Effect of Foliar Application of Carbofuran and a Related Compound on Plant-parasitic Nematodes under Greenhouse and Growth Chamber Conditions

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Abstract: Greenhouse and growth chamber studies were made to investigate the downward systemic nematicidal activity of carbofuran and its analog 2,3-dihydro-2,2-dimethyl-7-benzofuranyl [(di-n-butyl)-4-aminosulfenyl] carbamate against *Meloidogyne incognita, Tylenchorhynchus claytoni,* and *Pratylenchus penetrans.* Oxamyl was used as standard in tests with *T. claytoni.* Both carbofuran and its analog reduced all three plant-parasitic species when plant foliage was sprayed with chemical suspension of 1,200, 2,400 or 4,800 ppm. The studies show that fewer chemical applications were required to reduce populations of *P. penetrans* than to reduce populations of *T. claytoni.* Oxamyl was somewhat less active than either carbofuran or its analog. *Key words:* nonfumigants, nematicides, *Meloidogyne incognita, Tylenchorhynchus claytoni, Pratylenchus penetrans,* systemic nematicides, oxamyl, carbofuran analog.

Although nonfumigant nematicides are generally less efficient than fumigants, they offer some advantages: They are often less phytotoxic than fumigants and can be applied at planting time. They have greater residual activity than fumigants. Systemic nonfumigant nematicides would be most useful if they would move throughout the plant to act against the plant's nematode parasites. They would be particularly useful if they could be applied to foliage and would move downward. The only chemical extensively tested as a downward systemic nematicide has been oxamyl (4,7). Several nonfumigant nematicides applied around the base of plants move with water through the soil where they affect nematode populations (8). Carbofuran has provided nematode control when applied on the soil surface around banana plants (5). The studies reported here were designed to investigate the downward systemic nematicidal activity of carbofuran and its analog, 2,3-dihydro-2, 2-dimethyl-7-benzofuranyl [(dibutylamino) thio] methylcarbamate (FMC 35001; FMC Corporation, Middleport, NY) under greenhouse and growth chamber conditions.

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MATERIALS AND METHODS

Carbofuran (2,3-dihydro-2,2methyl-7-benzofuranyl methylcarbamate) and FMC 35001 (2,3-dihydro-2,2-dimethyl-7-benzofuranyl [(dibutylamino)thio] methylcarbamate), formulated as 25% wettable powders, were applied to host plants. Oxamyl 2L (S-methyl-1-(dimethyl-carbamoyl)-N-[(methylcarbamoyl)-oxy-thioformimidate]), a known downward moving systemic nematicide, was used as a standard for comparison with the two test chemicals. In all cases treatments were replicated four times.

Plants were grown in steam-sterilized sandy loam soil in 10-cm-d fiber pots and fertilized weekly with water-soluble 15-30-15 fertilizer. Pots were covered with paper discs during foliar treatment to prevent the nematicides from reaching the soil. The covers were removed when the foliage dried. In order to keep the foliage dry, plants were watered with a hose directly in the pot.

M. incognita: Tomato (*Lycopersicon esculentum,* Mill.) cv Heinz 1350 and tobacco (*Nicotiana tobacum,* L.) cv Turkish served as hosts for *Meloidogyne incognita* (Kofoid and White). Tomato plants with four fully expanded leaves were sprayed to run-off with an aqueous suspension of 2,400 or 4,800 ppm a.i. carbofuran or FMC 35001. One, four, and eight days after treatment 50 cm^3 of root-knot nematode infested soil obtained from greenhouse culture (3) was placed around the base of the tomato plants, providing about 1,000 larvae/pot.

In a similar test, tobacco plants at the four-leaf stage were treated one, two, or three times, at weekly intervals, with 2,400 ppm a.i. carbofuran. These plants were similarly inoculated with root-knot nematode infested soil at 5 and 11 d after the first treatment.

In a third experiment, the foliage of tomato plants was treated with carbofuran and FMC 35001 at 2,400 ppm a.i. In this last case the root-knot nematode larvae were put around the plant at 1 and 7 d after treatment.

In all three experiments, plants were harvested 2 wk after the last treatment and the level of control was estimated by the galling index systems based on a scale of 0–4 (3). Galling indices were transformed to fit a range of 0–100% gall reduction. Tests with this nematode were conducted in a greenhouse at 24–28 C.

P. penetrans: Pea (*Pisum sativum,* L.) cv Hundred fold was the host for *Pratylenchus penetrans* ([Cobb] Chitwood and Oteifa). Pea plants, 15 cm tall, were inoculated with about 2,000 specimens of *P. penetrans* extracted from callus tissue (6) and suspended in 5 ml water. The inoculum was poured around the base of the plants after removing some soil; the soil was replaced after the addition of inoculum. Beginning the day after inoculation, applications of 1,200 ppm carbofuran were made at 0, 1, 2, and 3 wk or in another similar experiment at 1, 2, 1+3, and 1+2,+3 wk. Applications at each timing were replicated four times. Forty-five days after the last treatment, the root systems were washed clean under running tap water and nematodes were extracted from the roots by incubation in a mist chamber (2) for 2 wk. The multiple application experiment was repeated. Experiments with this nematode were conducted in a growth room at 21 C with 12 h light of 21,000 lumens/m^2.

T. claytoni: Turkish tobacco and corn (*Zea mays* L.) cv Seneca Chief were the hosts for *Tylenchorhynchus claytoni* (Steiner). Corn plants, 25 cm tall, and tobacco plants at their fourth-leaf stage of growth, both inoculated 10 d earlier with about 2,500 specimens of *T. claytoni* (extracted from callus tissue and suspended in 5 ml water), were sprayed with FMC 35001, carbofuran, and oxamyl at 2,400 ppm. Four plants were treated once and four plants were treated twice, at the beginning of the experiment and 1 wk later. Nematodes were extracted from the soil 40 d after the second treatment. The entire soil and root system of the plants was soaked in a pail of tap water. The root systems were then washed clean with additional tap water. The roots were discarded, and the soil and water collected were combined and processed for nematode recovery by using a sieving and sugar flotation method (1). Tests with this nematode were conducted in a greenhouse at 24–28 C.

In another similar test, carbofuran and oxamyl were sprayed at 1,200 and 2,400 ppm on the foliage of tobacco and corn plants one, two, and three times at weekly intervals. Each spray timing was replicated four times.

Statistical methods: Analysis of variance (ANOVA) was used to partition variance in percent control and square root of percent control for *P. penetrans* and *T. claytoni.* A nonparametric method (Median Test by Chi-square) and ANOVA were used to partition variance in root-knot galling indices. Duncan's multiple range test (DMRT) was used to determine the significance of differences between means.

RESULTS

M. incognita: In all tests, 70–80% of the root system of control plants developed root-knot nematode galls. In the first experiment (Table 1), foliar application of carbofuran reduced the number of galls on tomato roots. The reduction of galls was more evident when the inoculation of *M. incognita* was delayed. The higher rate of carbofuran (4,800 ppm) was superior to the lower rate (2,400 ppm) only when inoculation occurred 8 d after treatment. On tobacco plants one

Table 1. Effect of foliar applications of carbofuran and FMC 35001 on galling from *Meloidogyne incognita* on tomato and tobacco.

Treatment	Rate (ppm)	Host plant	No. of applications	% control* — Time of inoculation in days after treatment: 1	4	5	7	8	11
Experiment 1									
Carbofuran	2,400	Tomato	1	25b	50c			60d	
	4,800	Tomato	1	25b	50c			75e	
Control				0a	0a			0a	
Experiment 2									
Carbofuran	2,400	Tobacco	1			0a			50c
			2			25b			60d
			3			25b			80e
Control						0a			0a
Experiment 3									
Carbofuran	2,400	Tomato	1	50b			75d		
FMC 35001	2,400	Tomato	1	0a			60c		
Control				0a			0a		

*Control based on galling index of 0-4; 0 = complete control (100%); 4 = no control (0%). Mean of four replicates. Means not followed by the same letter are significantly different at the 1% level.

application of carbofuran did not reduce the number of galls when inoculation occurred 5 d after treatment. On the other hand, 50% control was obtained when inoculations occurred 11 d after treatment. Multiple applications were more effective than single applications. In the last experiment, foliar application of carbofuran and FMC 35001 reduced galls on tomato roots. FMC 35001 did not prevent infection when inoculations occurred 1 d after treatment, but it reduced gall formation by 60% when inoculations were delayed by 7 d.

P. penetrans: All treatments reduced the number of *P. penetrans* recovered from pea roots, except the single foliar applications of carbofuran at the beginning of the experiment or 3 wk later (Table 2). One foliar application of carbofuran 1 or 2 wk after inoculation reduced the populations of *P. penetrans* to the same extent as did multiple applications. When this experiment was repeated similar results were obtained.

T. claytoni: FMC 35001, carbofuran, and oxamyl at 2,400 ppm reduced the number of *T. claytoni* in soil in which corn and tobacco plants were grown (Table 3). Two applications were superior to a single application. All treatments, except a single application of oxamyl on corn, are significantly different from the control at the 1% level. Oxamyl was less active than FMC 35001 or carbofuran.

Table 2. Control of *Pratylenchus penetrans* on peas 45 d after last treatment with foliar applications of carbofuran at 1,200 ppm.

Treatment	Time of application (weeks)	% control*
Carbofuran	0†	81 ab
	1	82 b
	2	81 b
	3	84 ab
	0+1	95 b
	0+2	97 b
	0+1+3	95 b
	0+1+2+3	91 b
Control		0 a

*Mean of four replicates. Means not followed by the same letter are significantly different at the 5% level.

†Indicates the first chemical application at the beginning of the experiment.

Three foliar applications of carbofuran at 2,400 ppm on corn and tobacco provided the highest percentage control of *T. claytoni* (Table 4). Oxamyl with the same number of treatments was equal to carbofuran on tobacco, but it was inferior on corn. In all cases, the control obtained at 1,200 ppm was significantly lower than that at 2,400 ppm.

Table 3. Control of *Tylenchorhynchus claytoni* on corn and tobacco 40 d after the second treatment with three nematicides applied as foliar spray at the rate of 2,400 ppm.

Treatment	No. of applications*	% control† Corn	% control† Tobacco
FMC 35001	1	89 de	83 cd
	2	97 e	88 d
Carbofuran	1	86 cd	81 c
	2	97 e	85 cd
Oxamyl	1	36 ab	72 b
	2	75 bc	80 bc
Control		0 a	0 a

*Second applications were made 7 d after the first application.

†Mean of four replicates. Means not followed by the same letter are significantly different at the 1% level.

DISCUSSION

The results from the experiments with *M. incognita* indicate that the degree of nematode control with foliar sprays of carbofuran increased when inoculations were delayed. The optimum time was not determined, but it is at least 11 d after treatment. Longer periods have not been examined. This time is likely to be influenced by the host plant. One foliar application of carbofuran reduced the galls on the roots of tomato plants when inoculations occurred 1 d after treatment in the first and third experiment. No reduction in root galls was found when tobacco plants were used and inoculation was delayed 5 d. It is possible that absorption and translocation of chemical is different for different plant species.

Table 4. Control of *Tylenchorhynchus claytoni* on corn and tobacco 40 d after last treatment with foliar applications of carbofuran and oxamyl.

Treatment	Rate (ppm)	Time of application*	% control† Corn	% control† Tobacco
Carbofuran	2,400	0‡	74 a-d	96 e
		0+1	95 de	97 e
		0+1+2	96 e	99 f
	1,200	0	56 a-e	78 bc
		0+1	91 de	91 cde
		0+1+2	91 cde	95 cde
Oxamyl	2,400	0	57 abc	91 cde
		0+1	90 de	95 de
		0+1+2	83 b-e	98 e
	1,200	0	0 a	82 bcd
		0+1	78 a-e	63 ab
		0+1+2	83 cde	81 bcd
Control			0 a	0 a

*Multiple applications applied at weekly intervals.

†Mean of four replicates. Means not followed by the same letter are significantly different at 1% level.

‡Indicates the first chemical application at the beginning of the experiment.

The nematicidal action of FMC 35001 was slower than that of carbofuran, probably because FMC 35001 must decompose to carbofuran before it is active. Carbofuran was less active against the root-knot nematode on tomato in the first experiment than in the third one (Table 1). We think that systemic translocation of carbofuran may be affected by the stage of growth of the plant and by environmental conditions. Since control was based on nematode symptoms, we do not know whether nematodes were affected after the infection had been initiated. Studies to elucidate this are in progress.

The studies with *P. penetrans* and *T. claytoni* indicate that multiple applications of carbofuran are not always justified. There is an indication that multiple applications were more beneficial in reducing populations of *T. claytoni* than in reducing populations of *P. penetrans*. It is possible that the ectoparasitic, *T. claytoni*, may be affected either by the chemical at the root surface or by toxicants exuded by the roots into the soil.

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