Effect of Foliar Applications of Carbofuran and a Related Compound on Plant-parasitic Nematodes under Microplot and Field Conditions

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Abstract: Studies were conducted to investigate the basipetal translocation of nematicidal activity from foliar treatments of carbofuran and its analog, 2,3-dihydro-2,2-dimethyl-7-benzofuranyl ([dibutylamino]thio)methyl carbamate, on corn in microplot studies and on tobacco and potato in field trials. Two and three foliar applications of either product at 2,400 μg/ml (2–20 Kg ai/Ha) significantly reduced populations of *Pratylenchus penetrans* in roots and populations of *Tylenchorhynchus claytoni, Xiphinema americanum,* and *Hoplolaimus* sp. in soil. In most cases there was no difference in control between two or three chemical applications. Foliar treatments with carbofuran were equivalent to, or better than, soil treatment, although rates of applications were different. *Key words:* chemical control, systemic, corn, tobacco, potato, carbofuran analog.
Journal of Nematology 14(2):208-212. 1982.

The concept of controlling plant parasitic nematodes with translocable compounds in plants is not new, and there is general agreement on the advantage of a systemic nematicide. Nematodes can be affected by systemic compounds which are absorbed either by the roots or by the foliage and then translocated to other parts of the plants. Nonfumigant nematicides mostly act in soil or are absorbed by the roots. Some chemicals, however, are known to be absorbed by the leaves and translocated to the roots. Basipetally translocable compounds are advantageous. The rate of foliar application of pesticide is often lower than the effective rate of soil application, because the chemical is not subjected to soil factors which influence the fate of the pesticide. All nonfumigant nematicides are dependent on soil water for their mobility through soil and under low moisture condition the compound may not be available to the nematode or to the plant. On the other hand, excessive precipitation may cause leaching of certain chemicals below the root zones, leaving the plant unprotected.

The progress toward the discovery of downward systemic nematicides has been slow and beset with problems such as the mechanisms of phloem transport, adsorption by leaf tissues, and physical barriers to adsorption. Peacock (9) reviewed compounds known to move in plants and from which systemic nematicides could be synthesized. Interest in downward systemic nematicides was renewed when Radewald et al. (12) reported that foliar application of oxamyl on several plant species reduced populations of *Meloidogyne incognita* (Kofoid and White) Chitwood and *Pratylenchus scribneri* Steiner in roots. Other studies confirmed this report (5,6,10,13) and indicated that foliar applications of phenamiphos retarded infection of sugarbeets by *Heterodera schachtii* Schmidt under greenhouse conditions (6). Recently, greenhouse and growth chamber studies indicated that foliar applications of carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) and its analog FMC 35001 (2,3-dihydro-2,2-dimethyl-7-benzofuranyl [(dibutylamino)thio]methylcarbamate), possessed downward systemic nematicidal properties against *Meloidogyne incognita, Pratylenchus penetrans,* and *Tylenchorhynchus claytoni,* infecting tomato, corn, and pea plants (4). The studies reported here were designed to further explore the downward systemic properties of carbofuran and FMC 35001 under microplot and field conditions.

MATERIALS AND METHODS

Carbofuran, formulated as 43% flowable liquid, and FMC 35001, formulated as 25% emulsifiable concentrate, were applied at 2.4 mg ai/ml with a hand sprayer. Carbofuran, formulated as 10% granules and applied at 20 kg ai/ha, was used as soil treatment; it was applied to the microplots with a salt shaker and incorporated into the top

Received for publication 12 June 1981.
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The author acknowledges the technical assistance of Russell Savage.

5 cm of soil with hand tools. During treatment, care was exercised to cover most of the foliage with the spray mixture and to prevent or to reduce to a minimum the chemical reaching the soil. The ground was not covered during treatment. Plants growing under microplot conditions were watered the day before treatment. The field treatments were made when the soil was moist. Treatments were replicated four times. Plant foliage was always treated on mornings of mostly sunny days. No precipitation occurred for a period of at least 48 h after treatment. Foliar treatments were repeated once or twice.

Microplot studies: Microplot units, 60 × 60 cm, were filled with sandy-loam soil naturally infested with a population of *Pratylenchus penetrans* (Cobb) Chitwood and Oteifa, *Xiphinema americanum* (Cobb 1913), *Tylenchorhynchus claytoni* (Steiner), *Helicotylenchus* sp. and *Hoplolaimus* sp. The initial nematode population was increased by further adding 5,000 specimens of *P. penetrans* and *T. claytoni* extracted from callus culture (8) by means of a mist chamber technique (2) and by planting plots to corn for 2 yr prior to the experiment. Experiments were initiated on the third year when the preplant soil nematode populations of the microplots, as revealed by the sugar flotation method (3), averaged about 200 *P. penetrans,* 100 *T. claytoni,* 60 *Helicotylenchus,* 40 *Hoplolaimus,* and 10 *X. americanum* specimens/100 cm^3 of soil. Two 10-cm tall corn seedlings, *Zea mays* L., grown in greenhouse in 7.5-cm-d fiber pots, were transplanted into each microplot unit on 4 June. Foliar sprays of carbofuran, formulated as 43% flowable liquid, and FMC 35001, formulated as a 25% emulsifiable concentrate, were adjusted to a concentration of 2.4 mg ai/ml and applied three times with a hand sprayer. The first application (100 ml) was made when transplants were 35–40 cm tall (22 days after transplanting); the next application (250 ml) was made when the transplants were 50 cm tall (35 days after transplanting); the last application (300 ml) was made at tasseling (44 days after transplanting). Soil incorporated carbofuran, formulated as 10% granules, was applied to the soil surface at the rate of 20 kg ai/ha, and worked into the top 5 cm of soil with hand tools. It was applied at the time of planting. The quantity of spray material used during the first, second, and third treatment for each replicate was 100, 250, and 300 ml, respectively.

Harvesting: Rhizosphere root samples were collected for nematode analysis on 7 August. Aliquants of 5 g of roots were washed under running tap water and the nematodes extracted by the mist chamber technique (2). Aliquants of 200 ml soil were processed for nematode recovery by a combination of sieving and sugar flotation methods (3).

Field studies: An area of loam soil uncultivated for at least 12 yr and infested with *Pratylenchus penetrans, Helicotylenchus* sp., and *Hoplolaimus* sp. was plowed and disced. A 15- × 110-m experimental site was planted on 23 May with seed potatoes, *Solanum tuberosum* L. 'Katahdin,' in rows 1 m apart. Carbofuran, formulated as 10% granules, was applied at the rate of 3 kg ai/ha in the furrow of every other row at the time of the planting.

A second experimental area, 15 × 110 m, was planted to tobacco (*Nicotiana tabacum* L. 'Turkish') transplanted on 21 June. The tobacco seedlings were grown in 7.5-cm-d pots in a greenhouse until they reached the fourth-leaf stage of growth; they were transplanted into rows 120 cm apart. There were nine plants for each replicate. Before transplanting carbofuran granules were spread on the soil surface in a 20-cm wide band at the rate of 20 kg ai/ha and incorporated to the depth of 5 cm with a rototiller.

A randomized block design was used for both the potato and tobacco experiments. Each replicate consisted of a 7-m row.

Foliar sprays of carbofuran and FMC 35001 were applied as described for the microplots. The first application (600 ml) was made when the potatoes were 25 cm tall (43 days after sowing) and the tobacco plants were at the eight-leaf stage (15 days after transplanting); the next application (900 ml) was made when the potatoes were 45 cm tall (53 days after sowing) and the tobacco plants were at the tenth-leaf stage (25 days after transplanting); the last application (1400 ml) was made when the potatoes were 60 cm tall (64 days after sowing) and the tobacco plants were 100 cm tall (36 days after transplanting).

Soil and root samples for nematode analysis were collected on 4 September from the tobacco experiment and on 14 September from the potato experiment. Two samples were collected from each replicate row and combined. Each root and soil sample was processed for nematode analysis as previously described.

Statistical methods: Analysis of variance (ANOVA) was used to partition variance in percent control and square roots of percent control for all nematodes recovered. Duncan's multiple-range test (DMRT) was used to determine the significance of differences between means.

RESULTS

Both carbofuran and FMC 35001 reduced the populations of *P. penetrans, X. americanum, T. claytoni,* and *X. americanum* on corn in the microplot studies (Table 1). Soil and foliar carbofuran treatments were equally effective against *P. penetrans* and *T. claytoni.* Carbofuran soil treatment, however, was less effective than foliar sprays in reducing the populations of *X. americanum.*

All chemicals reduced nematode populations (except for *Helicotylenchus* sp.) on potatoes in field trials (Table 2). Carbofuran soil treatment was less effective than foliar treatment in reducing *P. penetrans* populations in potato roots. Three foliar applications of carbofuran were also superior to the carbofuran soil treatment against *T. claytoni* and *Hoplolaimus* sp. Similar results were obtained with two foliar applications of either carbofuran or FMC 35001. The third foliar treatment increased the activity of carbofuran, but not that of FMC 35001.

The only plant-parasitic nematode that was abundant at the end of the tobacco experiment was *P. penetrans,* and all treatments were equally effective in protecting the plants (Table 3). In all cases, only populations of *P. penetrans* per gram of roots are reported, because at the time of sampling only a few speciments of *P. penetrans* were recovered from soil.

DISCUSSION

The results reported herein indicate that nematode populations can be reduced with foliar treatments of carbofuran or FMC 35001 under microplot and field conditions. Although the soil was not covered during spraying, the amount of chemical dripping from the leaves onto the soil was negligible. The control observed was achieved by the translocation of the products used or their metabolites directly or in association with root exudates. The control obtained varied with the susceptibility of nematode species and their mode of parasitism; *P. penetrans* appeared to be most susceptible to foliar

Table 1. Numbers of nematodes of several species recovered from soil and corn root after treatment with carbofuran and FMC 35001* under microplot conditions.

		Mean†			
		Nematode species			
Treatment‡	No. of applications	*Pratylenchus*/ g root	*Tylenchorhynchus*/ 200 cm³ soil	*Helicocotylenchus*/ 200 cm³ soil	*Xiphinema*/ 200 cm³ soil
Control		10340 a	236 a	77 a	38 a
FMC 35001	2	1742 b	3 b	12 a	3 bc
	3	1080 b	22 b	17 a	3 bc
Carbofuran	2	1585 b	38 b	17 a	2 c
	3	1063 b	25 b	16 a	0 c
Carbofuran (10G)§	1	893 b	26 b	20 a	12 b

*2,3-dihydro-2,2-dimethyl-7-benzofuranyl ([dibutylamino]thio) methylcarbamate.

†Values are means of four replicates. Column means followed by common letters are not different according to Duncan's multiple-range test ($P = 0.01$).

‡Spray suspension of 2,400 μg/ml (350–650 ml) used.

§Applied to soil at the rate of 20 kg ai/ha.

Table 2. Numbers of nematodes recovered from soil and potato root after treatment with carbofuran and FMC 35001.*

Treatment‡	No. of treatments	Mean† Nematode density at harvest *Pratylenchus*/g root	*Tylenchorhynchus*/200 cm³ soil	*Helicotylenchus*/200 cm³ soil	*Hoplolaimus*/200 cm³ soil
Control		3415 a	405 a	183 a	122 a
FMC 35001	2	211 c	101 bc	71 a	9 c
	3	278 c	117 bc	95 a	27 bc
Carbofuran	2	106 c	71 bc	24 a	9 bc
	3	135 c	65 c	22 a	4 c
Carbofuran (10G)§	1	1731 b	178 b	63 a	41 ab

*2,3-dihydro-2,2-dimethyl-7-benzofuranyl ([dibutylaminol]thio) methylcarbamate.
†Values are means of four replicates. Column means followed by common letters are not different according to Duncan's multiple-range test ($P = 0.01$).
‡Spray suspension of 2,400 μg/ml (1.5–2.9 liters) per 7-m row used.
§Applied to soil at the rate of 3 kg ai/ha.

treatments. This phenomenon may be related to the endoparasitic nature of the nematode. Endoparasitic species have greater contact with plant cells than do ectoparasitic nematodes. On the other hand, *X. americanum* and *Helicotylenchus* sp., both ectoparasitic species, were not equally affected by the treatments in the microplot experiment and consequently species susceptibility may also be important. Control of nematodes may also depend on the ability of host plants to absorb, translocate, and metabolize toxicants differently. In fact, three foliar sprays of carbofuran were better than two spray applications in reducing populations of *T. claytoni* when corn was used as host. In the tobacco experiment, however, there was no difference between two and three foliar treatments.

Table 3. Numbers of *Pratylenchus penetrans* recovered from tobacco root after treatment with Carbofuran and FMC 35001* under field conditions.

Treatment‡	No. of treatments	Mean *Pratylenchus*†/g roots
Control		742 a
FMC 35001	2	157 b
	3	80 b
Carbofuran	2	188 b
	3	120 b
Carbofuran (10G)§	1	102 b

*2,3-dihydro-2,2-dimethyl-7-benzofuranyl ([dibutylamino]thio) methylcarbamate.
†Values are means of four replicates. Column means followed by common letters are not different according to Duncan's multiple-range test ($P = 0.01$).
‡Chemical suspension of 2,400 μg/ml (1.5–2.9 liters) per 7-m row used.
§Applied to soil at the rate of 20 kg ai/ha.

Foliar applications were made when the soil was moist and on mornings of mostly sunny days in order to increase chemical penetration through stomata of turgid leaves and to promote translocation through photosynthesis. It remains to be demonstrated to what extent environmental conditions affect this translocation. Another question to be answered concerns the economics of their application. The amount of active ingredient of chemical per hectare used in our studies for two foliar applications translates to 20 kg for corn, 8 kg for potato and 2 kg for tobacco. Soil treatments were included as control, and the rates were different than those used for foliar applications.

As research in plant chemotherapy continues, problems now preventing the use of downward systemic nematicides may be resolved. Only a small amount of chemical applied to the foliage of the plants penetrates and is translocated in plants (15). New formulation may improve leaf penetration, although so far this has not been the case with oxamyl (7). Current research shows also interest in investigating other factors responsible for uptake of pesticide by foliage such as cuticle penetration, movement within plants, and formulation (1,11,14).

Nematode control with three foliar applications of carbofuran or FMC 35001 generally was no better than that achieved with two applications. Perhaps better formulations and single applications as well as multiple applications of lower concentrations of these chemicals should now be investigated.

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