Management of *Pratylenchus penetrans* Damage to Peppermint with Selected Nematicides

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ABSTRACT

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Pratylenchus penetrans is the major nematode pest of peppermint in Oregon. Oxamyl, aldoxycarb, and carbofuran applied as broadcast sprays during spring reduced nematode densities and increased yields. Single treatments of 5.5 kg a.i./ha in early April were as effective as multiple treatments in April and May, or April, May, and June. Treatment effects were still evident after two seasons. Fall applications of oxamyl and carbofuran neither reduced overwintering nematode populations nor enhanced spring regrowth. Yield from a severely stunted stand on a sandy loam soil was increased by a 0.6-kg a.i./ha oxamyl treatment synchronized with root initiation in the spring, but 1.1- and 2.2-kg a.i./ha rates produced even greater yields than the lower rate. However, yields were not increased with these rates on a silty loam soil with similar pretreatment density of *P. penetrans*. *P. penetrans* management guidelines based on stand vigor, nematode population density, and edaphic factors are discussed.

Peppermint (*Mentha piperita* L.) is a major crop in the Pacific Northwest and has ranked fourth among Oregon's commodities. Four nematodes, *Meloidogyne hapla* Chitwood, *Aphelenchoides parietinus* (Bastian) Steiner, *Paratylenchus macrophallus* (deMan) Goodey, and *Longidorus elongatus* (deMan) Thorne & Swanger, have been reported from Oregon peppermint plantings (5). *Pratylenchus penetrans* (Cobb) Chitwood & Otiefa was detected in Indiana peppermint fields in the early 1960s (3). This root-lesion nematode species is also found in Oregon peppermint fields, and it is recognized as the predominant nematode pest of peppermint in the state (11).

The disease syndrome produced by *P. penetrans* in this perennial crop is characterized by a chronic decline. The first symptoms, which appear 2–4 yr after planting, are stunted plants and reddish foliage. Severely infected roots show numerous necrotic lesions and rarely penetrate the soil below 5–8 cm. Damaged plants show water and nutrient stress symptoms throughout the growing season. As decline progresses, fewer rhizomes are produced, and, consequently, stands thin in successive years. Plant damage by *P. penetrans* is most severe in sandy soils, where yield losses can exceed 95% (11).

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Control of *Pratylenchus* spp. and yield increases in peppermint were attained after preplant soil fumigation with dichloropropene-dichloropropane (H. J. Jensen, *unpublished*). However, resurgent nematode populations can reach damaging levels within 2–4 yr of fumigation. A carbamate nematicide, oxamyl, controlled *L. elongatus* damage of peppermint in greenhouse experiments (6) and rejuvenated declining stands in field trials (12). Four weeks before the 1978 harvest, oxamyl was issued an emergency registration in Oregon for use on peppermint to control *L. elongatus*. Many growers also applied oxamyl at the labeled rate of 2.2 kg a.i./ha in unthrifty stands with high *P. penetrans* soil populations. We established plots with 3.3 and 6.6 kg a.i./ha in similar stand conditions in July. These late-season treatments, however, did not increase 1978 hay yield (*unpublished*). Field trials were established in 1979–1981 to evaluate carbamate nematicide rates and application timings for controlling *P. penetrans* damage on peppermint.

MATERIALS AND METHODS

Nematicide trials were conducted in peppermint fields in various stages of decline and with high *P. penetrans* population densities. All fields contained the cultivar Todd's Mitcham and were located in three mid-Willamette Valley counties of Oregon: Linn in 1979, Benton in 1980, and both Linn and Marion in 1981.

Linn County 1 experiment. In 1979, trials were established in a 5-yr-old peppermint stand located on a gravelly bench in a Newberg fine sandy loam soil (66.4% sand, 22.3% silt, and 11.3% clay). Treatments were arranged in a randomized complete block with four replicates. Three nematicides (aldoxycarb, carbofuran, and oxamyl) were broadcast at 5.5 kg a.i./ha one to three times for totals of 5.5, 11, and 16.5 kg a.i./ha on contiguous plots 3.1 × 3.1 m. The first treatments were applied on 5 April, when plants were 5–10 cm tall, and where applicable, second and third treatments followed 30 (3 May) and 60 (2 June) days later. Untreated controls were included. Liquid formulations applied to soil surface and foliage were chosen for their compatibility with grower practices and equipment. Aqueous solutions of nematicides were sprayed at 250 ml/m^2 and incorporated by rainfall or irrigation. Standard cultural practices were followed throughout the season.

Nematode densities were determined on 20 March, 28 June, immediately after harvest on 7 August 1979, and in April 1980 by randomly collecting cores 10×10 × 10 cm under five plants within each plot. Soil was washed from root systems with a jet of tap water, and feeder roots were trimmed from rhizomes and crowns. A 10-g composite root sample from each plot was placed in a mist chamber for 7 days to extract *P. penetrans*. Nine soil samples were also collected in each plot with a standard 2.54-cm soil probe to a depth of 25 cm. Samples were bulked and processed by the Baermann funnel technique (10) to determine occurrence of phytonematodes. Hay yield was evaluated by harvesting three 1-m^2 areas within each plot. Stems were mowed 2–4 cm above the soil surface, and fresh hay weight was determined.

The grower inadvertently harvested the field before hay yields were collected in 1980. Therefore, stand vigor was based on mean stem count and mean stem diameter in six randomly selected 0.093-m^2 areas within each plot after harvest. The following values were assigned to these parameters: stem diameter, where 1 = <2.5 mm, 2 = 2.5–3.5 mm, 3 = 3.6–4.5 mm, and 4 = >4.5 mm, and stem count, where 1 = 1–10, 2 = 11–15, 3 = 16–20, 4 = 21–25, and 5 = >25. Treatment comparisons were based on the sum of mean stem diameter and count values in each plot.

Benton County experiments. In the fall of 1979 and the spring of 1980, nematicide treatments and an untreated control were established in a severely damaged 5-yr-old stand on a sandy loam (70.7% sand, 20.6% silt, 8.7% clay) ridge in Dayton silt loam soil. Experimental design was a randomized complete block with four replicates of contiguous plots 3.1 × 3.1 m. The nematicide treatments varied as to rate, timing of application, and compound. Single oxamyl treatments of 2.2 or 4.4 kg a.i./ha were broadcast on 12 September (fall), 7 April (early spring), or 13 May (late spring). Carbofuran was applied at 2.2 kg a.i./ha in the fall. Split oxamyl treatments, fall/early spring, fall/late spring, and early spring/late spring, consisted of 2.2 kg a.i./ha applied at each date. A 2.2-kg a.i./ha carbofuran (fall) and 2.2-kg a.i./ha oxamyl (early spring) treatment was also included. Treatments were applied as in the Linn County 1 experiment. Nematode populations from roots in fall and early and late spring and fresh hay weight in midsummer (15 August) were determined as described.

Marion County and Linn County 2 experiments. In 1981, plots were established in two fields with similar cropping histories. Both fields had high pretreatment *P. penetrans* densities. However, the stand on a Newberg fine sandy loam soil (74.6% sand, 19.4% silt, and 60.0% clay) was unthrifty (Marion County), whereas the other on a Newberg silt loam soil (15.8% sand, 56.7% silt, and 27.5% clay) was only slightly stunted (Linn County 2). Treatments, including controls, were arranged in a randomized complete block design with five replicates of contiguous plots 4.5 × 4.5 m. Treatments consisting of 0.6, 1.1, 2.2, and 4.4 kg a.i./ha oxamyl were applied on 2 April. To obtain nematode population data, root samples were collected and processed as in previous years on 2 April, 26 June, and 26 August. Two strips 0.9 × 3.6 m were mechanically harvested in each plot on 30 July. Differences in measured parameters were tested for statistical significance with Duncan's multiple range test.

RESULTS AND DISCUSSION

Single applications of oxamyl, aldoxycarb, or carbofuran in 1979 Linn County 1 plots reduced ($P = 0.05$) *P. penetrans* root populations at midseason (Table 1). By harvest, however, only nematode densities in the oxamyl-treated plots were less than those in the untreated plots. Repeated applications reduced root populations further, but with the exception of three applications of carbofuran, nematode densities were not less ($P = 0.05$) than those in plots receiving single treatments. One year

Table 1. Effects of three carbamate nematicides on root population densities of *Pratylenchus penetrans* and peppermint growth in Linn County 1[x]

		1979				1980	
		No. of *P. penetrans*/g fresh root					
Nematicide	No. of applications[y]	29 Mar.	28 Jun.	7 Aug.	Fresh hay (kg/m^2)	No. of *P. penetrans*/g fresh root (4 Apr.)	Vigor rating[z] (11 Aug.)
Control	0	1,780 a[x]	2,782 a	2,295 a	0.74 c	4,586 a	3.75 a
Oxamyl	1	2,239 a	88 b	437 bcd	2.50 a	628 bcd	7.75 d
	2	883 a	9 b	32 d	2.28 ab	300 cd	8.00 d
	3	1,568 a	1 b	7 d	2.66 a	37 d	8.25 d
Aldoxycarb	1	1,128 a	576 b	1,524 ab	1.86 b	1,663 b	6.50 bc
	2	1,485 a	303 b	699 bcd	2.48 ab	1,209 bcd	6.25 b
	3	1,546 a	234 b	444 bcd	2.59 a	1,137 bcd	7.50 cd
Carbofuran	1	1,147 a	425 b	1,430 ab	2.37 ab	1,373 bc	5.75 b
	2	1,310 a	90 b	959 bcd	2.14 ab	765 bcd	8.00 d
	3	1,218 a	137 b	236 cd	2.42 ab	467 bcd	7.50 cd

[x] Values are means of four replicates. Means in a column followed by the same letter do not differ significantly ($P = \leq 0.05$) according to Duncan's multiple range test.
[y] Number and timing of 5.5-kg a.i./ha applications; 1 = 5 April, 2 = 5 April and 3 May, and 3 = 5 April, 3 May, and 2 June 1979.
[z] Vigor rating is sum of stem diameter and stem count ratings. Mean stem diameter rating on a scale of 1–4, where 1 = <2.5 mm, 2 = 2.5–3.5 mm, 3 = 3.6–4.5 mm, and 4 = >4.5 mm. Mean stem count/0.93 m^2 rating on a scale of 1–5, where 1 = 1–10, 2 = 11–15, 3 = 16–20, 4 = 21–25, and 5 = >25.

Table 2. Impact of oxamyl and carbofuran application timing on root population densities of *Pratylenchus penetrans* and peppermint hay yield in Benton County, 1979–1980[y]

			No. of *P. penetrans*/g fresh root			
Nematicides	Rate (kg a.i./ha)	Timing[z]	12 Sept. 1979	25 Mar. 1980	25 Jun. 1980	Fresh hay (kg/m^2)
Control	0		2,678 ab[y]	2,879 a	1,982 ab	0.43 a
Carbofuran	2.2	Fall	1,562 b	2,267 ab	1,245 bc	1.00 abc
Oxamyl	2.2	Fall	2,414 ab	1,784 abc	2,084 ab	0.66 ab
	2.2	Esp	1,700 b	1,066 bc	279 d	1.21 abcd
	2.2	Lsp	2,356 b	2,188 ab	285 d	1.46 abcd
	4.4	Fall	2,513 ab	1,414 bc	2,197 a	1.05 abc
	4.4	Esp	2,384 ab	1,265 bc	48 d	1.11 abcd
	4.4	Lsp	2,769 ab	1,635 abc	209 d	0.93 abc
	2.2	Fall	1,693 b	1,151 bc	167 d	1.43 abcd
	2.2	Esp				
	2.2	Esp	3,899 a	688 c	92 d	1.76 cd
	2.2	Lsp				
	2.2	Fall	1,778 b	1,394 bc	446 cd	1.25 abcd
	2.2	Lsp				
Carbofuran	2.2	Fall	1,851 b	1,242 bc	203 d	2.09 d
Oxamyl	2.2	Esp				

[y] Values are means of four replicates. Means in a column followed by the same letter do not differ significantly ($P = 0.05$) according to Duncan's multiple range test.
[z] Treatment timings: Fall = 12 September 1979; Esp = early spring, 7 April 1980; and LSP = late spring, 13 May 1980.

after harvest, root population densities in all treatments remained below untreated levels, and the lowest populations again were in oxamyl plots. No economically damaging levels of other phytonematodes were detected in soil samples during this study, and none were found in subsequent experiments.

Population decline was accompanied by yield increase (P = 0.05) in all treatments (Table 1). All nematicide treatments produced yields two to three times greater than controls. However, the magnitude of yield response among treatments was not correlated to *P. penetrans* population reduction at midseason and harvest. Root growth paralleled yield response. Feeder roots in control plots were confined to the upper 5-cm soil profile, whereas plant roots in treated plots penetrated below 30 cm. Treatment effects were still evident in 1980, when vigor ratings of all treated plots were greater (P = 0.05) than those of the control.

The Benton County experiment was limited to oxamyl and carbofuran, which were registered for use on peppermint. Because carbofuran applications in the spring produce undesirable changes in oil quality, it was applied only in the fall. In most plots, nematode root populations declined from September to March (Table 2). Winter mortality was similar in both fall-treated and untreated plots. Thus, fall treatments were ineffective in reducing overwinter survival, and spring populations in these treatments exceeded densities considered yield-depressing. Conversely, all spring oxamyl applications reduced nematode densities at midseason, but rate and timing of spring treatments did not affect the magnitude of population reduction.

The Benton County stand was more severely stunted before treatment than Linn County 1 or Marion County stands, and plant cover within the plot areas was highly variable. These stand characteristics resulted in large yield variance among treatments so that only the fall carbofuran/ early spring oxamyl treatment and the early spring/ late spring oxamyl treatment produced yields greater than the control (P = 0.05). However, all treatments except the 2.2-kg a.i./ha fall oxamyl treatment produced average yields at least double that of the control. Yield increases observed were due to vigorous growth of individual plants, and these plants produced abundant rhizomes that spread across barren areas between plants by late summer. Similar unthrifty commercial fields treated in successive springs produced abundant roots from such rhizomes so that these stand canopies closed and yield potentials were restored (11).

Edaphic factors and pretreatment stand vigor influenced plant response to oxamyl treatments in the Linn County 2 and Marion County experiments (Table 3). The lowest oxamyl rate, 0.6 kg a.i./ ha, doubled yield at the Marion County experiment (sandy loam soil), even though nematode densities increased through the season. Higher rates, 1.1, 2.2, and 4.4 kg a.i./ ha, reduced populations and increased (P = 0.05) yields over the lower rate. Conversely, no yield increase occurred in the Linn County 2 experiment (silty loam soil), although pretreatment nematode densities in roots were equal to those in the Marion County experiment. When nematode populations in the roots are high, the peppermint root systems are markedly reduced in length and more branched. In coarse-textured soils, these shallow-rooted plants are subjected to substantial water and nutrient stress. However, *P. penetrans* population densities increase less rapidly in silt loam soils than in sandy loam (11), finer textured soils retain more moisture, plants are less stressed, and yields are not suppressed. This interpretation is consistent with the observations on peppermint in western Oregon (J. N. Pinkerton, *unpublished*), where *P. penetrans* damage is confined to sandy areas within fields.

Understanding oxamyl activity and peppermint phenology is useful to the interpretation of these data. Oxamyl concentrations of less than 500 μg/ ml have been shown to be nematistatic to *Meloidogyne incognita* second-stage juveniles (7). However, oxamyl-treated *M. incognita* juveniles recovered mobility after transfer to water (16). Oxamyl also reduced nematode, root penetration (1,9), and egg hatch (8). Nematistatic activity was confined to root surfaces with foliar oxamyl applications (14), and nematodes were less sensitive after penetrating into roots (15,16). Finally, oxamyl degradation is rapid, with a half-life of 1 wk and only 5% of the parent compound remaining after 30 days (4). Although oxamyl demonstrates therapeutic action with *P. penetrans*-infected apple and peach seedlings (2), our data suggest that its action is predominantly prophylactic at the low rates that are registered for use on peppermint.

In western Oregon, peppermint root growth from rhizomes begins in mid-March, increases through early summer, and ceases in late summer as new rhizomes are produced. In mature stands, roots from the current season become senescent by midfall. *P. penetrans* population dynamics parallel root growth (13). Population densities are at their lowest in midwinter, increase rapidly in mid-March as eggs hatch in the soil and root debris, and peak in mid-June. Early spring oxamyl applications temporarily protect young roots from invasion by nematodes, and treated plants become deeply rooted and thrifty. As the nematistatic effect of oxamyl diminishes, vigorous plants tolerate subsequent nematode penetration and feeding with minimal yield loss. Similarly, thrifty plants, as in Linn County 2 experiments, tolerate high nematode densities. Without annual nematicide treatments, rejuvenated stands, such as those in Linn County 1, decline during the next 2–3 yr. When decline progresses to where few rhizomes are produced, as in the 1980 Benton County experiment, an economically acceptable yield is not obtained after a single spring treatment. Oxamyl applications not synchronized with initial root growth and increasing nematode densities do not revitalize unthrifty stands. Fall treatments fail to increase fall regrowth or reduce overwintering *P. penetrans* populations because they are applied when plant growth and nematode activity are retarded by cooling soil temperatures. Midsummer treatments, as in 1978,

Table 3. Influence of oxamyl on hay yields and root population densities of *Pratylenchus penetrans* in two western Oregon peppermint fields with different soil types and stand vigors in 1981[y]

Rate	Marion County[z]				Linn County 2[z]			
	No. of *P. penetrans*/g fresh root			Fresh hay	No. of *P. penetrans*/g fresh root			Fresh hay
(kg a.i./ha)	2 Apr.	10 Jun.	26 Aug.	(kg/m^2)	2 Apr.	10 Jun.	26 Aug.	(kg/m^2)
0.0	1,114 a[y]	4,215 a	3,236 a	1.36 a	1,045 b	1,689 a	711 ab	2.28 a
0.6	1,957 a	2,660 b	3,556 a	2.71 b	1,648 ab	1,238 ab	943 a	2.53 a
1.1	2,735 a	943 b	1,964 ab	3.08 c	1,336 ab	1,215 ab	933 a	2.58 a
2.2	1,129 a	470 b	1,877 ab	3.19 c	1,947 ab	415 c	319 b	2.95 a
4.4	1,694 a	395 b	1,030 b	3.37 c	3,014 a	203 c	182 b	2.47 a

[y] Values are means of five replicates. Means followed by the same letter do not differ significantly (P = 0.05) according to Duncan's multiple range test.
[z] Marion County plots were established in an unthrifty stand on sandy loam soil. Linn County 2 plots were established in a moderately vigorous stand on silty loam soil.

follow the period of maximum root growth so that plants are unable to establish a robust root system and recover from early-season stress. Therefore, application guidelines based on annual evaluation of stand vigor, nematode population densities, and edaphic factors have been established. Fields should be partitioned and sampled by soil characteristics, and oxamyl should be applied to areas of coarse-textured soil where *P. penetrans* densities are greater than 200/g fresh root weight. By following these guidelines for the last 7 yr, annual early spring oxamyl applications at 1.1 to 2.2 kg a.i./ha have increased net returns $400–800/ha and maintained stand productivity in infested peppermint fields.

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