Control of Globodera rostochiensis in Relation to Method of Applying Nematicides[1]

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Abstract: Soaking potato tuber pieces for 15 min in 8,000 $\mu g/ml$ of oxamyl just before planting reduced the number of *Globodera rostochiensis* cysts that developed on potato roots, but this treatment was phytotoxic. Five foliar applications of 1.12 kg a.i./ha of oxamyl or carbofuran at 10-day intervals beginning when 90% of the plants had emerged suppressed increase in *G. rostochiensis* densities. Similar foliar applications of phenamiphos were ineffective in controlling *G. rostochiensis*. Soil applications (in the row at planting) of aldicarb, carbofuran, phenamiphos, ethoprop, and oxamyl at 5.6 kg a.i./ha reduced the numbers of white females that developed on potato roots, but only those treatments involving aldicarb and oxamyl suppressed *G. rostochiensis* population increase. Combined soil and foliar treatments did not provide any advantage over soil treatment alone, as soil applications of 5.6 kg a.i./ha alone were equal to, or better than, combined soil (3.4 kg a.i./ha) and foliar (2.2 kg a.i./ha) applications in controlling *G. rostochiensis*. *Key words:* chemical control, *Globodera rostochiensis*, seed treatments, soil treatments, foliar treatments.   Journal of Nematology 15(4):491-495. 1983.

Since its discovery in the USA, *Globodera rostochiensis* has been under quarantine. To limit its spread, rigorous regulatory actions are inforced when new infestations of *G. rostochiensis* are discovered. Consequently, populations of *G. rostochiensis* never develop to plant damaging levels in the USA. By necessity, research on chemical control of *G. rostochiensis* concentrates on developing control tactics that will manage population densities at very low levels. Although effective against *G. rostochiensis*, soil fumigation is often impossible to accomplish within the same season that the potato crop is produced. Because organophosphate and oxime carbamate nematicides can be applied at time of planting, their use appeals to growers.

Various workers have investigated the efficacy of organophosphates and oxime carbamates in controlling *G. rostochiensis*, but mostly in the context of reducing plant damage sufficiently to improve potato yields. Damage to potatoes by *G. rostochiensis* has been reduced by soil applications of such nematicides (7,8), even though nematode population densities were not reduced (2,3,6,10,11). The effects of the nematicide may be on nematode feeding and development, as fewer cysts form on roots of plants growing in treated soil (3,6, 15).

Foliar treatments of oxamyl provide good control of *G. rostochiensis* in some cases but not in others. Application of 500 μg oxamyl/ml to the foliage of potatoes growing in oxamyl treated soil (1.25 μg oxamyl/g) almost completely eliminated *G. rostochiensis* (2). Other reports indicated that foliar application of oxamyl (2 or 4 kg oxamyl/ha) did not enhance control of *G. rostochiensis* on potatoes growing in oxamyl (2.5 μg oxamyl/g) treated soil (14). Repeated foliar applications of oxamyl (1, 2, or 4 kg oxamyl/ha) at weekly intervals for 2–6 weeks suppressed *G. rostochiensis* increase, but results were variable and control was not as good as that obtained when oxamyl was applied to the soil (16).

Limited research has been done on control of *G. rostochiensis* by chemical treatment of seed potatoes. Soaking seed potatoes in 2–66 g oxamyl/liter H_2O for 2 min just before planting reduced the number of cysts that developed on potato roots (5,12). Treatment of whole tubers rather than tuber pieces lessened phototoxicity without reducing efficacy (12).

This research was undertaken to determine the most effective chemical management program for *G. rostochiensis*.

MATERIALS AND METHODS

Tests involving treatment of seed potatoes were done in the greenhouse using 10-cm-d clay pots filled with a 1:1 mixture of soil and builders sand. A randomized complete block was used with each treatment replicated three times. Each pot represented an experimental unit and was in-

oculated with 30 *G. rostochiensis* cysts. Greenhouse temperatures ranged from 23 to 26 C. Tuber pieces (cv. Katahdin) were soaked for 15 min in the various concentrations of oxamyl (95% WP) or phenamiphos (35% EC) as indicated in Table 1. After treatment, the tuber pieces were air dried and then planted. Six weeks after planting, the plants were removed and their roots were examined for cysts. The test was repeated once.

Foliar treatment tests were done in a field light to moderately infested with *G. rostochiensis.* A randomized complete block design was used with each treatment replicated four times. Two rows, 91 cm apart and 1.5 m long, represented an experimental unit. Nematicide applications were made with a hand-held sprayer commencing when 90% of the plants had emerged (ca. 14 days after planting). Four additional applications were made at 10-day intervals after the first application. Desired amounts of carbofuran (490 g/liter, flowable), oxamyl (240 g/liter, emulsifiable concentrate or phenamiphos (240 g/liter, emulsifiable concentrate) were mixed with sufficient water to spray the foliage to run off at each application. Each nematicide was applied at a dosage of 1.12 kg a.i./ha at each application. This test was repeated twice. Data presented represent the results of all three tests.

Tests involving soil applications were done in a field light to moderately infested with *G. rostochiensis.* The desired dosage of each nematicide, as indicated in Table 3, was applied in a 10-cm-d band over the seed furrow at the time of planting. The only mixing of the chemical into the soil was that which occurred from the action of the covering disc as potato ridges were formed. The nematicides used were aldicarb (15% granules), carbofuran (10% granules), phenamiphos (15% granules), ethoprop (10% granules), and oxamyl (10% granules). The test was repeated three times, and data presented represent the results obtained from all four tests.

Combination soil and foliage treatment tests were done in a field light to moderately infested with *G. rostochiensis.* Soil treatments were made as previously described with nematicides and dosages as indicated in Table 4. Foliar treatments

were made as previously described except only two applications of 1.1 kg a.i./ha each of each nematicide as indicated in Table 4 were made. A split-plot design was used with soil treatments as main plots and foliar treatments as subplots. Each treatment was replicated four times. The test was repeated two times and data presented represent the results of all three tests.

Effectiveness of treatments in field tests was determined from Pf/Pi ratios as calculated from changes in the number of viable eggs of *G. rostochiensis* before planting and after harvest or from the number of white females per gram of root. Twenty subsamples of soil (ca. 20 g each) were taken from each plot and composited, and a 200-ml aliquot was processed by USDA cyst extractor for cysts. The cysts were crushed, and the number of viable eggs were determined from visual observations. Number of white females per gram of root was estimated from root samples taken just as the plants began to flower (ca. 8 weeks after planting). Five plants, selected at random from each plot, were carefully lifted and a portion (10–15 g) of each root system collected in a 500-ml jar. Enough water was added to each jar to completely cover the roots. The jars were shaken manually for 4 min; then their contents were poured onto a 20-mesh (850-μm pore) sieve nested on a 60-mesh (250-μm pore) sieve. The white females oclected on the 60-mesh sieve were washed into a counting dish and their numbers recorded. The roots collected on the 20-mesh sieve were blotted between paper towels to remove free water then weighed.

RESULTS

Seed treatments: Numbers of developing females of *G. rostochiensis* on the roots of potato plants grown from seed potatoes soaked for 15 minutes in 8,000 and 10,000 μg oxamyl/ml were significantly less than those on roots of plants from untreated seed potatoes (Table 1). Treatment with concentrations of oxamyl less than 8,000 μg/ml did not significantly suppress the number of developing females. Concentrations of 8,000 μg/ml and higher, although they reduced female devolpment, were phytotoxic, as indicated by stunted plant growth.

Table 1. Number of *Globodera rostochiensis* cysts developing on potato roots as influenced by soaking potato seed pieces for 15 min in different concentrations of oxamyl and phenamiphos.

Treatment	Nematicide concentration (μg/ml of H_2O)	No. females/ root system
Control	0	144 a*
Oxamyl	250	160 a
Oxamyl	500	143 a
Oxamyl	1,000	106 ab
Oxamyl	2,000	69 ab
Oxamyl	4,000	69 ab
Oxamyl	8,000	18 b
Oxamyl	10,000	12 b
Control	0	108 ab
Phenamiphos	250	155 a
Phenamiphos	500	52 ab
Phenamiphos	1,000	137 a
Phenamiphos	2,000	94 ab
Phenamiphos	4,000	15 b

*Means followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

Treatment with phenamiphos produced erratic results. Fewer females developed on roots of plants from seed potatoes soaked 15 minutes in 500 μg/ml than on those from seed potatoes soaked in 1,000 μg/ml, but neither treatment was significantly better than the control (Table 1). A significant suppression in the number of developing females was obtained when seed potatoes were soaked in 4,000 μg phenamiphos/ml, but this concentration was highly phytotoxic. Concentrations of phenamiphos above 4,000 μg/ml completely inhibited sprouting of the seed potatoes.

In field experiments, seed treatments (15-min soak) with 1,000 oxamyl or phenamiphos μg/ml did not significantly enhance control of *G. rostochiensis* when used in combination with soil or foliar treatments of oxamyl, phenamiphos, and carbofuran.

Foliar treatments: Five foliar applications of oxamyl or carbofuran (1.12 kg a.i./ha per application) significantly reduced *G. rostochiensis* Pf/Pi ratios, whereas similar applications of phenamiphos did not (Table 2). Yield of potatoes was significantly increased by foliar applications of oxamyl but not by carbofuran or phenamiphos.

Table 2. Effects of repeated foliar applications* of certain nematicides of Pf/Pi ratios of *Globodera rostochiensis* and yield of potatoes.

Treatment	Pf/Pi ratio	Potato yield (kg/plot)
Control	2.3 a†	38 b
Carbofuran	1.1 b	32 b
Oxamyl	0.6 b	46 a
Phenamiphos	1.3 ab	38 b

*Accumulative dosage consisting of five applications of 1.12 kg a.i./ha each at 10-day intervals beginning when 90% of the plants had emerged.

†Means in each column followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

Soil treatments: In-the-furrow application of aldicarb, carbofuran, phenamiphos, ethoprop, and oxamyl (5.6 kg a.i./ha) significantly suppressed the number of *G. rostochiensis* females developing on potato roots (Table 3). Aldicarb at 3.4 kg a.i./ha was equally as effective in suppressing female development as was aldicarb at 5.6 kg a.i./ha. Only aldicarb and oxamyl significantly reduced *G. rostochiensis* Pf/Pi ratios (Table 3). Increase in potato yield was generally associated with reductions in nematode population density, but only treatments involving aldicarb significantly increased potato yields.

Combined soil and foliar treatments. Combined soil and foliar treatments were no more effective in controlling *G. rostochiensis* than were soil treatments alone (Table 4). However, all combined treat-

Table 3. Number of white females on potato roots, Pf/Pi ratios of *Globodera rostochiensis*, and yield of potatoes as influenced by soil applications of certain nematicides.

Treatment	Dosage (kg a.i./ ha)	Females/g of root	Pf/Pi ratio	Yield (kg/plot)
Control		89.2 a*	1.4 a	23 c
Aldicarb	5.6	3.0 d	0.4 b	36 ab
Aldicarb	3.4	9.1 d	0.4 b	38 a
Carbofuran	5.6	50.8 bc	0.8 ab	26 bc
Phenamiphos	5.6	49.3 bcd	2.3 a	29 abc
Ethoprop	5.6	17.6 cd	0.7 ab	19 c
Oxamyl	5.6	17.6 cd	0.4 b	18 c

*Means in the same column followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

Table 4. Number of white females on potato roots, Pf/Pi ratios of *Globodera rostochiensis,* and yield of potatoes as influenced by combined soil and foliar applications of selected nematicides.

Treatments				Females/g of root	Pf/Pi ratio	Yield (kg/plot)
Soil kg a.i./ha		Foliar kg a.i./ha				
Control				107 a*	12.7 b	45
Carbofuran	5.6			26 cde	8.3 b	29
Carbofuran	3.4	Carbofuran	2.2†	17 cde	5.3 b	38
Carbofuran	3.4	Oxamyl	2.2	12 cde	2.4 b	47
Carbofuran	3.4	Phenamiphos	2.2	50 bcde	3.7 b	40
Control				123 a	67.7 a	53
Aldicarb	5.6			21 cde	9.3 b	61
Aldicarb	3.4	Carbofuran	2.2	7 cde	7.1 b	57
Aldicarb	3.4	Oxamyl	2.2	25 cde	5.0 b	68
Aldicarb	3.4	Phenamiphos	2.2	14 cde	5.0 b	61
Control				80 ab	15.0 b	37
Ethoprop	5.6			2 de	9.4 b	36
Ethoprop	3.4	Carbofuran	2.2	7 cde	11.6 b	49
Ethoprop	3.4	Oxamyl	2.2	16 cde	5.3 b	47
Ethoprop	3.4	Phenamiphos	2.2	2 de	12.7 b	52
Control				56 bc	34.4 b	39
Phenamiphos	5.6			2 de	23.2 b	50
Phenamiphos	3.4	Carbofuran	2.2	52 bde	8.6 b	39
Phenamiphos	3.4	Oxamyl	2.2	15 bcd	17.6 b	49
Phenamiphos	3.4	Phenamiphos	2.2	7 bcd	13.0 b	49
Control				34 bcde	19.3 a	46
Oxamyl	5.6			1 e	1.4 b	34
Oxamyl	3.4	Carbofuran	2.2	3 de	2.3 b	48
Oxamyl	3.4	Oxamyl	2.2	16 cde	3.9 b	41
Oxamyl	3.4	Phenamiphos	2.2	5 de	0.9 b	38

*Means in the same column followed by the same letters are not significantly different ($P = 0.05$) according to Duncan's multiple-range test.

†Applied at 1.1 kg a.i./ha 5 and 15 days after plant emergence.

ments, except those with phenamiphos as a soil treatment, significantly reduced the number of *G. rostochiensis females* that developed on potato roots. Combined treatments involving soil application of aldicarb or oxamyl significantly reduced *G. rostochiensis* Pf/Pi ratios, but were no more effective than were soil treatments alone. Yield of potatoes was variable, and none of the treatments significantly influenced yield.

DISCUSSION

Control measures to confine the spread of *G. rostochiensis* should result in a decrease in nematode population density. However, less effective control measures that signficantly suppress population increase are useful when integrated with other control tactics to manage densities of *G. rostochiensis.* The use of such treatments in systems involving resistant cultivars and nonhost crops may effectively manage densities of *G. rostochiensis* at levels where spread is limited.

Seed potato treatments with oxamyl and phenamiphos, although they significantly reduced cyst development when compared to no treatment, did not provide sufficient control of *G. rostochiensis* to be used in an integrated control system. Also, a problem with phytotoxicity exists with this treatment. Proudfoot and Morris (12) found that treatment of whole tubers reduced phytotoxicity, but this technique was considered impractical because most potatoes in the United States are planted with cut tuber pieces.

My results with repeated foliar applications of oxamyl agreed somewhat with those of Whitehead et al. (16), but with lower dosages and longer time intervals. Five foliar applications of 1.12 kg a.i.

oxamyl/ha at weekly intervals resulted in a population decline. Such a treatment is practical; however, if oxamyl is applied too near harvest, considerable residue could accumulate in the tubers (16).

Applications of nematicides to the soil at the time of planting potatoes resulted in the best control of *G. rostochiensis* in terms of suppressing cyst development on roots, reducing Pf/Pi ratios, and increasing yield of potatoes. Whitehead et al. (15) advocated incorporation of nematicides by rotavating; however, the incorporation technique used here works equally as well and is more practical in soils containing large stones.

Combined foliar and soil applications did not result in better control of *G. rostochiensis* than did soil applications alone. My data indicate that soil application of organophosphate and oxime carbamate nematicides at 5.6 kg a.i./ha provides equally as good control of *G. rostochiensis* as does spliting the dosage and applying 3.4 kg a.i./ha to the soil and 2.2 kg a.i./ha to foliage. These data support the conclusion of Whitehead et al. (13) that application of oxamyl to the foliage of plants growing in oxamyl treated soil does not enhance the control of *G. rostochiensis*.

Several theories have been advanced concerning the mode of action of certain organophosphates and oxime carbamates against *G. rostochiensis*. Some workers (4,9) concluded that oxamyl and aldicarb interfere with hatching by interacting with the hatching stimulant. Others (1,3,11) concluded that oxamyl, aldicarb, and phenamiphos inhibit penetration by repelling the infective juveniles. The significant reduction in number of developing females on potato roots without a corresponding reduction in final population density of *G. rostochiensis* obtained in my experiments supports the theory that these compounds delay or inhibit hatching of *G. rostochiensis*.

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. Bunt, J. A. 1972. De systemische werking van D-1410, S, methyl 1-(dimethylcarbamoyl)-N-[(methyl-carbamoyl)Oxy]thioformimidate, tegen Heterodera rostochiensis bij aardapple en Pratylenchus penetrans bij Rosa canina. Mededelingen Fakulteit Landbouwwentenschappen Gent. 37:798-807.

3. Coolen, W. A., G. L. Hendrickx, and C. J. D'Herde. 1972. Orienterend onderzock naar de werking van de systemica aldicarb en D 1410 tegen endoparasiterende Wortelnematoden. Publikatie No. W9. Rijksstation voor Nematologie en Entomologie, Merelbeke.

4. Harrison, M. B. 1971. Evidence of the mode of action of a systemic nematicide. J. Nematol. 3: 311-312.

5. Hoestra, H., and H. Harshagen. 1978. Treatment of seed potatoes to control Globodera rostochiensis. Abstract 363 *in* Abstract of Papers, 3rd International Congress of Plant Pathology, Munich.

6. Homeyer, B. 1973. Ergebnisse mit Nemacur gegen nematoden im kartoffelbau. Mededelingen Fakulteit Landbouwwetenschappen Gent. 38:1251-1257.

7. Jones, J. M., and J. J. Uncles. 1976. Economics of nematicide use for the control of potato cyst nematode in ware crops. British Crop Protection Council Monograph No. 18:35-36.

8. MacKintosh, G. M., P. Osborne, R. M. Stewart, and D. L. Trudgill. 1977. Control of potato cyst eelworm with a resistant cultivar and with nematicides in Scotland. Pp. 36-37 *in* R. A. Fox, ed. Proceedings of a Symposium on problems of pest and disease control in northern Britain.

9. Osborne, J. 1973. The effects of aldicarb on the hatching of Heterodera rostochiensis larvae. Nematologica 19:7-14.

10. Ouden, H. den. 1971. De ontwikkeling van Heterodera rostochiensis larven in aardappelwortels bij behandeling met systemische nematicidenc in het biyzonder aldicarb. Mededelingen Fakulteit Landbouwwentenschappen Gent. 36:889-903.

11. Pain, B. F., and N. G. M. Hague. 1971. The effect of organo-phosphate and carbomyl-oxime nematicides against the potato cyst eelworm Heterodera rostochiensis Woll. Mededilingen Fakulteit Landbouwwentenschappen Gent. 36:161-173.

12. Proudfoot, K. G., and R. F. Morris. 1972. Chemical control of the golden nematode, Heterodera rostochiensis: greenhouse observations on DPX 1410 as a potato seed piece treatment. Canadian Plant Disease Survey 52:105-106.

13. Whitehead, A. G., J. E. Fraser, and G. Storey. 1972. Chemical control of potato cyst-nematode in sandy clay soil. Ann. Appl. Biol. 72:81-88.

14. Whitehead, A. G., D. J. Tite, and J. E. Fraser. 1973. Control of potato cyst-nematode, Heterodera rostochiensis in sandy loam by DuPont 1410 (S-methyl 1-(dimethylcarbamayl)-N-[(methyl-carbamoyl)oxy]thioformimidate) applied to soil at planting time. Ann. Appl. Biol. 73:325-328.

15. Whitehead, A. G., D. J. Tite, J. E. Fraser, and E. M. French. 1973. Control of potato cyst-nematode, Heterodera rostochiensis, in silt and peat loams by ten pesticides applied to the soil at planting time. Ann. Appl. Biol. 73:197-201.

16. Whitehead, A. G., D. J. Tite, J. E. Fraser, and E. M. French. 1979. Effect of oxamyl as a foliar spray. Pp. 170-171 *in* Report of Rothamsted Experimental Station for 1978. Part 1.