens, the most critical area of a golf course, cannot be treated due to self-imposed restrictions by the manufacturer. Therefore, while 1,3-D could be an acceptable alternative to organophosphate nematicides for certain golf course uses, it is not suited for all situations. Research is being conducted to identify other biological, chemical, and application equipment options.

TABLE 4. Effects of injection with 1,3-dichloropropene at 55 kg a.i./ha on population densities of *Belonolaimus longicaudatus,* turf density of 'Tifgreen' bermudagrass, root damage, and root volume at 4 and 8 weeks after treatment.

	B. longicaudatus/ 100 cm^3 soil	Turf density[a]	Root damage index[b]	Root volume[c]
	4 weeks after treatment			
Untreated	86	55	2.40	39
1,3-D	6*	58	1.26*	57*
	8 weeks after treatment			
Untreated	73	52	2.16	52
1,3-D	11*	58*	1.50*	62*

Data are means of 4 replicates. Means followed by an asterisk are different from untreated ($P < 0.05$).

[a] Turf density was rated as a percentage of complete ground cover with 0 as bare soil and 100 as maximum possible density.

[b] Root damage index was a 0- to 5-scale, where 0 = no root damage (white to light-tan colored roots with abundant root hairs) to 5 = 100% of roots dark colored and "stubby" in appearance with no root hairs.

[c] Root volume was rated as a percentage of the sample with the greatest root volume.

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