Nonfumigant Nematicides for Control of Root-knot Nematode to Protect Carrot Root Growth in Organic Soils[1]

T. C. VRAIN, G. BELAIR, and P. MARTEL[2]

Abstract: Greenhouse tests were conducted to determine the effects of two kinds of *Meloidogyne hapla* inoculum on the growth and quality of carrot roots, and the protection afforded in each case by nonfumigant nematicides in organic soils. For all treatments the percentage of carrots damaged was greater with larvae alone as inoculum than with larvae and eggs, indicating that most of the damage occurs early during formation of the taproot. Fosthietan, aldicarb, and oxamyl at 4 and 6 kg ai/ha protected the roots during formation and gave a lasting control of root-knot nematode. There was some nematode damage to the roots with phenamiphos and carbofuran at 4 and 6 kg ai/ha. Isazophos, diflubenzuron, and fenvalerate gave little protection to carrot roots and did not control root-knot nematode effectively. *Key Words: Meloidogyne hapla,* fosthietan, aldicarb, oxamyl, carbofuran, phenamiphos, isazophos, fenvalerate, diflubenzuron, chemical control.

Because of their light texture, high moisture-holding capacity, and high available nitrogen content, the organic peat and muck soils of Canada and the eastern United States are an ideal substrate for root crops such as carrots. These soils are commonly infested with root-knot nematodes, and carrot yield losses can be extremely high even with low initial nematode densities (2, 10, 11, 15). Because highly organic soils adsorb or inactivate pesticides to a great extent (1, 5, 16) the doses of nematicides required for control are higher than in sandy soils, and the cost of fumigation is often prohibitive. Field trials of fumigant and nonfumigant nematicides in Quebec indicated that at relatively low initial nematode population densities nonfumigant nematicides performed as well as fumigant nematicides (unpublished data). Previous observations and studies (11) have shown that early

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[1] Contribution No. J.745 of the Research Station, Agriculture Canada, St. Jean, Quebec.

[2] Research Station, St. Jean, CP 457, P.Q., Canada J3B 6Z8. Current address of senior author: Agriculture Canada Research Station, 6660 N.W. Marine Drive, Vancouver, B.C., Canada V6T 1X2.

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planting of carrot results in less damage to the taproot by root-knot nematode in organic soils. This practice allows the taproot to form before nematode activity is maximum, thereby reducing the effective initial population density.

In Canada, however, most carrots are sown late in the spring. These are to be harvested as late as possible in the fall for storage to ensure a continuous supply during winter and the next spring.

This study evaluated several nematicides at various rates in the greenhouse, to determine their ability to prevent invasion and deformation of carrot roots grown in organic soils infested with two different kinds of primary inoculum.

MATERIALS AND METHODS

Two greenhouse experiments were conducted successively at St. Jean, Quebec. A fibrisol, with pH 5.6–5.8, 43.4% carbon, 2.5% nitrogen, and 18% mineral matter, was steam-sterilized and then aerated for 4 weeks before use. The chemicals tested were: 1) three organophosphate compounds, isazophos 20G, fosthietan 15G, and phenamiphos 15G; 2) a synthetic pyrethroid, fenvalerate 30EC; 3) three carbamates, carbofuran 10G, aldicarb 15G, and oxamyl 10G; and 4) a benzoyl phenyl urea which is a chitin synthesis inhibitor, diflubenzuron 25WP. The chemicals used in each experiment and the rate applied are shown in Table 1, 2, and 3. Inoculum of *Meloidogyne hapla* Chitwood was from a greenhouse culture on tomato, *Lycopersicon esculentum* cv. Rutgers. In the first experiment, it consisted of 2,000 freshly hatched second-stage larvae per liter of soil (14). In the second experiment, it was a mixture of 800 larvae and

TABLE 1. Effect of nonfumigant nematicides on carrot root growth in root-knot-nematode-infested organic soil.

Treatment	Rate (kg ai/ha)	Root length (mm)[x]		Root weight (g)	
		Expt. 1	Expt. 2	Expt. 1	Expt. 2
Uninfested control		108.9 lm	102.5 klm	15.3 cde	16.5 c-f
Infested control		16.3 ab	49.7 c-g	4.0 a	17.6 c-f
Fosthietan 15G	2	45.8 b-f	73.1 f-k	10.5 a-d	18.4 c-f
	4	87.5 h-m	79.7 f-m	11.0 a-e	11.4 a-e
	6	93.8 j-m		12.7 a-e	
Aldicarb 15G	2	74.6 f-k	76.3 f-l	19.9 c-f	12.8 a-e
	4	93.4 j-m	111.4 m	17.4 c-f	25.9 f
	6	56.3 d-h		12.7 a-e	
Oxamyl 10G	2	31.7 a-e	91.9 i-m	11.0 a-e	17.8 c-f
	4	64.2 d-j	88.2 h-m	9.9 abc	14.8 b-e
	6	89.2 h-m		14.3 b-e	
Carbofuran 10G	2	29.2 a-d		13.1 a-e	
	4	46.5 b-f	101.1 klm	10.4 abc	21.2 ef
	6	76.3 f-l	83.4 g-m	18.0 c-f	15.8 c-f
Phenamiphos 15G	2	38.8 a-e		13.9 a-e	
	4	38.9 a-e	74.5 g-k	14.4 b-e	11.8 a-e
	6	63.6 d-j	89.1 h-m	17.9 c-f	14.0 b-e
Isazophos 20G	4	9.8 a		5.0 ab	
	6	20.9 abc		5.0 ab	
Diflubenzuron 25WP	0.2		57.4 d-i		21.0 def
	0.6		55.6 d-h		17.6 c-f
	1.2		66.1 e-j		15.2 b-e
Fenvalerate 30E	0.3		63.0 d-j		15.2 cde
	1.5		55.5 d-h		15.9 c-f
	6		52.6 c-g		15.5 cde

[x]Length of tuberized portion or length from the crown to the nearest bifurcation or gall. Means followed by a common letter do not vary significantly by Duncan's new multiple-range test (P = 0.05).

1,500 free eggs per liter of soil (7). All chemicals were applied at the highest rate to uninfested soil to determine their phytotoxicity.

A commercial fertilizer, 6-12-24, was added to the soil at 0.2 g/L. The nematode inoculum, fertilizer, nematicides tested, and soil were mixed thoroughly in a cement mixer. For each of the four replicates per treatment, 10 liters of soil were placed in plastic containers (20 × 27 × 27 cm) and 30 carrot seeds (*Daucus carota* L.) cv. Goldpack were sown. The containers were placed in a randomized complete block design in a greenhouse where the temperature fluctuated between 15 and 28 C during the two experiments. After 7 days the seedlings were thinned to 12 per pot. After 90 days the soil was sampled by taking five 2.5-cm-diam cores, and a 100-cm^3 aliquant for each container was extracted by the Baermann pan method. Densities of *Meloidogyne hapla* second-stage larvae in the soil, or hatched from egg masses in the soil during the 7 days' extraction, and saprophytic nematode densities were recorded. All nematode data were subjected to a log (X + 1) transformation before statistical analysis; untransformed means are presented in the tables. Measurements of carrot growth and nematode damage included: individual fresh weight of roots and foliage, length of tuberized portion of roots, or length from the crown to the nearest bifurcation or gall when the root was forked or galled. The carrot roots were indexed for each of two kinds of nematode-induced deformation: ramification (hairy roots) and galling of primary or secondary roots. Each index had values between 1 (no damage) and 4 (extreme damage).

The effect of the soil chemical treatments on carrot length and weight, leaf weight, two index values, root-knot nematode densities, and total nematode densities at harvest were analysed for statistical significance by analysis of variance (ANOVA), and the treatment means were compared by Duncan's multiple-range test. After the ANOVA, treatment means for index values of galling and forking were transformed to fit a range of 0 to 100, making it easier to compare with the percentage of forked carrots.

RESULTS AND DISCUSSION

When the carrot seeds germinated and the tap root started to form, the different types of nematode inoculum used in the two experiments gave rise to different levels of damage to the carrots. In nematode-infested control pots without chemicals the root length and weight were greater in the second experiment than in the first. However, the severity of forking and galling was not different between the two experiments, and the roots were less ramified in the second experiment than in the first experiment (Tables 1 and 2).

The freshly hatched larvae mixed in the soil were ready to invade the root of the germinating carrots as they elongated, simulating a field situation where carrots would be sown very late in the spring, when the soil is warm and most of the larvae have hatched. The mixture of larvae and NaOCl-extracted eggs simulated a field situation where carrots would be sown early in the spring, when the soil is still cold and a large percentage of the eggs are still developing.

The first experiment was conducted in the fall and winter at a greenhouse temperature fluctuating between 15 and 20 C. Root-knot nematode final densities in inoculated control pots of Experiment 1 are rather low (Table 3) considering the initial inoculum of 2,000 larvae per liter of soil. In preliminary tests, however, the efficiency of the Baermann pan and other extraction methods for root-knot nematode in muck soil was found to be between 10 and 20%. Moreover, *Meloidogyne hapla* is known to develop and reproduce slowly at temperatures below 20 C (13). In the second experiment, done in the winter and spring, the greenhouse temperature fluctuated between 15 and 20 C for the first two months and between 17 and 28 C in the third month. These differences in temperature between the two experiments had no noticeable effect on the growth of the carrots, as shown by their length and weight in the uninoculated control pots of both experiments (Table 1). The higher temperature in the latter part of the second experiment allowed for a very high rate of nematode multiplication (Table 3), but this did not result in a significant reduction in carrot root weight (Table 1).

TABLE 2. Effect of nonfumigant nematicides on carrot root damage in root-knot-nematode-infested organic soil.

Treatment	Rate (kg ai/ha)	% forked		Gall index[x]		Ramification index[x]	
		Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1	Expt. 2
Uninfested control		0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
Infested control		95.0 j	79.3 ij	95.8 p	91.6 op	95.8 k	69.4 j
Fosthietan 15G	2	41.7 d-h	34.1 b-f	57.7 g-l	68.8 j-n	27.2 e-i	39.1 a-f
	4	2.3 ab	0.0 a	1.3 ab	34.7 d-g	2.2 a	7.5 ab
	6	0.0 a		4.5 abc		1.4 a	
Aldicarb 15G	2	27.3 a-e	8.9 abc	49.4 g-k	68.8 k-o	21.7 a-e	21.3 a-e
	4	18.6 a-d	4.2 ab	24.1 cde	41.5 e-h	11.1 a-d	5.3 ab
	6	28.9 a-d		20.1 bcd		2.2 a	
Oxamyl 10G	2	64.3 f-j	0.0 a	82.5 m-p	62.3 h-n	37.9 e-i	23.7 a-e
	4	6.0 abc	0.0 a	38.6 d-g	38.7 d-g	3.4 a	3.8 a
	6	7.0 abc		26.0 c-f		5.1 ab	
Carbofuran 10G	2	67.2 g-j		82.0 m-p		70.9 jk	
	4	38.4 c-h	4.2 ab	64.2 i-n	47.6 g-j	33.9 c-h	8.1 ab
	6	26.0 a-e	11.8 a-d	21.4 a-d	45.3 f-i	14.2 a-e	8.9 abc
Phenamiphos 15G	2	64.2 f-j		80.4 m-p		53.5 g-j	
	4	74.0 ij	6.6 abc	82.1 nop	60.2 h-n	63.3 j	4.7 ab
	6	50.8 e-i	2.8 ab	76.1 l-p	38.6 d-g	34.8 d-h	4.4 a
Isazophos 20G	4	76.4 ij		91.8 op		71.0 jk	
	6	68.2 g-j		90:9 op		70.3 jk	
Diflubenzuron 25WP	0.2		70.4 g-j		91.8 op		59.9 hij
	0.6		71.4 hij		92.4 p		61.2 ij
	1.2		16.7 a-d		73.8 l-p		37.7 e-i
Fenvalerate 30E	0.3		30.0 a-e		81.9 nop		32.3 b-g
	1.5		52.0 e-i		84.7 nop		52.2 g-j
	6		66.0 g-j		82.6 nop		49.9 f-j

[x]Index values transformed to fit in a range of 0 to 100. Means followed by a common letter are not significantly different by Duncan's new multiple-range test (P = 0.05).

Fosthietan, oxamyl, and aldicarb gave a significant protection of carrots at doses of 4 and 6 kg ai/ha (Tables 1, 2). The quality of protection did not seem to have been affected by the kind of nematode inoculum used. The nematode mobility or infectivity was probably lowered considerably by treatment (3, 4, 6, 8) soon after sowing, so that very little forking occurred. Control was prolonged since the final nematode population densities at harvest were very low compared with densities in control pots which did not receive any chemical (Table 3). The dose of 2 kg ai/ha appeared in many cases to have been insufficient to protect the carrots or control the nematodes.

Carbofuran and phenamiphos at 4 kg ai/ha gave a better protection of carrot roots in the second experiment than in the first experiment (Tables 1, 2). A greater percentage of carrots were forked when larvae alone were used as inoculum than when larvae and eggs were used. This may indicate that despite thorough chemical admixture, several days were required for the chemical to diffuse, allowing many larvae to reach roots before they could be affected. The movement of a pesticide in a soil is limited by the extent to which it is adsorbed in the soil. With most chemicals, organic matter is responsible for most of the adsorptive capacity of the soil (5, 16). The diffusion of nonfumigant nematicides is determined by the proportion of chemical that remains in the soil water. The proportion of phenamiphos in soil water has been found to be considerably lower than that of other nonfumigants, such as oxamyl or

TABLE 3. Effect of nonfumigant nematicides on root-knot and saprophytic nematodes in organic soils.

Treatment	Rate (kg ai/ha)	*M. hapla* final density (number/1 of soil)		% control[x]		Total nematodes (number/1 of soil)[y]
		Expt. 1	Expt. 2	Expt. 1	Expt. 2	Expt. 1
Infested control		320 ab	13317 a	0.0	0.0	14645 a-e
Fosthietan 15G	2	17 cde	1362 c-f	95.5	90.0	11150 c-f
	4	7 de	572 efg	97.7	95.9	6365 e-f
	6	0 e		100.0		3900 f
Aldicarb 15G	2	12 cde	797 c-f	96.1	94.0	15550 a-e
	4	27 cde	312.5 fg	91.4	97.7	11426 b-f
	6	0 e		100.0		6235 ef
Oxamyl 10G	2	52 bcd	5217 abc	83.6	60.9	16857 a-e
	4	7 de	115 g	97.7	99.2	8128 def
	6	5 de		98.5		13173 b-f
Carbofuran 10G	2	127 bc		60.4		13505 b-f
	4	32 bcd	2062 b-e	89.9	84.6	9856 c-f
	6	22 cde	985 c-f	93.0	92.7	12153 b-f
Phenamiphos 15G	2	305 ab		4.7		53690 a
	4	205 ab	1640 b-e	46.0	87.8	35147 abc
	6	35 bcd	347 efg	89.1	97.4	22500 a-e
Isazophos 20G	4	237 ab		26.0		14018 b-f
	6	765 a		0.0		25252 a-d
Diflubenzuron 25WP	0.2		8462 ab		46.6	
	0.6		20125 a		0.0	
	1.2		13422 a		0.0	
Fenvalerate 30E	0.3		8645 ab		46.3	
	1.5		7012 abc		47.5	
	6		3420 a-d		74.4	

[x]% control expressed as mean nematode density of each treatment × 100/mean nematode density of control pots. Means followed by common letter do not vary significantly by Duncan's new multiple-range test (P = 0.05).

[y]Total nematode density includes root-knot nematodes.

aldicarb sulphone and aldicarb sulphoxide (1), giving the latter products a greater mobility in soil than phenamiphos.

Isazophos, diflubenzuron, and fenvalerate were tested only once. Isazophos has been found fairly selective in its action against different nematode genera (9). Diflubenzuron, a chitin-synthesis inhibitor, affects root-knot nematode multiplication (12). In our preliminary trials, diflubenzuron was phytotoxic to carrots at 6 kg ai/ha in organic soil, and thus lower doses were tested. Fenvalerate, a synthetic pyrethroid, is very effective against several insects at doses as low as 25 g ai/ha (Shell Development Co. technical data). None of these three products gave adequate protection of carrots or adequate control of root-knot nematodes at the concentrations used (Tables 1, 2, and 3).

Saprophytic nematodes recolonized the soil during the experiment. Although there were wide differences between treatments, only fosthietan at 6 kg ai/ha suppressed their reproduction significantly. No phytotoxicity was observed for any of the eight chemicals tested, and there were no significant differences in weight or length of roots between uninoculated controls without chemicals and uninoculated pots with the high concentration of each chemical.

LITERATURE CITED

1. BROMILOW, R. H. 1973. Breakdown and fate of oxime carbamate nematicides in crops and soils. Ann. Appl. Biol. 75:473-479.
2. BRZESKI, M. W., and Z. BOJDA. 1974. The northern root-knot nematode (Meloidogyne hapla Chitw.) on carrot-pathogenicity and control. Zezyty Problemowe Postepow Nauk Rolniczych 154:159-172.

3. BUNT, J. A. 1975. Effect and mode of action of some systemic nematicides. 127 p. Agricultural University 75(10), Wageningen.
4. FUKUTO, R. T. 1957. The chemistry and action of organic phosphorus insecticides. In: Advances in pest control research. R. L. Metcalf, ed. Vol. I, p. 147-192. Interscientific Publications.
5. HARRIS, C. R. 1972. Factors influencing the effectiveness of soil insecticides. Ann. Rev. Entomol. 17:177-198.
6. HOUGH, A., and I. J. THOMASON. 1975. Effects of aldicarb on the behavior of Heterodera schachtii and Meloidogyne javanica. J. Nematol. 7:221-229.
7. HUSSEY, R. S., and K. R. BARKER. 1973. A comparison of methods of collecting inocula of Meloidogyne spp., including a new technique. Plant Dis. Rep. 57:1025-1028.
8. McLEOD, R. W., and G. T. KHAIR. 1975. Effects of oxime carbamate, organophosphate and benzimidazole nematicides on life cycle stages of root-knot nematodes, Meloidogyne spp. Ann. Appl. Biol. 79:329-341.
9. NORTON, D. C., J. TOLLEFSON, P. HINZ, and S. H. THOMAS. 1978. Corn yield increases relative to nonfumigant control of nematodes. J. Nematol. 10:160-166.
10. SLINGER, L. A., and G. W. BIRD. 1978. Ontogeny of Daucus carota infected with Meloidogyne hapla. J. Nematol. 10:188-194.
11. VAN ARKEL, R. G., and G. W. BIRD. 1978. Effect of Meloidogyne hapla on carrot under two temperature progressions. J. Nematol. 10: 300-301 (Abst.).
12. VEECH, J. A. 1978. The effect of diflubenzuron on egg formation by the root-knot nematode. J. Nematol. 10:208-209.
13. VRAIN, T. C., K. R. BARKER, and G. I. HOLTZMAN. 1978. Influence of low temperature on rate of development of Meloidogyne incognita and M. hapla larvae. J. Nematol. 10:166-171.
14. VRAIN, T. C. 1977. A technique for the collection of larvae of Meloidogyne spp. and a comparison of eggs and larvae as inocula. J. Nematol. 9:249-251.
15. WILSON, J. D. 1964. Effect of repeated applications of nematicides on vegetable yields and nematode populations in muck soil. Plant Dis. Rep. 48:698-702.
16. WOLCOTT, A. R. 1970. Retention of pesticides by organic materials in soil. Proc. Symp. Pesticides in Soil: Ecology, Degradation and Movement. Michigan State University, p. 128-138.