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Growth of Carrot and Tomato from Oxamyl-coated Seed and Control of *Meloidogyne hapla*

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Abstract: Oxamyl was coated on carrot (*Daucus carota* L. cv. Spartan Fancy-80) and tomato (*Lycopersicon esculentum* Mill. cv. Glamour) seeds with a polymer sticker for the control of *Meloidogyne hapla*. The sticker diluted in water 1:1 delayed carrot seedling emergence. Oxamyl at 40 mg/ml in a 1:5 dilution of sticker lowered the rate of carrot seedling emergence until day 13 and plant growth until day 28. Oxamyl at 20 or 40 mg/ml in a 1:5 dilution of sticker on carrot seeds planted in *M. hapla*-infested muck soil resulted in fewer galled tap roots and fewer galls per root system 4 weeks after planting. Tap root lengths were greater than those of the control. Tomato seedling emergence was delayed and top and root weights were reduced, relative to the control, at 25 days by the sticker diluted 1:1 to 1:3. Oxamyl at 20 or 40 mg/ml in a 1:5 diluted sticker delayed tomato seedling emergence. Top weights of tomato seedlings from seeds coated with 20 mg/ml of oxamyl in a 1:5 diluted sticker planted in a silt loam were greater than control top weights at 4 and 6 weeks. Root weights were greater than those of the control only at 4 weeks. There were fewer galls per gram of root on seedlings from oxamyl-coated seeds and fewer juveniles per pot of soil, relative to the controls, only at 4 weeks.

Key words: carrot, *Daucus carota*, *Lycopersicon esculentum*, *Meloidogyne hapla*, northern root-knot nematode, oxamyl, seed coating, tomato.

The northern root-knot nematode, *Meloidogyne hapla* Chitwood, is widespread in southwestern and central Ontario (3) and eastern Canada (9,13). *Meloidogyne hapla* is more common in Ontario than reported earlier (3). The nematode occurs in the mineral soils of Ontario; in agricultural marsh areas along Lake Huron, Lake Erie, and Lake Ontario (unpubl. data); and in the marsh soils of southeastern Quebec (10). In both provinces *M. hapla* is harmful to carrot (*Daucus carota* L.) (5,11) and tomato (*Lycopersicon esculentum* Mill.) (2). Many carrots are discarded in the fresh market and processing industry because of tap root galling caused by *M. hapla* infections. This paper reports the results of studies conducted to prevent infection by *M. hapla* during the preemergence and seedling stages of carrot and tomato when oxamyl was applied to the seed in a polymer sticker.

MATERIALS AND METHODS

Seeds of carrot cv. Spartan Fancy-80 and tomato cv. Glamour were coated as described earlier (6,7). Before each experiment with carrot, 3 g of seeds were placed in a tumbler and 1 ml of polymer sticker or sticker plus oxamyl was added. The seeds were dried on a screened trough in warm air from a hair dryer, and the coating procedure was repeated twice. For experiments with tomato, 2 g of seeds were coated using 1 ml in a first coat and 0.5 ml each in second and third coats.

The northern root-knot nematode, *M. hapla*, originated from the Niagara Peninsula in southern Ontario. For studies with carrot, *M. hapla* was reared on celery (*Apium graveolens* Pers. cv. Utah 15) in a muck soil (pH 5.7, 70% OM) from the Port Colborne marsh, Ontario. In the study with tomato, *M. hapla* was reared on celery in a Vineland very fine sandy loam (60% sand, 32% silt, 8% clay; pH 6.2, 2.3% OM). Both soils were contained in plastic tubs (46 cm^2 × 27 cm) in a greenhouse. Infested soils were diluted to the desired inoculum density with steam-treated soil (124 C, 103.4 KPa for 40 minutes) of the same type that had been exposed to the air for 7 weeks to develop a microflora prior to use.

A series of six experiments were conducted, three each with carrot and tomato. Carrot and tomato experiments were conducted in growth chambers adjusted to 14 C night and 17 C day (carrot) and 18 C

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night and 22 C day (tomato) with 11,000 lux for 16 hours. Seedling growth and nematode data were subjected to analysis of variance.

Effect of polymer sticker on growth

Carrot: The polymer sticker was diluted in water (v/v) 0:1, 1:1, 1:2, 1:3, 1:4, or 1:5, and three coats were applied to carrot seeds as described earlier. Steam-treated muck soil was placed in 60 styrofoam pots (11.5 cm d × 7.5 cm high). Twenty seeding sites were impressed into the soil surface with a multipoint dibble, a single seed was inserted into each site, and the soil surface was covered with 30 ml steamed muck soil. Each treatment was replicated 10 times in a randomized block design in a growth chamber. Seedling counts were recorded daily, and fresh top and root weights were recorded 4 weeks after planting.

Tomato: The experiment described for carrot was repeated using sticker-coated tomato seeds in a Vineland very fine sandy loam. Seedling counts were recorded daily, and fresh top and root weights were recorded 25 days after planting.

Effect of oxamyl on growth

Carrot: Four solutions of oxamyl (5, 10, 20, and 40 mg/ml) were prepared with the polymer sticker diluted in water 1:4. Three coats were applied to carrot seeds and experimental conditions were as described for the polymer sticker test. Treatments consisted of two controls (uncoated seeds and polymer sticker only) and four concentrations of oxamyl + sticker coated seed replicated 10 times. Seedling counts were recorded daily, and fresh top and root weights were recorded 4 weeks after planting.

Tomato: The experiment described for carrot was repeated with tomato seeds in a Vineland very fine sandy loam. Seedling counts were recorded daily, and fresh top and root weights were recorded 25 days after planting.

Efficacy of oxamyl

Carrot: The efficacy of oxamyl was determined by applying 20 and 40 mg/ml to carrot seeds in a polymer sticker (diluted 1:5) and a 2% cellulose solution. Three control seed treatments were untreated, polymer-sticker coated, and cellulose coated. Treatments were replicated 10 times in a randomized-block design. Muck soil infested with one *M. hapla* juvenile (J2) per gram was placed in 70 styrofoam pots (11 cm d × 14 cm high). Five seeding sites were impressed in the soil surface, and two seeds from the appropriate treatment were planted in each site. The soil surface was covered with 30 ml infested soil. Seedling counts were recorded daily. Fresh weights of tap and lateral roots, numbers of galls on tap roots and total root system, and length of tap roots were recorded 4 weeks after planting.

Tomato: Vineland very fine sandy loam infested with *M. hapla* was diluted with steamed Vineland very fine sandy loam to give an inoculum density of five J2/g soil. Forty-eight styrofoam pots (11 cm d × 14 cm high) were filled with the infested soil. Five seeding sites were impressed into the soil surface of each pot, two untreated tomato seeds were planted in each site in half of the pots, and two oxamyl-coated (20 mg/ml in sticker solution 1:5) seeds were planted in each site in the remaining pots. The soil surface of each pot was covered with 30 ml infested soil. Seedling counts were recorded daily. After 2 weeks the seedlings were thinned to one per pot. Eight pots planted with untreated seeds and eight pots planted with oxamyl-coated seeds were harvested at 4, 6, and 8 weeks. Fresh top weights, root weights, and the number of root galls were determined at each harvest. Juveniles of *M. hapla* were extracted by the pan method (4) from 50-g soil subsamples for 1 week and from roots for 2 weeks.

Results

Effect of polymer sticker on growth

Carrot: During 26 days, carrot seedling emergence was inhibited from seeds coated with the polymer sticker diluted with water 1:1, but not with higher dilutions (Table 1). Fresh root weights at 28 days were less than those of the control with 1:

TABLE 1. Effect of five concentrations of a polymer sticker coated on carrot seed on seedling emergence 11–26 days after planting and fresh weight 4 weeks after planting.

Sticker : water concentration	Seedling emerged				Weight (g/pot)	
	11	16	21	26	Top	Root
0	7.3	13.2	15.5	15.9	1.5	0.6
1:5	7.3	12.5	15.7	15.8	1.4	0.6
1:4	6.8	12.7	14.7	15.4	1.3	0.5
1:3	6.7	12.5	14.5	15.0	1.3	0.5
1:2	6.3	11.4	14.2	14.5	1.3	0.4
1:1	2.6	7.8	11.4	12.2	0.9	0.3
$LSD_{0.05}$	1.8	1.9	1.6	1.6	0.2	0.1

Values are means of 10 replications.
Twenty seeds were planted in each pot.

2 and 1:1 dilutions and top weight was reduced only at 1:1.

Tomato: During the first 16 days, tomato seedling emergence was inhibited from seeds coated with the polymer sticker diluted 1:1 to 1:4 with water (Table 2); by 21 days only sticker dilutions of 1:1 to 1:3 coated on seed inhibited seedling emergence. At 25 days, fresh weights of tops and roots of seedlings that emerged from seed coated with sticker diluted 1:1 to 1:3 were less than those of the untreated control.

Effect of oxamyl on growth

Carrot: On day 13, carrot seedling emergence was delayed only from seeds coated with oxamyl 40 mg/ml (Table 3). Oxamyl had no adverse effect on the fresh weight of tops and roots after 4 weeks. However, the total fresh weight of seedlings from seed coated with oxamyl 40 mg/ml was less than that of the control.

Tomato: Throughout the 25 days of the experiment, tomato seedling emergence was delayed from seeds coated with oxamyl 20 mg/ml and 40 mg/ml (Table 4). However, only fresh top and root weights and total fresh weight of seedlings from seeds coated with oxamyl 40 mg/ml were less than the control.

Efficacy of oxamyl

Carrot: Over 17 days, carrot seedling emergence from seeds coated with oxamyl of 20 mg/ml and 40 mg/ml in polymer and cellulose stickers was similar to the control, 3.9 vs. 4.1, in *M. hapla*-infested muck soil (Table 5). Fresh top and root weights of seedlings from seeds treated with oxamyl were not greater than the untreated control: tops 1.8 vs. 1.8 g and roots 1.9 vs. 1.0 g. However, tap roots of carrots from seeds coated with the two concentrations of oxamyl were longer than those of the untreated control. There were no dif-

TABLE 2. Effect of five concentrations of a polymer sticker coated on tomato seed on seedling emergence 6–21 days after planting and fresh weight 25 days after planting.

Sticker : water concentration	Seedling emerged				Weight (g/pot)	
	6	11	16	21	Top	Root
0	7.2	16.4	17.8	18.6	15.3	2.8
1:5	6.2	14.8	16.0	17.2	14.3	2.5
1:4	3.8	11.6	13.2	16.0	13.6	2.4
1:3	3.6	11.0	12.4	14.2	13.3	2.3
1:2	3.6	10.8	12.2	13.8	11.7	1.9
1:1	2.8	10.0	12.2	13.2	11.6	1.8
$LSD_{0.05}$	2.2	3.6	3.8	4.0	1.9	0.5

Values are means of 10 replications.
Twenty seeds were planted in each pot.

TABLE 3. Effect of four concentrations of oxamyl in a polymer sticker coated on carrot seeds on seedling emergence 9–27 days after planting and fresh weight 4 weeks after planting.

Oxamyl concentration (mg/ml)	Seedling emerged				Weight (g/pot)	
	9	13	18	27	Top	Root
0†	6.5	11.9	13.5	13.7	3.0	1.4
0‡	4.7	10.6	11.9	12.8	2.8	1.0
5	5.9	11.8	13.5	14.4	3.0	1.4
10	5.1	11.2	12.3	13.1	2.7	1.4
20	5.0	10.4	12.6	13.3	2.7	1.6
40	4.5	9.1	11.5	12.0	2.5	1.1
$LSD_{0.05}$	n.s.	1.8	n.s.	n.s.	n.s.	n.s.

Values are means of 10 replications.
Twenty seeds were planted in each pot.
† No sticker or oxamyl used.
‡ Polymer sticker diluted 1:5 (sticker : water).

ferences in seedling emergence and growth between the two concentrations of oxamyl. There were fewer galls on the root system of seedlings from oxamyl-coated seeds than on the control. The fewest galls were on roots of seedlings from seed coated with oxamyl 40 mg/ml in polymer sticker. The cellulose and polymer sticker had no adverse effects on the growth of carrot nor on the efficacy of oxamyl.

Tomato: Shoot growth of tomato seedlings from oxamyl-coated seeds exceeded that of the control seedlings 4 and 6 weeks after planting but not after 8 weeks (Table 6). Root growth of tomato seedlings from oxamyl-coated seeds exceeded that of the control only 4 weeks after planting.

Total numbers of galls on roots of tomato seedlings from oxamyl-coated seeds and from untreated seeds did not differ (Table 6). Fewer galls per gram of roots were found on the roots of tomato seedlings from oxamyl-coated seeds than on roots of seedlings from untreated seeds 4 weeks after planting. The number of juveniles extracted from the roots of tomato seedlings from oxamyl-coated seeds was greater than that from untreated seeds 8 weeks after planting. Fewer juveniles were extracted from pots of soil planted with oxamyl-coated seeds than from pots of soil planted with untreated seed 4 weeks after planting but not thereafter.

DISCUSSION

Coating seeds with oxamyl promises greater success with carrot than tomato. Although there was no increase in top and

TABLE 4. Effect of four concentrations of oxamyl coated on tomato seeds with a polymer sticker on seedling emergence 7–21 days after planting and fresh weight 25 days after planting.

Oxamyl concentration (mg/ml)	Seedling emerged				Weight (g/pot)	
	7	11	16	21	Top	Root
0†	8.2	15.2	16.9	17.1	15.5	1.4
0‡	7.2	15.0	16.8	16.9	15.3	1.3
5	6.7	14.7	16.8	16.8	14.8	1.3
10	6.6	14.5	15.6	16.5	14.7	1.1
20	6.5	12.3	14.7	14.7	14.7	1.1
40	4.8	10.3	14.4	14.4	12.3	0.7
$LSD_{0.05}$	1.8	1.9	2.2	1.9	1.7	0.3

Values are means of 10 replications.
Twenty seeds were planted in each pot.
† No sticker or oxamyl used.
‡ Polymer sticker diluted 1:5 (sticker : water).

TABLE 5. Efficacy of two concentrations of oxamyl coated on carrot seeds with a polymer sticker (diluted 1:5) and 2% cellulose solution on the control of *Meloidogyne hapla* 4 weeks after planting.

Oxamyl concentration (mg/ml)	Coating agent	Tap root length (cm)	Tap roots galled	Galls per root system
0	0	7.8	3	8
	Cellulose	8.4	3	8
	Sticker	9.0	2	8
	Cellulose	10.0	1	5
20	Sticker	10.1	1	6
40	Cellulose	10.1	1	5
	Sticker	10.0	1	3
$LSD_{0.05}$		1.0	0.8	2

Values are the means of 10 replications.
Five seeds were planted in each pot.

root weight of carrot seedlings from treated seed 4 weeks after planting, there was an increase ($P \leq 0.05$) in tap root length. Similar results were obtained in greenhouse (12) and field (1) experiments with granular oxamyl applied to muck soils in Quebec. Coating of carrot seeds provides only limited protection from *M. hapla* because these small seeds retain only a minute quantity of oxamyl and can be coated only with oxamyl solutions less than 40 mg/ml to avoid toxicity. In contrast, alfalfa seeds are tolerant to oxamyl coating with solutions up to 160 mg/ml (6). It appears that cotyledons of hard seeds such as alfalfa provide better protection of the embryo than do soft seeds such as tomato and carrot when coated with oxamyl. Potato seed pieces provide good protection against *Pratylenchus penetrans* Cobb when soaked in oxamyl 32 mg/ml (8). The large potato seed piece, relative to carrot and tomato seeds, provides a sink for oxamyl. Seed coating could be followed by spray applications of oxamyl on carrot after seedling emergence to provide additional protection against *M. hapla*. For precision seeding of carrot, seeds are pelleted with clay. Consequently, the much larger seed pellet would be a better sink for oxamyl than the small seeds. Unfortunately, however, the pelleting compound inactivates oxamyl (6); other nonalkaline pelleting compounds need to be investigated.

Coating tomato seeds with oxamyl may not be practical because most tomato fields are established with transplants. Top growth of tomato seedlings from oxamyl-coated seeds was greater than controls for 6 weeks, and root growth for only 4 weeks. The only reduction in the number of galls was observed as number of galls per gram of root. The larger root systems of seedlings from oxamyl-coated seeds would increase the chances of more nematode infections and galling. Of concern was the increase in the number of juveniles per pot of roots on seedlings from oxamyl-coated seeds relative to the control at 8 weeks. It appears that the most viable nematodes are

TABLE 6. Duration of control of *Meloidogyne hapla* and weight of tomato plants in infested soil planted with oxamyl-coated seeds (20 mg/ml in sticker diluted 1:5).

Weeks after planting	Treatment	Fresh weight (g/pot)		Galls/pot roots	Galls/g root	*M. hapla* juveniles/pot	
		Top	Root			Root	Soil
4	Control	3.2	0.6	75	131	0†	700
	Oxamyl	5.1	1.2	65	56	0	323
$LSD_{0.05}$		0.6	0.2	n.s.	25		170
6	Control	22.0	4.6	382	72	9,290	850
	Oxamyl	24.0	5.5	462	66	13,830	776
$LSD_{0.05}$		1.8	n.s.	n.s.	n.s.	n.s.	n.s.
8	Control	30.0	6.4	514	110	25,870	1,530
	Oxamyl	30.0	7.5	481	72	60,660	3,210
$LSD_{0.05}$		n.s.	n.s.	n.s.	n.s.	9,500	n.s.

Values are the means of eight replications.
Five seeds were planted in each pot.
† No juveniles were recovered from roots 4 weeks after planting.

surviving to enter the roots with a subsequent greater production of juveniles. The increase in galls and juveniles at 6 weeks may be the result of late-penetrating juveniles.

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