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Control of *Ditylenchus dipsaci* in Infected Garlic Seed Cloves by Nonfumigant Nematicides[1]

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Abstract: Different rates of granular formulations of aldicarb, carbofuran, ethoprop, fensulfothion, and phenamiphos were applied directly onto garlic seed cloves in the seed furrow in sandy clay loam, clay loam, and loam soils at planting to assess efficacy for control of *Ditylenchus dipsaci* in infected seed cloves. All treatments were compared to hotwater–formalin clove dip disinfection treatment and to nontreated infected controls. Aldicarb and phenamiphos at 2.52 and 5.04 kg a.i./ha, but not at lower rates, effectively suppressed infection by *D. dipsaci* and increased yields. Although both nematicides slightly slowed the rate of plant emergence, normal stands were established. Trace levels of infection occurred in all treatments, including the hotwater–formalin dip. Carbofuran at 5.04 kg a.i./ha controlled the nematode but was phytotoxic. Ethoprop was phytotoxic. Fensulfothion did not control *D. dipsaci* even at the highest application rate, 8.90 kg a.i./ha. Single and multiple applications of oxamyl at 1.12–8.96 kg a.i./ha, applied as a surface spray or in furrow irrigation water, slowed the early progression of disease symptoms but failed to provide season-long nematode control.
Key words: aldicarb, carbofuran, ethoprop, fensulfothion, formalin, oxamyl, phenamiphos, hotwater dip, seedborne infection, stem nematode, *Allium sativum.*

The stem and bulb nematode, *Ditylenchus dipsaci* (Kuhn) Filipjev, is a serious pest of commercial garlic (*Allium sativum* L.) plantings in California where most of the garlic in the United States is produced. *D. dipsaci* infections can arise from planting in nematode-infested soil or more commonly from planting infected garlic seed cloves.

A rotation of 4 years of nonhost crops between garlic plantings effectively manages soil infestations of *D. dipsaci.* Crop injury from seed clove infection is prevented by disinfection of cloves by hotwater–formalin dip treatment (4,5), combined with efforts to produce nematode-free planting stock.

Mixed results relative to efficacy and phytotoxicity were reported in several studies of various nonfumigant nematicides to control soil-borne and seed-borne *D. dipsaci* (1,6,9–11) and *D. destructor* (2) in onions, phlox, and different ornamental bulbs. Our objectives were to investigate the efficacy of soil-applied aldicarb, carbofuran, ethoprop, fensulfothion, oxamyl, and phenamiphos as alternatives to the hotwater–formalin dip for controlling *D. dipsaci* in infected garlic seed cloves.

Materials and Methods

Allium sativum cv. California Late naturally infected with *D. dipsaci* was used in all experiments. Cloves were selected from bulbs harvested from field plantings that showed light to moderate disease symptoms the previous season.

During the week before planting, bulbs were mechanically separated into cloves. Some cloves were dipped in hotwater–formalin to provide disinfected controls (4,5). Cloves were treated by immersion in 0.26% aqueous formaldehyde for 30 minutes at 38 C followed by immersion for 20 minutes at 49 C, then 10 minutes in tap water at 18 C and air dried. Batches of cloves for planting in all the other treatments were dipped in 0.06% benomyl at 18 C for surface sterilization to minimize fungal contamination.

Three subsamples of 30 cloves from the hotwater–formalin treated batch and from the benomyl treated batch were then examined for *D. dipsaci* by placing diced cloves on modified Baermann funnels in a mist chamber for 3 days.

Experiments were conducted on field sites not infested with *D. dipsaci* (Table 1). Soil samples removed from each site before planting were analysed for *D. dipsaci.* Within an experiment each treatment was rep-

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TABLE 1. Soil characteristics, clove infection levels, and crop dates in each experiment.

Experiment and location	Soil type	Mechanical analysis (%)			Soil pH	Mean initial *D. dipsaci*/ clove	Date	
		Sand	Silt	Clay			Planting	Harvest
1, King City	Sandy clay loam	50.4	26.2	23.4	7.03	2.4	14 Nov. 80	31 July 81
2, King City	Sandy clay loam	53.4	27.4	19.2	7.01	17.3	20 Nov. 81	12 Aug. 82
3, King City	Sandy clay loam	46.0	28.1	25.9	6.99	9.6	12 Nov. 81	13 Aug. 82
4, Five Points	Sandy clay loam	52.4	27.3	20.3	6.98	1.3	15 Nov. 82	2 Aug. 83
5, San Ardo	Sandy clay loam	50.1	27.2	22.7	7.08	1.3	18 Nov. 82	18 Aug. 83
6, Five Points	Clay loam	36.6	27.3	36.1	6.97	0.5	9 Nov. 83	13 Aug. 84
7, King City	Loam	51.1	28.5	20.4	6.99	17.3	20 Nov. 81	12 Aug. 82
8, King City	Sandy clay loam	51.3	27.1	21.6	7.01	2.0	12 Nov. 81	13 Aug. 82
9, Five Points	Sandy clay loam	52.4	27.3	20.3	6.98	1.3	15 Nov. 82	2 Aug. 83

licated four times in a randomized complete block design. In Experiments 1 through 8, each replicate consisted of two 3-m rows planted 30 cm apart on a single 1-m-wide bed. A 3-m-long buffer of nematode-free garlic separated replicates linearly along a bed, and experimental beds were buffered on each side with one (Experiments 1–3, 7, 8) or two beds (Experiments 4–6) of nematode-free garlic. Experiment 9 plots were each two beds wide and 12 m long, separated on each side with two beds of nematode-free garlic and at each end with a 3-m fallow border.

Granular formulations of aldicarb, carbofuran, ethoprop, fensulfothion, and phenamiphos were applied by hand shaking from a vial directly onto and around the planted cloves in an open 8-cm-wide × 6-cm-deep planting furrow before covering with soil.

In Experiments 7 and 8, liquid oxamyl was applied with a hand sprayer in a 20–25-cm band onto each plant row with the desired concentration in a total volume of 153 liters/ha. The oxamyl band was applied at planting directly onto cloves and surrounding soil before covering cloves with soil, whereas the post-plant oxamyl treatments were applied onto plants and soil in the plant rows. Oxamyl applications were followed with sprinkler irrigation. In Experiment 7, applications of oxamyl at 1.12 or 0.56 kg a.i./ha were applied on day 0 (at plant); days 0 and 55; days 0, 55, and 115; day 55; days 55 and 115; or days 55, 115, and 175. In Experiment 8, oxamyl at 4.48 kg a.i./ha was applied on day 0, or on days 0 and 64.

In Experiment 9, oxamyl was metered into the head of water applied for furrow irrigation. Irrigation water was applied for 10–15 minutes, then oxamyl in irrigation water was applied for 30–35 minutes followed by water only for 10 minutes. The oxamyl was applied in the three irrigation furrows that bordered the two test beds in each subplot. Oxamyl at 2.24 kg a.i./ha was applied on days 14, 31, 50, and 66 from planting (early regime), or on days 91, 113, 134, and 151 (late regime).

Garlic culture followed the standard commercial procedures for California Late (8). Emergence data were collected by counting total numbers of plants emerged following hand planting of 10 cloves per 30 cm of row. Infection ratings were by visual observation of plants per replicate showing typical above-ground infection symptoms (stem bloating, leaf yellowing and wilting), using a scale of 0 = no plants with symptoms, 1 = up to 3 plants with symptoms, 2 = from 4 to 10 plants with symptoms, and 3 = more than 10 plants with symptoms.

Approximately 3 weeks before harvest, bulbs were mechanically undercut to separate roots and facilitate drying. At harvest, all bulbs were dug and the tops cut off by hand. Bulbs were separated into infection-damage categories of "none" = no symptoms, "slight/moderate" = discoloration but acceptable for commercial processing, and "severe" = not commercially acceptable. Bulbs in each category were counted and weighed. Yield values represent bulbs assigned to the "none" and "slight/moderate" categories.

TABLE 2. Effects of five granular nematicides and hotwater–formalin dip on *Ditylenchus dipsaci* damage to bulbs and yield of garlic (Experiment 1).

Treatment	Rate (kg a.i./ha)	Total bulbs/nematode damage category at harvest*			Yield† (kg/ha)
		None	Slight/moderate	Severe	
Hotwater–formalin clove dip		512	12	2	14,214 ab
Aldicarb 10G	2.24	575	23	6	16,119 b
Phenamiphos 15G	5.34	592	38	0	15,671 b
Carbofuran 10G	4.48	614	15	0	16,187 b
Fensulfothion 15G	8.90	574	3	4	15,144 b
Fensulfothion 15G	5.34	561	41	27	15,604 b
Ethoprop 10G	4.48	466	49	26	13,093 a
Control		424	41	91	13,070 a

Values within a column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.
* Total for four replicate plots per treatment.
† Yield comprised of bulbs in the none and slight/moderate damage categories.

Following harvest, a composite soil sample of 10 cores (2.5 cm × 30 cm deep) per replicate was collected to determine *D. dipsaci* population densities in the planting rows. A 250-cm^3 aliquot of soil from each sample was elutriated and passed through a series of 850-, 150-, and 45-μm-pore sieves followed by Baermann funnel extraction of all sievings in a mist chamber for 3 days. Hotwater–formalin dipped cloves used in the nine experiments contained no detectable *D. dipsaci*.

RESULTS

Granular nematicide: Phenamiphos and aldicarb at rates of 2.52 kg a.i./ha and higher were equally effective in significantly controlling *D. dipsaci* infection in six experiments (Tables 2–5). Both materials provided control similar to the hotwater–formalin dip. This control is shown by low midseason infection, reduced bulb damage at harvest, and increased yield of bulbs. Phenamiphos and aldicarb at 0.84 and 1.68 kg a.i./ha were less effective than at the higher rate (Tables 4, 5), although partial control was achieved with both materials. Aldicarb was more effective than phenamiphos at these lower rates in Experiments 4 and 5 (Table 4).

In Experiments 2 and 3 (Table 3) and Experiment 6 (Table 5), both phenamiphos and aldicarb at 2.52 kg a.i./ha or more retarded plant emergence early in the season, shown by emergence counts on days 31, 39, and 41 in the three experiments. Emergence counts on days 126, 143, and 121, however, show that a full stand was eventually established in each experiment, similar to the stand in the hotwater–formalin dip treatments. Retardation of emergence was less pronounced in aldicarb than in phenamiphos treatments in Experiment 2 (Table 3), but more pronounced in aldicarb treatments in Experiment 6 (Table 5).

Carbofuran at 4.48 (Experiments 1, 2) and 5.04 (Experiments 4, 5) kg a.i./ha significantly suppressed infection and increased yields and partly suppressed infection in Experiment 3 (Tables 2–4). Carbofuran was not effective at 2.52 kg a.i./ha or less in Experiments 2, 4, and 5. In Experiment 4, 2.52 and 5.04 kg a.i./ha of carbofuran was phytotoxic to garlic. Phytotoxicity, a prominent yellowing and necrosis of 1–3 cm of leaf tips, was observed about 60 days after planting.

Fensulfothion at 8.90 and 6.72 kg a.i./ha did not fully control *D. dipsaci,* and it was ineffective at lower rates (Tables 2, 3). Ethoprop at 4.48 kg a.i./ha did not control *D. dipsaci* infection (Table 2). In a preliminary experiment, 6.72 kg a.i./ha of ethoprop was severely phytotoxic and interrupted normal garlic growth.

Oxamyl treatments: No oxamyl treatments in Experiment 7 controlled *D. dipsaci.* In Experiment 8, oxamyl at 4.48 (one application) and 8.96 (in two applications) kg a.i./ha partly suppressed *D. dipsaci* up

Table 3. Effects of four granular nematicides and hotwater–formalin dip on garlic emergence and yield, and on *Ditylenchus dipsaci* infection and damage to bulbs (Experiments 2 and 3).

		Experiment 2								Experiment 3		
		Emergence (%)			Total bulbs/nematode damage category at harvest‡					Emergence (%)		
Treatment	Rate (kg a.i./ha)	Day 31*	Day 126*	Infection rating on day 175†	None	Slight/moderate	Severe	Yield§ (kg/ha)	*D. dipsaci*/250 cm^3 soil at harvest	Day 39*	Day 143*	Infection rating on day 183†
Hotwater–formalin clove dip		25.4 a	87.4 c	0 a	637	46	3	24,566 cd	0.8	50.9 ab	89.5 a	0.25 a
Aldicarb 15G	5.04	18.2 bc	97.8 abc	0.25 ab	685	24	12	24,858 d	2.0	33.3 d	92.5 a	1.00 b
Aldicarb 15G	2.52	14.8 cd	91.0 bc	0 a	686	11	0	24,609 cd	0			
Phenamiphos 15G	6.72	9.0 e	94.2 abc	0 a	640	17	33	22,485 cd	1.5	35.6 cd	88.4 a	0.50 a
Phenamiphos 15G	3.56	11.8 de	100.0 ab	0 a	711	25	6	23,599 cd	0			
Carbofuran 10G	4.48	19.7 b	100.0 ab	0.25 ab	610	71	59	21,900 cd	1.5	44.1 bc	84.6 a	2.50 c
Carbofuran 10G	2.24	17.5 bc	88.0 c	0.50 abc	455	69	86	15,039 abc	401.0			
Fensulfothion 15G	6.72	19.5 b	89.8 bc	0.75 bcd	479	85	80	19,790 bcd	3.0	38.6 cd	89.0 a	2.25 c
Fensulfothion 15G	3.56	12.5 de	100.0 ab	1.00 cd	304	149	216	13,784 a	1.0			
Control		20.3 b	100.0 ab	1.25 d	338	74	223	14,590 ab	188.8	39.3 cd	71.9 b	3.00 d

Values within a column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

* Day from planting.

† Infection rating scale 0 = no infection symptoms to 3 = severe infection, most plants with symptoms.

‡ Total for four replicate plots per treatment.

§ Yield comprised of bulbs in the none and slight/moderate damage categories.

TABLE 4. Effects of aldicarb, phenamiphos, carbofuran, and hotwater–formalin dip on garlic emergence and yield, and on *Ditylenchus dipsaci* infection and damage to bulbs (Experiments 4 and 5).

			Experiment 4					Experiment 5				
			Total bulbs/nematode damage category at harvest‡					Total bulbs/nematode damage category at harvest‡				
Treatment	Rate (kg a.i./ha)	Infection rating on day 212*†	None	Slight/moderate	Severe	Yield§ (kg/ha)	*D. dipsaci*/250 cm^3 soil at harvest	None	Slight/moderate	Severe	Yield§ (kg/ha)	*D. dipsaci*/250 cm^3 soil at harvest
Hotwater–formalin clove dip		0.25 a	639	7	2	18,824 g	0	612	3	5	19,637 a	0
Aldicarb 15G	5.04	0 a	594	6	0	15,535 cdef	0	696	2	6	17,967 a	1.3
Aldicarb 15G	2.52	0.25 a	592	4	3	16,992 f	0	603	41	36	18,052 a	0
Aldicarb 15G	1.68	0.50 a	588	3	1	16,385 ef	0	590	42	39	17,839 a	5.8
Aldicarb 15G	0.84	1.00 abc	522	0	6	15,981 def	1.3	491	47	52	15,934 a	4.3
Phenamiphos 15G	5.04	0.50 ab	548	15	3	14,941 cde	0	626	6	9	16,765 a	0.3
Phenamiphos 15G	2.52	0.75 abc	532	12	3	14,817 cde	0.8	664	31	34	17,957 a	0.8
Phenamiphos 15G	1.68	1.75 c	500	15	16	14,172 cd	5.5	538	51	13	18,663 a	0
Phenamiphos 15G	0.84	1.50 bc	499	10	11	13,697 bc	1.0	312	56	140	11,162 a	16.0
Carbofuran 10G	5.04	0.50 ab	503	4	3	14,217 cd	0	599	9	4	15,981 a	0
Carbofuran 10G	2.52	1.75 c	417	12	14	12,348 ab	0	596	19	23	16,118 a	0.5
Control		2.75 d	405	21	24	11,045 a	33.3	525	28	32	15,078 a	1.3

Values within a column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.
* Day from planting.
† Infection rating scale 0 = no infection symptoms to 3 = severe infection, most plants with symptoms.
‡ Total for four replicate plots per treatment.
§ Yield comprised of bulbs in the none and slight/moderate damage categories.

TABLE 5. Effects of different amounts of aldicarb and phenamiphos, and hotwater–formalin dip on garlic emergence and yield, and on *Ditylenchus dipsaci* infection and damage to bulbs (Experiment 6).

Treatment	Rate (kg a.i./ha)	Emergence %		Infection rating†		Total bulbs/nematode damage category at harvest‡			Yield§ (kg/ha)
		Day 41*	Day 121	Day 169	Day 226	None	Slight/moderate	Severe	
Hotwater–formalin clove dip		39.9 abc	94.7 bcd	0 a	0 a	692	0	1	17,065 ab
Aldicarb 15G	5.04	31.9 c	95.3 abc	0 a	0.25 ab	681	0	0	16,889 b
Aldicarb 15G	2.52	32.7 c	91.5 d	0 a	0.50 abc	685	0	1	17,154 ab
Aldicarb 15G	1.68	42.2 ab	91.9 cd	0.50 a	0.25 ab	652	2	0	16,817 b
Aldicarb 15G	0.84	44.0 ab	96.2 ab	0.25 a	0.75 abc	700	0	0	17,154 ab
Phenamiphos 15G	5.04	36.3 bc	98.8 a	0 a	0.25 ab	737	0	1	17,329 ab
Phenamiphos 15G	2.52	41.0 ab	95.7 ab	0 a	0.25 ab	729	0	0	16,684 b
Phenamiphos 15G	1.68	42.9 ab	96.9 ab	0.50 a	1.00 bc	737	0	1	17,813 a
Phenamiphos 15G	0.84	46.4 a	97.9 ab	0.25 a	1.25 c	716	2	3	16,920 b
Control		48.5 a	98.7 a	1.50 b	2.00 d	663	5	4	15,279 c

Values within a column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.
* Day from planting.
† Infection rating scale 0 = no infection symptoms to 3 = severe infection, most plants with symptoms.
‡ Total for four replicate plots per treatment.
§ Yield comprised of bulbs in the none and slight/moderate damage categories.

to midseason, but *D. dipsaci* bulb damage was extensive at harvest.

In Experiment 9, both the early and delayed oxamyl application regimes significantly ($P = 0.05$) suppressed infection assessed on day 184, from 50.3% of plants infected (infected control) to 34.7 and 37.3%, respectively, compared with 0.1 percent in the hotwater–formalin dip treatment. At harvest, however, the infected control and the early and the late regimes of oxamyl respectively yielded 26.7, 42.9, and 34.1% of the yield in the hotwater–formalin dip treatment.

Discussion

The hotwater–formalin dip used in these tests effectively prevented garlic yield suppression by *D. dipsaci,* although a few infected plants were found at harvest in several experiments. A 4-year rotation of nonhosts between garlic crops is routinely implemented to protect against infection from soil *D. dipsaci* (Roberts, pers. comm.). This rotation plan is justified even when seed cloves have been disinfected because eradication is not achieved.

The sampling and extraction methods detected *D. dipsaci* in all the infected lots of clove seeds, although the mean numbers per clove were not consistently correlated with the degree of infection occurring after planting. The lack of correlation may be due in part to the uneven distribution of nematode infection in cloves. No *D. dipsaci* were detected in cloves dipped in hotwater–formalin; however, a few infected plants developed from treated cloves, indicating that the treatment was not completely effective.

Plant infection and numbers of *D. dipsaci* per soil sample at harvest also lacked correlation. This variability may also be due to uneven distribution of nematode infection in cloves. High variability in *D. dipsaci* population densities in post-harvest soil samples after onions, oats, and rye has been attributed to aggregated distribution of nematodes immediately under the plant rows (7). Whitehead (10) similarly observed high variability in numbers of *D. dipsaci* in soil samples following onions.

Aldicarb and phenamiphos applied directly onto and around garlic cloves in the seed furrow at planting were consistently effective in controlling clove-borne *D. dipsaci* in six experiments. Rates of 2.52 kg a.i./ha and higher gave effective control, even when heavily infected cloves were planted. Levels of *D. dipsaci* infection of garlic at harvest after application of aldicarb and phenamiphos at these rates were similar to those for hotwater–formalin treated cloves.

Following slow early season emergence of garlic after aldicarb and phenamiphos applications, full plant stands became established and there was no persistent retardation of plant growth. Where 5.04 kg a.i./ha of phenamiphos was applied at planting, residue analysis showed 0.027 ppm of phenamiphos in cloves at harvest, which is well below the acceptable residue level of 0.5 ppm in harvested cloves. Provided that effective rates of aldicarb do not result in unacceptable residues in the harvested cloves, soil phenamiphos and aldicarb applications combined with a rotation would be effective alternatives to the hotwater–formalin dip.

Our results are consistent with those of Haglund (2) demonstrating control of *D. destructor* in iris with 3.3–13.4 kg a.i./ha of phenamiphos applied directly onto bulbs at planting; aldicarb was less effective in his experiments (2). Aldicarb at 1.4–5.6 kg a.i./ha applied directly over the seed furrows at planting (10), or at 2.2–9.0 kg a.i./ha broadcast incorporated before planting (9), prevented much of the damage from soil *D. dipsaci* on onions grown in spring and summer in England; at 9 kg a.i./ha aldicarb was phytotoxic (9). Aldicarb effectively eliminated dieback of *Phlox subulata* L. induced by soil-borne *D. dipsaci* (6).

Phytotoxicity induced by ethoprop and carbofuran at concentrations necessary to control *D. dipsaci* infection makes them unacceptable for use on garlic, although *D. dipsaci* control with carbofuran at 5.04 kg a.i./ha was similar to that obtained with aldicarb and phenamiphos. Carbofuran as a bulb treatment was found to be phytotoxic to narcissus (1). Fensulfothion did not effectively control nematode infection, although it was not phytotoxic. Fensulfothion failed to control *D. destructor* in iris (2).

Multiple applications of oxamyl reduced infection up to mid-season, but not enough to prevent severe bulb damage at harvest. Oxamyl did not control *D. destructor* in iris bulbs (2). Foliar-applied oxamyl controlled *D. dipsaci* in tissues of *Phlox subulata* (7) however, and oxamyl controls soil *D. dipsaci* and stubby-root nematodes on garlic and onions by protecting growing plants from nematodes in the rhizosphere (3,10).

Although hotwater–formalin dip does provide excellent control of *D. dipsaci* in garlic seed cloves, it has two serious disadvantages: 1) disposing of large quantities of formalin solution and 2) human handling of formaldehyde-treated clove lots prior to planting. Therefore, the development of alternative *D. dipsaci* control strategies, in this case nematicides applied to the soil at planting, is important in providing options to a single control strategy that may not be available in the future.

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