Supplement to the Journal of Nematology 31(4S):644–649. 1999.

Efficacy of Insecticides for Control of *Aphelenchoides fragariae* and *Ditylenchus dipsaci* in Flowering Perennial Ornamentals

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Abstract: The effects of abamectin B1, diazinon, and methiocarb insecticides on *Aphelenchoides fragariae* and *Ditylenchus dipsaci* in *Lamium maculatum, Phlox subulata, Rhododendron indicum,* and *Begonia* × *tuberhybrida* were determined in a series of greenhouse experiments. Abamectin at 0.005 or 0.011 g a.i./liter (0.3 or 0.6 ml/liter Avid 0.15 EC), diazinon at 0.62 or 1.87 g a.i./liter (2.6 or 7.8 ml/liter KnoxOut GH), or methiocarb at 3.5 g a.i./liter (4.7 g/liter Mesurol) were applied in two to six weekly or biweekly applications to foliage until runoff. Diazinon and abamectin reduced both *A. fragariae* and *D. dipsaci* populations in *Lamium* and *Phlox,* especially after repeated applications. Diazinon was generally more effective than abamectin. While methiocarb reduced *A. fragariae* densities in *Lamium,* it was not as efficacious as diazinon or abamectin. Nematode populations varied widely between host plant species and over time. Management of high nematode populations was difficult, and none of the materials tested was effective against *A. fragariae* in azalea or begonia. Both abamectin and diazinon are currently registered for insect control in ornamentals and may be combined with cultural control tactics to manage foliar nematodes.

Key words: abamectin, *Aphelenchoides fragariae,* Avid, azalea, begonia, diazinon, *Ditylenchus dipsaci,* KnoxOut, *Lamium maculatum,* Mesurol, methiocarb, nematicide, nematode, *Phlox subulata,* stem and bulb nematode.

Plant-parasitic nematodes can cause severe damage to the foliage of a large number of flowering ornamentals in nurseries and landscape plantings (Daughtrey et al., 1995). The range of symptoms observed on flowering ornamentals can vary considerably with plant and nematode species, but leaves, stems, flowers, or buds are commonly distorted, dwarfed, and killed. The most common foliar nematode, *Aphelenchoides fragariae,* can attack more than 250 plant species in 47 families, including many flowering ornamentals (Franklin, 1965). *Ditylenchus dipsaci,* the stem and bulb nematode, can occur in more than 450 hosts, including both monocots and dicots (Hooper, 1972). Both of these nematodes are widely distributed and can quickly ruin foliage and flowers.

Aphelenchoides and *Ditylenchus* spp. have been detected on annual and perennial flowering ornamental species worldwide (Daughtrey et al., 1995; Stretton et al., 1987; Wick, 1995). The Connecticut Agricultural Experiment Station diagnostic laboratory recently collected *Aphelenchoides* and *Ditylenchus* spp. from field-grown and potted nursery plants submitted from Connecticut, Massachusetts, and New York. *Aphelenchoides* spp. have been a recurring problem on several plant species in commercial production. This nematode was recently identified as the pathogen causing leaf necrosis and stunting of *Lamium maculatum* (LaMondia, 1995). *Ditylenchus dipsaci* is a particular problem on flowering perennials such as *Phlox subulata.* Populations of both nematodes can increase rapidly to tremendous numbers per leaf. Because they can be dispersed in detached or dried leaves, infection can quickly become widespread and damaging. Propagation of perennial flowering ornamentals is often done by division for reasons such as 'trueness-to-cultivar'. As a consequence, this method of propagation can result in increased spread and distribution of these nematodes.

Control of foliar nematodes can be extremely difficult. Diagnosis of plants with foliar nematodes is often confounded by additional infection with pathogens such as *Bot-*

Received for publication 20 January 1999.
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The author thanks J. Canepa-Morrison, R. Ballinger, and D. Gaskill for technical assistance. This research was partially supported by the Perennial Plant Association.
This paper was edited by T. L. Kirkpatrick.

rytis cinerea. Nursery and greenhouse crops are particularly susceptible, and any nematode-infested material usually results in the spread and establishment of the nematode. Sanitation, avoidance, and irrigation management may help to slow the spread of foliar nematodes, but there are no chemical nematicides currently registered for foliar nematode control on established plants. The lack of effective control options may be responsible for the recent increased frequency of diagnosis of foliar nematode infestations in the Northeast.

Preliminary research has indicated that abamectin and diazinon insecticides have some nematicidal activity and may be useful for control of both *A. fragariae* (LaMondia, 1996) and *D. dipsaci* (unpubl.). Both insecticides currently are labeled for control of arthropods in flowering ornamentals. Abamectin has been shown to have activity against a number of mites, insects, and nematodes (Cayrol et al., 1993; Heungens, 1985; LaMondia, 1996). Diazinon is listed as a means of foliar nematode control in the Cornell Recommendations for Integrated Management of Greenhouse Florists Crops (Anonymous, 1998), but little information on efficacy is available in the literature. Methiocarb, used in greenhouses for insect and slug control, may also have nematicidal properties and was associated with declining foliar nematodes in one greenhouse in Connecticut (LaMondia, unpubl.).

The objectives of this research were to determine the efficacy of selected foliar insecticides as post-plant control tactics for the foliar nematodes *A. fragariae* and *D. dipsaci* on flowering ornamentals.

Materials and Methods

Experiment 1: Abamectin B1 (Avid 0.15 EC, Novartis, Greensboro, NC) was evaluated against *A. fragariae* infecting *Lamium maculatum* 'White Nancy' under greenhouse conditions in Windsor, Connecticut. Forty *L. maculatum* plants in 325-cm^3 pots were infested with *A. fragariae* in suspension and kept under high humidity for 48 hours. Nematode inoculum was collected from infected *L. maculatum* leaves placed in water in pie pans overnight. Abamectin B1 was applied to leaves and stems 2 weeks later at two rates (0.005 or 0.011 g a.i./liter based on labeled rates for spider mites or leafminers, respectively) in one or two applications of each rate, with a hand-held mist sprayer until runoff. The two applications were made 1 week apart. Water was applied to control plants at each date. After 2 or 5 weeks, nematodes were extracted from foliage of 10 replicate plants/treatment by means of pie-pan extraction for 4 days. Nematodes were collected by sieving and counted.

Experiment 2: Control of *Ditylenchus dipsaci* in *Phlox subulata* by abamectin B1 (Avid 0.15 EC at 0.3 or 0.6 ml/liter; 0.005 or 0.011 g a.i./liter) or diazinon (KnoxOut GH at 2.6 or 7.8 ml/liter; 0.6 or 1.6 g a.i./liter, Cleary's, Somerset, NJ) applied to runoff. Treatments consisted of up to four weekly applications of each insecticide and were evaluated for each individual plant by arbitrarily sampling 2 g of foliage prior to the first application and again immediately before each subsequent application. Nematodes were extracted from foliage by means of shaker extraction for 24 hours, then collected on a sieve. There were five treatments and eight replicate plants per treatment.

Experiment 3: The experiment was repeated with six replicate plants of each of the same five treatments and up to six weekly applications of the same treatments. In the repeat experiment, Triton 27 spreader-sticker was applied to all treatments at the rate of 0.04 ml/liter for the first four sprays but not the last two.

Experiment 4: Azalea (*Rhododendron indicum*), begonia (*Begonia* × *tuberhybrida* 'Barbara'), and lamium ('White Nancy') naturally infested with *A. fragariae* were kept under high humidity for 48 hours to ensure nematode infection. Infected azalea, begonia, and lamium plants were sprayed to runoff with abamectin, diazinon, or methiocarb using a hand-held sprayer. Treatments included two biweekly sprays of abamectin (0.011 g a.i./liter), diazinon (1.8 g a.i./liter), or methiocarb (3.5 g a.i./liter Mesurol, Gowan, Yuma, AZ). Control plants were sprayed with water. There were 10 replicate plants of each of four treatments per plant species. One week after each spray, nematodes were collected from 1 g of foliage of treated plants by means of shaker extraction for 24 hours, then gathered on a sieve.

Differences in numbers of nematodes collected from Experiment 1 were analyzed by means of analysis of variance, and the means were separated by linear contrasts. As individual plants were sampled repeatedly in Experiments 2 through 4, data were analyzed by repeated measures analysis of variance. Data are presented as normalized means, determined by dividing each observation by the initial pre-treatment nematode population for each plant.

Results and Discussion

Experiment 1: The numbers of foliar nematodes collected from *Lamium maculatum* 2 or 5 weeks after abamectin application were not different, and data were combined for linear contrast of the means (Table 1). Abamectin application significantly reduced the number of nematodes extracted from foliage. There were no differences in effects of the two rates, and no phytotoxicity was observed. There were no differences in efficacy between one or two abamectin applications a week apart.

Table 1. Effect of abamectin insecticide (Avid 0.15 EC) on *Aphelenchoides fragariae* populations from *Lamium maculatum.*

Treatment	Rate g a.i./liter	Number of applications	*Aphelenchoides fragariae*/pot
Control	0.0		35.7[a]
Abamectin	0.005	1	6.7
Abamectin	0.005	2	1.9
Abamectin	0.011	1	19.5
Abamectin	0.011	2	0.0

ANOVA

Factor	df	P
Treatment	4	0.04
Recovery date	1	NS
Interaction	4	NS

[a] Each number is the mean of eight observations.

Table 2. Effect of up to four applications of abamectin (Avid 0.15 EC) or diazinon (KnoxOut GH) on *Ditylenchus dipsaci* populations extracted from *Phlox subulata.*

	Percent nematode extraction from 1 g tissue after 1 to 4 sprays[a]				
Treatment	Rate (g a.i./liter)	1 spray	2 sprays	3 sprays	4 sprays
Control	—	119[b]	46	23	15
Abamectin	0.005	10	19	16	16
Abamectin	0.011	5	7	6	5
Diazinon	0.62	22	28	7	1
Diazinon	1.87	16	18	4	1

Repeated Measures ANOVA

Factor	df	P
Treatment	4	0.002
Time	4	0.001
Interaction	16	0.02

[a] Repeated measures analysis of variance performed on count data. Reported data normalized by dividing by the initial nematode number before treatments were applied.
[b] Each number is the mean of eight observations.

Experiment 2: Some control of *D. dipsaci* in *P. subulata* was observed with up to four weekly applications of abamectin or diazinon (Table 2). However, *D. dipsaci* populations were very large and neither abamectin nor diazinon completely controlled them, even after four applications. Linear contrasts of the means indicated that there were no significant differences between abamectin and diazinon, or between high or low rates of the insecticides. These high nematode populations resulted in necrosis and death of foliage. As a result, there was a general population decline over time in all plants, including the unsprayed controls, which were particularly damaged.

Experiment 3: When the experiment was repeated, *D. dipsaci* populations were lower and were more effectively controlled by up to six spray applications of diazinon (Table 3). As in the previous experiment, diazinon appeared to be more effective than abamectin, but not significantly so through the first four sprays. After four sprays, the efficacy of diazinon was markedly better than abamectin ($P = 0.001$). Triton 27 was used as an

TABLE 3. Effect of up to six applications of abamectin (Avid 0.15 EC) or diazinon (KnoxOut GH) on *Ditylenchus dipsaci* populations extracted from *Phlox subulata.*

		Percent nematode extraction from 1 g tissue after 1 to 6 sprays[a]					
Treatment[b]	Rate (g a.i./liter)	1	2	3	4	5	6
Control	—	115[c]	35	202	91	97	125
Abamectin	0.005	41	89	330	113	235	220
Abamectin	0.011	94	177	441	136	70	68
Diazinon	0.62	38	8	20	8	1	1
Diazinon	1.87	28	53	68	6	2	2

Repeated Measures ANOVA

Factor	df	P
Treatment	4	0.05
Time	5	0.01
Interaction	20	0.12

[a] Repeated measures analysis of variance performed on count data. Reported data normalized by dividing by the initial nematode number before treatments were applied.
[b] Triton 27 was applied to all treatments at the rate of 0.04 ml/liter for the first four sprays.
[c] Each number is the mean of six observations.

adjuvant in this experiment but caused phytotoxicity in combination with abamectin, and was not used in any treatment after the fourth spray.

Experiment 4: Aphelenchoides fragariae populations naturally declined over time in azalea and increased over the course of the experiment in begonia and lamium (Table 4). Insecticide treatments affected only foliar nematodes in lamium, and not in the other hosts. Diazinon was again the most efficacious material tested, although abamectin and methiocarb also reduced nematode populations in lamium. These plants were naturally infected with different populations of *A. fragariae*. Previous exposure to insecticides was unknown, and populations were not tested for differential sensitivity to each insecticide.

Abamectin is labeled for use on ornamentals to control mites and leafminers and had previously been shown to reduce populations of both root-knot (Cayrol et al., 1993) and foliar (Heungens, 1985) nematodes.

TABLE 4. Normalized populations of *Aphelenchoides fragariae* from 1 gram of leaf tissue of azalea, begonia, or lamium after one or two foliar applications of abamectin (Avid 0.15 EC), diazinon (KnoxOut GH), or methiocarb (Mesurol).

		Azalea		Begonia		Lamium	
Treatment	Rate	1 spray	2 sprays	1 spray	2 sprays	1 spray	2 sprays
Control	—	41[a]	11	1,163	3,802	383	429
Abamectin	0.01 g a.i./liter	50	2	192	3,007	336	26
Diazinon	1.87 g a.i./liter	17	5	1,953	3,688	26	7
Methiocarb	3.5 g a.i./liter	11	3	1,587	3,795	322	189

Repeated Measures ANOVA

Factor	df	P (Azalea)	P (Begonia)	P (Lamium)
Treatment	3	NS	NS	0.003
Time	1	0.001	0.001	0.06
Interaction	3	NS	NS	NS

[a] Repeated measures analysis of variance performed on count data. Reported data normalized by dividing by the initial nematode number before treatments were applied. Each number is the mean of 10 replications.

Avermectins have been shown to be highly nematicidal, reducing nematode infectivity, hatch, oxygen uptake, and mobility (Cayrol et al., 1993; Stretton et al., 1987). Although diazinon is listed as a means of foliar nematode control, little information on efficacy is available in the literature. Methiocarb, used in greenhouses for slug control, appears to have nematicidal properties and was previously associated with declining foliar nematode populations in one greenhouse (LaMondia, unpubl.). In these experiments, multiple applications of diazinon resulted in the most consistent control of both *A. fragariae* and *D. dipsaci*. Heungens (1985) reported acceptable control of *A. fragariae* in azalea by means of oxamyl nematicide or by multiple applications of abamectin B1. Oxamyl was reported to achieve the best control despite the fact that avermectins were more nematicidal to nematodes in vitro (Stretton et al., 1987). Unfortunately, oxamyl is no longer labeled for greenhouse use.

Results reported by Heungens may differ from the experiments reported here due to differences in nematode density. Heungens (1985) reported mean numbers of 80-85 nematodes/leaf, whereas approximately 1,000 nematodes/leaf were extracted from naturally infected azaleas in these experiments. Additionally, Heungens used a spreader-sticker and an agglutinant and we did not use adjuvants due to previous observations of phytotoxicity. These differences suggest that difficulties in foliar nematode control and differences among plant species may depend on insecticide uptake into leaf tissues. Absorption of abamectin was greater for pear than apple, and lower in older leaves compared to recently produced leaves (Beers et al., 1997). Translaminar activity was minimal, and absorption was better through the bottom leaf surface than the top, correlated with the greater presence of stomata. In addition, other leaf characteristics such as the thickness of the cuticle may act as a barrier to abamectin absorption (Price, 1982). Alternatively, there may be differential sensitivity to the insecticides in different nematode populations. These hypotheses remain to be tested.

Nematode populations can vary tremendously among host plants and over time. Consequently, management of very high nematode populations by insecticide application would be very difficult, especially in light of the high reproductive potential of both *Aphelenchoides* and *Ditylenchus* spp. and the low tolerance to these pathogens in commercial production. Control of low populations would be easier to achieve and maintain. Therefore, integration of chemical methods with cultural control tactics such as sanitation, removal of diseased plants or tissues from a crop or between plantings, and management of leaf wetness by reducing overhead irrigation frequency and increasing air flow through a crop will be necessary to manage foliar nematode infection.

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