Supplement to Journal of Nematology 26(4S):683–689. 1994.

Influence of 1,3-Dichloropropene, Fenamiphos, and Carbofuran on *Meloidogyne incognita* Populations and Yield of Chile Peppers

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Abstract: Field trials were conducted during 1986, 1988, 1989, and 1991 to compare the effects of 1,3-dichloropropene, fenamiphos, and carbofuran on yield and quality of chile peppers (*Capsicum annuum*) in soil infested with *Meloidogyne incognita.* When compared with untreated plots, numbers of *M. incognita* juveniles recovered from soil 60 and(or) 90 days after chile pepper emergence were reduced ($P = 0.05$) following 1,3-D treatment every year except 1986. Nematode numbers were also reduced ($P = 0.05$) by fenamiphos in 1989. Chile pepper yields were significantly higher than those in untreated control plots ($P = 0.05$) all 4 years in plots treated with 1,3-D and in 1989 in plots treated with fenamiphos. Use of carbofuran did not significantly reduce nematode numbers or enhance yields in these experiments. Green chile pepper fruit quality was enhanced ($P = 0.05$) following 1,3-D treatments in 1988 and 1989 but was unaffected by fenamiphos or carbofuran application. Increasing placement depth of 1,3-D from 28 to 48 cm increased ($P = 0.05$) red chile pepper yield compared with that obtained with conventional placement in 1988 only, and did not affect green chile pepper yield.

Key words: application technique, *Capsicum annuum,* carbofuran, chile pepper, crop quality, depth of placement, fenamiphos, fumigation, *Meloidogyne incognita,* nematode, 1,3-dichloropropene, root-knot nematode, yield.

Revenue from chile peppers (pungent-fruited cultivars of *Capsicum annuum*) ranks first among annual cash crops in New Mexico (4). Peppers are grown for two different markets: i) fresh green chile peppers for processing and ii) dried red peppers for use as a spice. Fruit quality is a concern to the green chile producers, who must comply with specific fruit size and shape requirements established by processors. *Meloidogyne incognita,* a serious pathogen of chile (10,13), infests over two-thirds of the chile pepper acreage in New Mexico. Other crops commonly grown in rotation with chile, such as cotton (8,15) and onion (3), are good hosts that also sustain damage from this nematode, therefore limiting the efficacy of crop rotation for nematode management. No resistance to *M. incognita* exists in any of the *C. annuum* cultivars grown in New Mexico. These factors, along with the 125–135 day growing season for chile peppers, have contributed to reliance on nematicides for management of *M. incognita* in this crop.

Despite its importance to the New Mexico economy, chile pepper acreage in the United States is small, necessitating minor use registration of most pesticides. New Mexico has Special Local Need registrations for granular formulations of carbofuran to control early season insects and fenamiphos to control nematodes in chile peppers. Soil fumigation has been the traditional method of management for *M. incognita* in this crop. Cool soil temperatures and the need for rapid dissipation of the nematicide before planting in mid-March have resulted in common use of 1,3-dichloropropene for soil fumigation. Concerns brought about by the suspension of 1,3-D use in California (1) stimulated efforts to identify application methods likely to reduce the potential for air pollution from this chemical. Information was also lacking on the efficacy of alternative non-fumigant nematicides that can be applied at planting, thereby reducing the number of operations required to establish the crop. This report describes the effects of

Received for publication 28 February 1994.
Supported by the New Mexico Agricultural Experiment Station, DowElanco Chemical Corporation, FMC Chemical Corporation, Miles Incorporated, New Mexico Chile Commission, and USDA Western Regional Pesticide Impact Assessment Program (subcontract #S22738). Mention of a company does not constitute a guarantee of its products by the New Mexico Agricultural Experiment Station or an endorsement over products of other companies not mentioned.
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fenamiphos, carbofuran, and 1,3-D applied at two depths on *M. incognita* numbers and yield and fruit quality of chile peppers.

Materials and Methods

Experiments were conducted during 1986, 1988, 1989, and 1991 at the New Mexico State University Leyendecker Plant Science Research Center in Dona Ana County, New Mexico. The 1986 experiment was located in an Agua loam (49% sand, 32% silt, 19% clay; 0.8% organic matter; pH 7.7) and the remaining three experiments in an Anthony-Vinton fine sandy loam (76% sand, 11% silt, 13% clay; 0.8% organic matter; pH 7.9). Chile pepper was the crop preceding the 1986 and 1989 experiments, whereas the 1988 and 1991 studies were preceded by sorghum (*Sorghum bicolor*) and cotton (*Gossypium hirsutum*), respectively.

Chile peppers (cv. New Mexico 6-4) were seeded at 5.6 kg/ha on raised plant beds with a two-row John Deere Flex-Planter (John Deere Inc., Moline, IL) and grown with furrow irrigation in all experiments. All fumigation with 1,3-D was applied through a single chisel per row with a two-row Reddick Flo-Meter (Reddick Fumigants, Williamston, NC), followed immediately by formation of plant beds, which established the final placement depths of 28 or 48 cm. Granular nematicides were applied with electrically driven granular application units. Fenamiphos was dispersed through 15- or 30-cm banding devices followed by incorporation to 2.5 cm with a mechanical tiller. Carbofuran was placed in the seed furrow at planting and sidedressed 10 cm deep on both sides of the plant bed after chile peppers were thinned.

The 1986 experiment was a randomized complete block with four replications. Each block included an untreated control and four treated plots: 5.7 ml/m of row (56 liter/ha) 1,3-D applied 28 or 48 cm deep in the center of the bed and 0.11 or 0.23 g a. i./m of row (1.1 or 2.2 kg a. i./ha) fenamiphos applied in a 15-cm-wide band over the plant bed. Plots were two rows 1 m apart and 55 m long with 12-m alleys between blocks. The 1,3-D treatments were applied 18 March and fenamiphos on 10 April. All treatments were followed by crop seeding on 10 April. Plots were thinned to five plants/m in late May, and were sidedressed on 2 June with 101 kg/ha 46-0-0 (N-P-K) and treated with 0.17 g a. i./m^2 metolachlor to control weeds. Red chile pepper fruits were harvested from 7.9-m rows in each plot on 13 and 14 October. Root galling was determined for 10 adjacent plants from each plot on 6 January 1987.

The 1988 experiment was a randomized complete block with 10 replications. Each block included an untreated control and three treated plots: 5.7 ml/m of row 1,3-D applied 28 or 48 cm deep and 1.1 g a. i./m of row carbofuran applied in the seed furrow, plus 2.2 g a. i./m of row sidedressed 15 July. Plots were four rows 1 m apart and 15 m long with 3-m alleys between blocks. The 1,3-D treatments were applied 30 March and carbofuran on 26 April as the crop was planted. Plots were sidedressed with 168 kg/ha 46-0-0 (N-P-K) on 16 June and received an additional 75 kg/ha nitrogen in the irrigation water on 22 July. Chile peppers were sprayed with 0.11 g a. i./m of row carbaryl on 3 June for flea beetle (*Epitrix fuscula*) control, and 0.025 g a. i./m^2 sethoxydim was applied on 30 June to reduce grass emergence in plots. Green fruits were harvested from 4.0 m of each of the center two rows of all plots on 9 September, and red chile peppers were harvested from the adjacent 4.0 m of these rows on 10–14 December. Root gall ratings were recorded for 10 plants/plot on 14–15 December.

The 1989 experiment was a randomized complete block with 10 replications. Each block included an untreated control and four treated plots: 5.7 ml/m of row 1,3-D applied 48 cm deep in the fall of 1988 or spring 1989; 0.23 g a. i./m of row fenamiphos applied in a 30-cm band; 0.11 g a. i./m of row carbofuran applied in the seed furrow, plus 0.23 g a. i./m of row sidedressed 13 June. Plot size was the same as in the 1988 experiment. The 1,3-D treatments were applied 7 December 1988 or 22 March 1989. Fenamiphos was applied 4 April and carbofuran on 6 April at the time of planting. Plots were sidedressed with 56 kg/ha 46-0-0 (N-P-K) and 112 kg/ha 0-44-0 (N-P-K) on 5 April and additional nitrogen applied at 56 kg/ha in the irrigation water 12 May, 2 June, 22 June, 24 July, and 17 August. Plots were sprayed with 0.11 g a. i./m of row carbaryl on 9 May for flea beetle control and 0.22 g a. i./m^2 metolachlor plus 0.08 g a. i./m^2 trifluralin was applied on 25 May for weed suppression, followed by crop thinning on 1 June. Green fruits were harvested from 4.0 m of each of the center two rows of all plots on 21–22 August, and red chile peppers were harvested from the adjacent 4.0 m of these rows on 30–31 October. Root gall ratings were recorded for 10 plants/plot on 13 November.

The 1991 experiment was a randomized complete block with six replications. Each block included an untreated control and three treated plots: 5.7 ml/m of row 1,3-D applied 28 or 48 cm deep and 0.23 g a. i./m of row fenamiphos applied in a 30-cm band. Plots consisted of two rows 1 m apart and 12 m long with 3-m alleys between blocks. The field was fertilized with 267 kg/ha 11-50-0 (N-P-K) on 8 March. The 1,3-D treatments were applied 12 March and fenamiphos on 18 March, followed by irrigation 2 days later. Plots were seeded on 1 April and beds capped to preserve soil moisture and enhance germination. The cap was removed 16 days later and plots were irrigated again to stimulate additional seedling emergence. Due to poor plant stands, the field was replanted on 25 April. No bed preparation was performed before replanting to minimize disturbance of treated soil. Supplemental nitrogen was applied at 84 kg/ha in irrigation water on 27 May, 3, 10, 17 and 24 June, and 2, 8, 15 and 29 July. No herbicides or insecticides were applied. Plots were thinned to five plants/m on 5–11 July. Green fruits were harvested from 4.0 m of each row of all plots on 3–4 September and red chile peppers were harvested from the adjacent 4.0 m of these rows on 8 and 11 November.

Population densities of *M. incognita* second-stage juveniles (J2) were determined from 10 soil cores 2.5-cm-d × 30 cm deep collected from the root zone of the pepper plants in all plots 60 and 90 days after pepper emergence in all four experiments. Nematodes were extracted from 500-cm^3 subsamples with a semi-automatic elutriator (2) and sugar flotation (7). In 1989, root systems of five plants were collected from all plots during the thinning process, composited, and *M. incognita* eggs were extracted with NaOCl (6). Numbers of green chile pepper fruit, total fruit fresh weight, length of 20 green fruits (1988), numbers of green fruit longer than 12.4 cm (1989 and 1991), and total dry red fruit weights were recorded for all plots. Nematode numbers and chile pepper yield and quality data were subjected to analysis of variance by the general linear models procedure of SAS (SAS Circle, Cary, NC). Means of significant ($P = 0.05$) treatment effects were separated by Fisher's protected least significant difference test (LSD) at $P = 0.05$.

Results

Nematode control: The numbers of *M. incognita* J2 extracted from soil sampled 60 days after chile pepper emergence were lower ($P = 0.05$) in plots treated with 1,3-D than in untreated plots in all experiments except 1986 (Table 1). Numbers of J2 recovered 90 days after emergence were also unaffected in 1986 and in 1988, but were lower ($P = 0.05$) in 1989 and 1991. No differences in numbers of J2 were observed between the two fumigation depths examined. Numbers of J2 extracted from samples from 1,3-D plots fumigated in fall of 1988 did not differ from those from spring-fumigated plots receiving the same treatment and application depth in the 1989 experiment (data not presented). Numbers of J2 in samples

TABLE 1. Effect of nematicide treatments on soil population densities of *Meloidogyne incognita* associated with chile peppers in Las Cruces, NM, in 1986, 1988, 1989, and 1991.

			M. incognita J2/500 cm^3 soil							
			60 d‡				90 d‡			
Treatment	Rate/ha	Method of application†	1986	1988	1989	1991	1986	1988	1989	1991
Control	0	—	3	117	388	160	81	120	583	915
1,3-D	56 liters	SC 28 cm	6	51	—	15	16	35	—	140
1,3-D	56 liters	SC 48 cm	7	55	50	0	13	58	285	25
Fenamiphos	1.1 kg	BAP 15 cm	16	—	—	—	131	—	—	—
Fenamiphos	2.2 kg	BAP 15 cm	16	—	—	—	28	—	—	—
Fenamiphos	2.2 kg	BAP 30 cm	—	—	212	200	—	—	313	640
Carbofuran	1.1 kg+ 2.2 kg	IFAP SDT	—	113	—	—	—	138	610	—
LSD (P = 0.05)			32	55	91	110	144	86	155	480

† SC = fumigant applied with a single chisel in the center of the plant bed at the depth indicated; BAP = banded at width indicated and incorporated 2.5 cm deep at planting; IFAP = in furrow at planting; SDT = side dressed at thinning 25 cm from the plant on both sides of the bed; dashes (—) in any column indicate absence of the treatment.
‡ Days after chile pepper emergence.

from plots treated with 3.8 ml/m of row 1,3-D at 28 or 48 cm were also no different from those from plots treated with 5.7 ml/m of row during 1991 (data not presented).

The numbers of J2 extracted from samples from plots treated with 0.23 g a. i./m of row fenamiphos applied in a 30-cm band were lower (P = 0.05) than those from control plots at both sampling dates during 1989 only, and were similar to those from 1,3-D plots 90 days after emergence in 1989. Nematode numbers from soil in fenamiphos-treated plots in all other experiments were similar to those in untreated plots. Carbofuran treatment failed to reduce numbers of *M. incognita* J2 extracted in these experiments.

Root galling was least severe (P = 0.05) on chile peppers grown in plots treated with 1,3-D in the three experiments in which roots were rated (Table 2). Galling was more severe (P = 0.05) in plots fumigated at 28 cm during 1986, but no such differences occurred in 1988. The higher rate of fenamiphos was associated with reduced galling (P = 0.05) in 1986, but not in 1989, and no differences in galling were

TABLE 2. Effect of nematicide treatment on *Meloidogyne incognita*-induced root galling and nematode reproduction on chile peppers in Las Cruces, NM, in 1986, 1988, and 1989.

			Gall rating‡			
Treatment	Rate/ha	Method of application†	1986	1988	1989	Eggs/g root§
Control	0	—	4.3	4.4	3.9	25,138
1,3-D	56 liters	SC 28 cm	2.6	3.0	—	—
1,3-D	56 liters	SC 48 cm	1.1	2.7	2.2	2,874
Fenamiphos	1.1 kg	BAP 15 cm	4.2	—	—	—
Fenamiphos	2.2 kg	BAP 15 cm	2.6	—	—	—
Fenamiphos	2.2 kg	BAP 30 cm	—	—	3.5	1,382
Carbofuran	1.1 kg+ 2.2 kg	IFAP SDT	—	3.8	3.9	12,542
LSD (P = 0.05)			1.3	0.7	0.6	17,928

† SC = fumigant applied with a single chisel in the center of the plant bed at the depth indicated; BAP = banded at width indicated and incorporated 2.5 cm deep at planting; IFAP = in furrow at planting; SDT = side dressed at thinning 25 cm from the plant on both sides of the bed; dashes (—) in any column indicate absence of the treatment.
‡ Rated to the scale of 1 = no galling, 2 = <10%, 3 = 11–30%, 4 = 31–70%, 5 = >71% of roots galled.
§ At time of plant thinning in 1989.

observed due to carbofuran treatments. Chile peppers from plots treated with carbofuran, 1,3-D, and fenamiphos produced similar numbers of *M. incognita* eggs on roots at thinning, but only plants from plots treated with 1,3-D or fenamiphos had fewer ($P = 0.05$) eggs than those from control plots (Table 2).

Chile pepper yield and quality: Yields of fresh green chile peppers and dried red fruits were greatest ($P = 0.05$) from all plots treated with 1,3-D in all experiments, except for the 28-cm fumigation depth in 1986 (Table 3). Depth of 1,3-D placement did not affect yields, except for dried red chile peppers in 1988 where 48 cm placement enhanced yield. Plots treated with fenamiphos showed no yield increases over untreated plots, except in 1989 when green chile pepper yields were increased ($P = 0.05$) by this treatment. No yield increases were observed with carbofuran treatment in 1988 or 1989.

Numbers of green chile pepper fruit per m row were always greater ($P = 0.05$) from plots treated with 1,3-D than from those treated with other nematicides or from the control plot (Table 4). Fruit lengths in 1988 and the percentage of marketable fruits (fruit >12.4 cm in length) in 1989 were also greater from plots treated with 1,3-D. Neither fenamiphos nor carbofuran treatment increased the number of green fruits or fruit quality.

Discussion

Control of *M. incognita* and associated yield losses in chile peppers was consistently greatest when soil was treated with 1,3-D in all studies. The lack of measurable differences in nematode populations between fumigated treatments and control plots in 1986 was most likely the result of larger plots and fewer samples (4 replications, compared with 6–10 during other years) (5,11). Differences in yields and root ratings from plots treated with 1,3-D in 1986 were consistent with those from other years. Increasing fumigant placement depth generally did not affect efficacy, although red chile pepper yield was enhanced and root galling suppressed during 1988. A similar lack of effect due to depth of placement was reported when 1,3-D was applied at 25 cm or 51 cm to potato for control of *Meloidogyne chitwoodi* (12).

Crop quality substantially influences the price paid to green chile pepper producers in New Mexico by processors. Inherent fruit characteristics and postharvest han-

Table 3. Effect of nematicide treatments on chile pepper yields at sites infested with *Meloidogyne incognita* in Las Cruces, NM, in 1986, 1988, 1989, and 1991.

			Yield (kg/ha)						
			Dry red				Fresh green		
Treatment	Rate/ha	Method of application†	1986	1988	1989	1991	1988	1989	1991
Control	0	—	1,314	910	814	1,305	647	2,676	4,539
1,3-D	56 liters	SC 28 cm	1,829	1,805	—	2,980	4,890	—	12,353
1,3-D	56 liters	SC 48 cm	2,375	2,498	2,398	3,283	6,543	12,162	12,049
Fenamiphos	1.1 kg	BAP 15 cm	1,383	—	—	—	—	—	—
Fenamiphos	2.2 kg	BAP 15 cm	1,604	—	—	—	—	—	—
Fenamiphos	2.2 kg	BAP 30 cm	—	—	1,670	1,188	—	5,481	5,299
Carbofuran	1.1 kg+	IFAP	—	1,410	1,049		1,664	3,126	—
	2.2 kg	SDT							
			—						
LSD ($P = 0.05$)			980	690	1,041	653	2,780	1,894	2,699

† SC = fumigant applied with a single chisel in the center of the plant bed at the depth indicated; BAP = banded at width indicated and incorporated 2.5 cm deep at planting; IFAP = in furrow at planting; SDT = side dressed at thinning 25 cm from the plant on both sides of the bed; dashes (—) in any column indicate absence of the treatment.

TABLE 4. Effect of nematicide treatment on green chile pepper fruit production and quality at sites infested with *Meloidogyne incognita* in Las Cruces, NM, in 1988, 1989, and 1991.

Treatment	Rate/ha	Method of application†	Fruit/meter of row			Fruit length, 1988 (cm)	% marketable fruit‡	
			1988	1989	1991		1989	1991
Control	0	—	1.7	8.9	10.9	8.3	53.9	44.7
1,3-D	56 liters	SC 28 cm	11.0	—	26.0	12.8	—	54.1
1,3-D	56 liters	SC 48 cm	15.0	31.0	27.6	13.3	67.9	48.6
Fenamiphos	1.1 kg	BAP 15 cm	—	—	—	—	—	—
Fenamiphos	2.2 kg	BAP 15 cm	—	—	—	—	—	—
Fenamiphos	2.2 kg	BAP 30 cm	—	17.0	11.3	—	52.2	39.6
Carbofuran	1.1 kg+ 2.2 kg	IFAP SDT	4.1	10.5	—	10.2	60.3	—
LSD (P = 0.05)			5.2	8.7	6.1	3.3	12.1	16.9

† SC = fumigant applied with a single chisel in the center of the plant bed at the depth indicated; BAP = banded at width indicated and incorporated 2.5 cm deep at planting; IFAP = in furrow at planting; SDT = side dressed at thinning 25 cm from the plant on both sides of the bed; dashes (—) in any column indicate absence of the treatment.

‡ Percentage of fruits >12.4 cm in length.

dling of the crop determine quality. The percentage of marketable fruits (those exceeding 12.4 cm in length) is one characteristic of major importance for proper mechanical processing of whole green chile peppers. Shorter fruits are suitable for chopping only, and bring a lower price. Percentage of premium fruits and its analog (average fruit length) were greater from plots treated with 1,3-D in 1988 and 1989, indicating that *M. incognita* may influence this aspect of crop quality.

Nematode control and yield responses were consistent within experiments for fenamiphos treatments but were variable between studies. For example, yield increases accompanied reductions in *M. incognita* J2 in fenamiphos-treated plots in 1989, whereas similar treatment in 1991 failed to affect either nematode populations or yield. Caution should be exercised when evaluating the 1991 results, however, due to the necessity of replanting these plots. The period separating fenamiphos application and plant establishment was 4 weeks longer during 1991, perhaps reducing the amount of nematicide present in the root zone of pepper seedlings.

Increasing the depth of 1,3-D placement using a single chisel in the center of plant beds has been proposed as a method for reducing unwanted volatilization into the atmosphere (9,14). Results from these experiments with chile peppers indicate that increasing depth of fumigation has no detrimental effects on nematicide efficacy and may sometimes enhance treatments. Although a significant increase in red chile pepper yield occurred with deeper placement of 1,3-D only in 1988, average yields from the other years remained somewhat higher with the deep treatment. The benefit from even a small additional yield under conditions of fixed treatment costs may be of interest to producers of high-value crops. For example, red chile pepper yields were closest between the 28-cm and 48-cm placements of 1,3-D in 1991, when the 10% yield increase with deeper placement translates to additional income of $343/ha.

Fumigation with 1,3-D for management of *M. incognita* in chile peppers provided the greatest and most consistent benefits to producers in these experiments. Fumigation also enhanced fruit quality, which did not occur with either fenamiphos or carbofuran. Deeper placement of 1,3-D may sometimes benefit yield, and may reduce unwanted atmospheric volatilization of the nematicide. Although less reliable than 1,3-D fumigation, soil treatment with fenamiphos may benefit producers by increasing pepper yields. Because this material is applied at planting, it provides flexibility for treatment, which is not permitted with fumigants. Carbofuran was not effective in reducing nematode numbers or increasing pepper yields under the conditions of these experiments.

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