Effect of Time of Application on the Action of Foliar Sprays of Oxamyl on Meloidogyne hapla in Tomato

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Abstract: Foliar sprays containing 3,000 or 4,000 ppm oxamyl applied before inoculation with *Meloidogyne hapla* completely protected tomato plants from infection for up to 36 days but sprays containing 1,000 or 2,000 ppm provided only partial protection. Postinoculation sprays were less effective than preinoculation sprays but they decreased the numbers of females and their rate of development and increased the numbers of males. Similar amounts of oxamyl applied to the soil as a drench or as granules controlled *M. hapla* more effectively than foliar sprays but the longer treatment was delayed after infection the fewer the larvae that were killed and the more that became male. *Key words:* root-knot nematode, control, Vydate, *Lycopersicon esculentum*, sex ratio.

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Incorporation of the oxime-carbamate nematicide oxamyl into soil prior to planting effectively controls many species of plant parasitic nematodes. Oxamyl is translocated from the leaves to the roots (6,22), and foliar sprays of the chemical are reported to control root feeding ectoparasitic (2,11,16), endoparasitic (12,15), and semi-endoparasitic nematodes (1,10,14). However, oxamyl is not always effective. Potato cyst nematode (*Globodera rostochiensis* Woll.) was not controlled by a single foliar treatment, although it was controlled by repeated treatments (20), and *G. rostochiensis* and *Meloidogyne incognita* (Kofoid and White) Chitwood were not controlled by oxamyl applied to the soil after infection had occurred (5). Other research has indicated that maximum control of endoparasitic species was obtained only when oxamyl was applied prior to invasion (10,14); foliar sprays applied after infection only slowed or delayed nematode development (3,15,21).

The experiments reported in this paper examined the effects of foliar sprays of oxamyl, applied at different times before and after infection, and of granules and drenches applied after infection on the development, survival, and sex of *M. hapla* Chitwood infecting tomato (*Lycopersicon esculentum* L.).

MATERIALS AND METHODS

Three-week-old tomato plants (cv. Rutgers) growing in steam sterilized soil (3

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parts field soil: 1 part peat) in 10-cm pots were used in all experiments. Juveniles of *M. hapla,* obtained by placing egg masses on nylon sieves over water for 7 days at 20–25 C (4), were inoculated in 2–5 ml water into holes made in the soil around the stem base. Oxamyl (Vydate liquid) was applied to the foliage of the plants as a fine spray at concentrations of 1,000, 2,000, 3,000, or 4,000 ppm a.i. with a laboratory spray gun. In one test 3-week-old plants retained a mean of 2.6 ml of the solution. The soil surface was shielded from the run-off with aluminium foil. Care was also taken to avoid washing oxamyl from the leaves into the soil during watering.

Two initial experiments tested the effect of sprays, applied before inoculation, on the infection of tomato by the root-knot juveniles. The first experiment tested 3,000 and 4,000 ppm solutions of oxamyl applied three times, at 2-day intervals, prior to inoculating 1,000 freshly hatched juveniles 1, 7, or 14 days after the third oxamyl treatment. The second experiment tested sprays of 1,000 and 2,000 ppm identically applied. Inoculated, nontreated plants were maintained as controls. Each treatment in each experiment was replicated 10 times. The experiments were terminated 36 days after inoculation.

A third experiment tested the effect of foliar sprays of 3,000 and 4,000 ppm of oxamyl applied 2, 4, 6, 8, 10, or 12 days after inoculation of each tomato plant with 1,000 eggs and juveniles of *M. hapla.* Immediately prior to spraying, the plants were transplanted into sterilized soil and the sprays were repeated three times at 2-day intervals. Four concentrations of oxamyl (1,000, 2,000, 3,000 or 4,000 ppm) were applied to the plants treated on the 12th day after inoculation. Each treatment, including inoculated untreated controls, was replicated 10 times. The numbers of nematodes, galls, and egg masses in the roots were determined 36 days after the third application of chemical.

In a fourth experiment, the tomato plants were transplanted into steam sterilized soil 3 days after being inoculated with 1,500 larvae. Oxamyl sprays (3,000 or 4,000 ppm) were first applied to the foliage 3, 6, 9, or 12 days after transplanting and each treatment was repeated 2 days later. Inoculated untreated plants were maintained as controls. Two further groups of plants were also sprayed 6 days before inoculation. Each treatment was replicated five times.

A fifth experiment tested the effect on *M. hapla* of applying oxamyl at different times after inoculation as a spray, as a soil drench, or as granules incorporated in the soil. In this experiment, the tomato plants were inoculated with 1,000 juveniles and 3 days later their roots were washed free of soil and they were transplanted into nematode-free, steam sterilized soil. Plants were treated 6, 9, 12, or 15 days after inoculation by washing the roots free of soil and again transplanting into sterilized soil into which oxamyl granules had been incorporated or to which a 20-ml drench was applied. Plants receiving the foliar spray (4,000 ppm solution) were transplanted a second time immediately prior to treatment. The granule and drench treatments were applied at 10.6 mg oxamyl per pot. This amount was approximately equal to the amount of chemical retained by the sprayed plants. The experiment was replicated four times; untreated control plants were transplanted only once.

The fourth and fifth experiments were terminated 25 days after inoculation. The roots were washed free of soil and the numbers of root galls, nematodes, and egg masses counted. If available, up to 50 nematodes were dissected from the galls. Their length and breadth at the center were measured and their volume calculated on the assumption that they were cone shaped. All experiments were fully randomized in a glasshouse maintained at 20–22 C.

RESULTS

In the first experiment, all plants sprayed with 3,000 or 4,000 ppm oxamyl solution, including those sprayed 14 days before inoculation, were completely free of *M. hapla* when their roots were examined 36 days later. Control plants contained a mean of 22 galls and 31 females.

In the second experiment, foliar sprays of 1,000 ppm and 2,000 ppm oxamyl significantly decreased ($P<0.001$) the mean numbers of nematodes and egg masses compared with the untreated control (Table 1). The

Table 1. Effect of foliar sprays of oxamyl applied at various times before inoculation on numbers of galls, nematodes, and egg masses of *Meloidogyne hapla* 36 days after inoculation. Means of 10 replicates.†

	Oxamyl (ppm)	Days before inoculation 1	7	14
Galls	Untreated	165	165	165
	1,000	25***	66***	85***
	2,000	12***	45***	60***
Nematodes	Untreated	205	205	205
	1,000	25***	45***	77***
	2,000	12***	31***	60***
Egg masses	Untreated	145	145	145
	1,000	0***	14***	25***
	2,000	0***	9***	13***

†Results converted to logs for analysis; detransformed results presented here.

***Significantly different ($P < 0.001$) from the untreated controls.

time of treatment also affected the degree of control, since more galls, nematodes, and egg masses were present the longer the interval between treatment and inoculation.

In the third experiment, postinoculation foliar sprays of 3,000 or 4,000 ppm oxamyl significantly ($P< 0.05$) decreased the mean numbers of galls, nematodes, and egg masses compared with the untreated controls (Table 2). However, these treatments were less effective than foliar sprays applied prior to inoculation. Since there was no significant difference in the effectiveness of 3,000 ppm and 4,000 ppm foliar sprays applied between 2 and 12 days after inoculation, mean data for the two rates are given.

In plants first sprayed 12 days after inoculation (Table 3), there was a significant negative correlation ($P<0.05$) between increasing oxamyl concentration and the numbers of galls, juveniles and females, and egg masses and a significant positive correlation ($P<0.05$) with the numbers of males recovered from the roots.

In the fourth experiment, plants sprayed 6 days before inoculation were completely free of *M. hapla* when their roots were examined 25 days after inoculation. In plants sprayed after inoculation, *M. hapla* was not completely controlled but the numbers of

Table 2. Effect of foliar sprays of oxamyl applied at various times after inoculation on numbers of galls, nematodes and egg masses of *Meloidogyne hapla* 36 days after inoculation. Results for the treated plants are the mean of 3,000 and 4,000 ppm treatments.

	Treatment	Days after inoculation 2	4	6	8	10	12
Galls	Untreated	12†	21	20	21	25	63
	Treated	2	6	4	8	10	37
Nematodes	Untreated	18	33	22	28	32	95
	Treated	1	4	2	3	5	15
Egg masses	Untreated	5.0	9.0	13.0	4.0	6.0	4.0
	Treated	0	0.8	0.3	1.0	0.7	0.2

†All treatments significantly ($P < 0.05$) decreased numbers.

Table 3. Mean numbers of root galls, nematodes, males, and egg masses of *Meloidogyne hapla* on tomato plants sprayed with oxamyl 12 days after inoculation. Means of four plants.

Dose (ppm)	Root galls	Juveniles and females	Males	Egg masses
Control	63a†	95a	1a	44a
1,000	44b	45b	2b	6b
2,000	54c	35c	4c	8c
3,000	32d	17d	3d	0.3d
4,000	41d	13d	5e	0.1d

†Data followed by the same letter within columns are not significantly different ($P < 0.05$).

females and egg masses were significantly reduced. The effect was greatest for plants sprayed 6 days after inoculation and least for those sprayed 15 days after inoculation (Table 4). The mean volume of the developing juvenile and female nematodes was also reduced in the oxamyl treated plants. Sprays applied 6 days after inoculation produced the greatest effect, and those applied after 15 days the least. Although oxamyl sprays decreased the incidence of females and egg masses, the numbers of males were increased, significantly so for plants sprayed 15 days after inoculation.

In the fifth experiment, oxamyl applied to the soil as granules or as a drench controlled *M. hapla* more effectively than similar amounts of oxamyl applied to the foliage in a single spray (Table 5). In plants treated 6, 9, or 12 days after inoculation, no females were recovered from the granule or drench treated plants, whereas females were recovered from the sprayed plants for all dates of treatment. However, as in the previous experiments, the degree of control and the effect on the size of the females decreased the greater the interval between inoculation and spray treatment. The number of males recovered was increased in plants treated with either granules or the drench 12 and 15 days after inoculation.

DISCUSSION

Our results show that foliar sprays of oxamyl will control *M. hapla* attacking tomato but, as others have found (1,10,14), sprays applied before infection are more effective than those applied after. The results indicate that the extent to which *M. hapla* is controlled is related to the concentration and number of applications of the chemical; also that foliar treatments are less effective than similar amounts of oxamyl applied to the soil.

Sprays applied after infection reduced the numbers of nematodes in the roots and retarded or delayed the development of the survivors. These effects, however, decreased as the interval between infection and treatment increased. Sprays or soil treatments applied 12 or 15 days after infection tended to increase the numbers of males. Presumably this was a consequence of development being delayed at a critical stage by the oxamyl interfering with the feeding of the second-stage juvenile (8,17, 19).

The relative effectiveness of the preinfection, as compared with the postinfection, sprays is probably a consequence of the distribution of the oxamyl in the root system. Only a small proportion of the oxamyl applied to the foliage is translocated to the

Table 4. Mean numbers of females, males, egg masses, and volume of *Meloidogyne hapla* in tomato roots 25 days after inoculation. Means of five plants.

Spraying days from inoculation	Oxamyl (ppm)	Volume of nematodes (1,000 μm^3)	Number of nematodes		
			Females	Males	egg masses
Control		843*	34de†	2abc	21e
6 days before	3,000	0	0a	0a	0a
	4,000	0	0a	0a	0a
6 days after	3,000	462	21bc	0a	4bc
	4,000	279	16b	2abc	0a
9 " "	3,000	458	24abc	1ab	5bc
	4,000	415	22bc	4cd	1ab
12 " "	3,000	606	30bcd	3bc	10d
	4,000	379	26abc	5de	5bc
15 " "	3,000	689	30bcd	7e	10d
	4,000	676	27cd	11f	8cd

*LSD 157 ($P < 0.05$).

†Values followed by the same letter within each column are not significantly different according to Duncan's multiple-range test ($P < 0.05$).

Table 5. Effect of oxamyl applied to the soil, as granules, as a drench, and as a foliar spray on the numbers of *Meloidogyne hapla* females, their volume, and the numbers of males. Results are means of four replicates.

Time of treatment (days after inoculation)	Treatments			
	Control	Granules	Drench	Foliar spray
	Number of females†			
Untreated	93†			
6		0***	0***	6***
9		0***	0***	23***
12		0***	0***	78
15		0***	6***	80
	Mean volume of females (10^6 um^3)			
Untreated	101			
6		0	0	15***
9		0	0	48***
12		0	0	55***
15		0	7***	83***
	Numbers of males†			
Untreated	0			
6		0	0	0
9		0	0	0
12		19***	10***	0
15		21***	22***	0

†Results converted to logs for analysis; detransformed results presented here.
***Significantly different from the untreated ($P < 0.001$).

roots (7), and work on cabbage (14) and on banana (9) indicate that nematicidal activity was confined to the root surface or the immediate rhizosphere. Wright et al. (22) further suggested that the concentration of oxamyl was greatest at the root tips, the preferred site for nematode invasion. Thus, oxamyl has a strong effect on nematode juveniles attempting to penetrate the roots but much less effect on those already within the roots.

In one of our experiments, the mortality of juveniles that had invaded was greater when oxamyl was applied 6 days after infection than when it was applied 15 days after infection. Another oxime-carbamate nematicide, aldicarb, was also more effective against juveniles in roots when applied soon after infection; undeveloped second-stage juveniles were stimulated to re-emerge from the roots (13). However, in an experiment in which tomato plants were transplanted into gravel so that juveniles could be collected (18), no egress of *M. hapla* juveniles was observed in plants treated with oxamyl 3 or 6 days after infection.

Our experiments have demonstrated that foliar oxamyl treatments on tomato have to be applied before the juveniles invade the roots to be effective in controlling *M. hapla*. The relative ineffectiveness of oxamyl sprays applied after juveniles became established means that time of treatment in relation to infection is an important factor affecting the success of oxamyl sprays.

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