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Effects of Fumigants and Systemic Pesticides on *Pratylenchus penetrans* and Potato Yield

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Abstract: Replicated trials were conducted near Alliston, Ontario, in 1983 and 1984 to evaluate the efficacy of five chemical treatments in controlling the root-lesion nematode *Pratylenchus penetrans* on potato, *Solanum tuberosum* cv. Russet Burbank. The fumigants Vorlex, at 55 liters product/ha, and Telone II B, at 75 liters product/ha, were more effective in suppressing high initial population densities of 18,320 and 50,880 *P. penetrans*/kg soil in 1983 and 1984, respectively, than single applications of the systemic pesticides Temik 10 G at 22 kg product/ha, Vydate L at 18 and 9 liters product/ha, and Furadan 10 G at 33 kg product/ha. The combination of Vorlex + Temik resulted in greatest nematode suppression and lowest populations at harvest. In 1983, marketable tuber yield (> 7 cm) in the Vorlex + Temik plots was 20.7 t/ha, compared to 4.7 t for the untreated check. Vorlex alone and Telone II B plots yielded 17.3 and 15.9 t/ha, respectively; Temik with 7.5 t also yielded better than the check. Vydate and Furadan did not influence yields significantly. Total yields differed from the check in all treatments except with Furadan. In 1984, marketable yields ranged from 15.5 t/ha for the Vorlex + Temik treatment to 11.2 for the untreated check, but the differences were not statistically significant. Total yields, however, were significantly increased by the fumigants. The difference in response to chemical treatment in the 2 years was attributed to greater heat stress and lack of supplementary irrigation in 1983.
Key words: root lesion nematode, chemical control, Vorlex, Telone, aldicarb, oxamyl, carbofuran, cost, population dynamics, *Solanum tuberosum,* potato.

Damage to potato (*Solanum tuberosum* L.) by the root-lesion nematode *Pratylenchus penetrans* Cobb under field conditions has been reported earlier (3,21,22); no such effect was recently observed in greenhouse experiments (10). An interaction of *Pratylenchus penetrans* and the vascular wilt fungus, *Verticillium dahliae* Kleb., has been shown to cause the potato early dying disease (PED) in Ohio (11,24,25).

Fifty growers' fields suspected of having a nematode problem were surveyed in Simcoe County, Ontario, where 36% of Ontario's potato production is located. Sixty-four percent of these were infested with *P. penetrans* at a median density of 1,695/kg soil (18). Initial densities of 1,850 *P. penetrans*/kg soil have reduced the marketable yield of the Russet Burbank cultivar by 15.7% in microplots (15). As 47% of the *P. penetrans*-infested fields surveyed in Simcoe County contained late-summer and early-fall populations in excess of 2,000/kg, with 12% over 10,000/kg, the need for control measures became apparent.

Since *P. penetrans* reproduces on most crops, rotation is not practical. Similarly, although differences in susceptibility to damage by *P. penetrans* exist among potato cultivars (15,17), no economic degree of tolerance is known. *P. penetrans* is routinely controlled with nematicides in the flue-cured tobacco-growing areas of southwestern Ontario in soils of comparable texture (19). Elsewhere, increased potato yields after using nematicides in the field have been demonstrated (5–7,9,12,13,23).

This report describes the effects of row applications of fumigants and systemic insecticides–nematicides on population densities of *P. penetrans* and yields of Russet Burbank potatoes in field plots in Simcoe County, Ontario, in 1983 and 1984. A part of this study has been presented briefly elsewhere (16).

MATERIALS AND METHODS

Experimental plots were established near Alliston, Ontario, in a grower's field of Tioga loamy sand which had been in a potato–rye (*Secale cereale* L.) rotation for many years. Each plot, 2.7 m × 6.0 m, consisted of two experimental rows, 6.0 m long and

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0.9 m apart, with Russet Burbank potato plants spaced 0.3 m in the row for a total of 36 plants per plot. Guard rows, also spaced 0.9 m apart, on both sides of the two experimental rows, separated the plots. All the plots were arranged in a randomized block design with five replications. There was one untreated check and seven treatments with the following five chemicals: Vorlex (methyl isothiocyanate at 225 g/liter plus 1,3-dichloropropene and related chlorinated C_3 hydrocarbons at 925 g/liter) at 55 liters product/ha; Telone II B (guaranteed 92% 1,3-dichloropropene) at 75 liters product/ha; aldicarb, 2-methyl-2-(methylthio)propionaldehyde-*O*-methyl carbamoyl) oxime (Temik 10 G), at 22 kg product/ha; oxamyl, methyl 2-(dimethylamino)-N-[[methylamino)carbonyl]oxy]-2-oxoethanimidothioate (Vydate L, 24% a.i.), at 18 and 9 liters product/ha; and carbofuran, 2,3-dihydro-2, 2-dimethyl-7-benzofuranyl methylcarbamate (Furadan 10 G), at 33 kg product/ha. The fumigants Vorlex and Telone II B were applied in the row 29 days before planting, whereas the three systemic compounds were applied in the row at planting (24 May).

On 25 April 1983, the rye-covered plots were cultivated in two directions with a triple K-type cultivator and the soil compacted with a roller before fumigation. On the same date in 1984, the bare soil was drag harrowed to smoothness. In both years, six soil cores, 2.5 cm d and 20 cm deep, were collected from each experimental row, a total of 12 per plot, for determination of pretreatment nematode population densities by the Baermann pan method (26). Immediately thereafter, Vorlex and Telone II B were applied with an Arimitsu HP-2 soil injector (Pfizer C & G, Inc., London, Ontario) 15 cm deep at 20-cm intervals within the row at rates listed in Tables 1–3, and the soil surface sealed by compaction. On 24 May in both years, soil samples for the determination of the initial population densities (Pi) were taken as before. Furrows, 7.5–10 cm deep and 5–10 cm wide, were dug with hoes, and granules of Temik 10 G and Furadan 10 G, mixed with 200 g sieved, dried soil for carrying purposes, were sprinkled on the bottom of the 6-m-long furrows at rates shown in Tables 1–3. Vydate, diluted in 2 liters water, was poured along the bottom of the furrows. Immediately afterward, whole certified seed tubers were placed on the bottom and the furrows closed. Seventeen days after planting, all plots received a 15-15-15 commercial fertilizer at 1,540 kg/ha as a broadcast treatment, followed by hilling of all rows with a regular moulding unit. Three days later, the area was sprayed with the pre-emergent herbicide Afolan F (linuron 450 g/liter) at 2.8 liters/ha including (in 1983) Gramoxone (paraquat 200 g/liter) at 2.75 liters/ha to control the rye, some of which had re-emerged. Sprays of fungicides (zineb) and insecticides (methidathion) as required were applied by aerial spraying by contract applicator for the balance of the season. Natural rainfall was supplemented by sprinkler irrigation in 1984 only.

On 12 July 1983 and 11 July 1984, the number of missing plants (percentage stand) was recorded, plant vigor (height and spread of plant tops) at mid-season was visually rated, and soil samples for the determination of population densities at mid-season (Pm) were taken. On 3 October 1983 and 2 October 1984, soil samples were collected as before for the determination of final nematode population densities (Pf), followed by hand harvesting of all plots. Tubers 7.0 cm long or longer were classified as marketable as in commercial practice. Nematode count data were transformed (log [x + 200]) before statistical analysis. A Duncan multiple-range test was carried out on all data after checking for significance of the *F*-value, and orthogonal comparisons made.

Results

In 1983, percentage stand determined 7 weeks after planting was 98.5% and plant vigor was increased only by Vorlex + Temik, Telone, and Vydate at 9 liters/ha. In 1984, percentage stand was 99.4% and all treatments had increased plant vigor at that

TABLE 1. Soil population densities of *Pratylenchus penetrans* in nematicide-treated and control Russet Burbank potato plots at Alliston, Ontario, at planting, mid-season, and harvest, 1983. Data are means of five replications.

Treatment	Rate product/ha	No. *P. penetrans*/kg soil At planting (Pi) (24 May)	At mid-season (Pm) (12 July)	At harvest (Pf) (3 October)
Vorlex + Temik 10 G	55 liters + 22 kg	100 b y	10 f y	720 e x
Vorlex	55 liters	350 b y	550 de y	10,540 bcd x
Telone II B	75 liters	260 b y	130 ef y	5,540 d x
Temik 10 G	22 kg	17,880 a x	2,600 d y	6,960 cd x
Vydate	18 liters	15,960 a x	1,820 cd y	17,520 ab x
Vydate	9 liters	16,480 a x	4,000 bc y	25,960 ab x
Furadan 10 G	33 kg	14,100 a x	5,820 b y	15,340 abc x
Check		18,320 a x	20,130 a x	27,820 a x
S.E.M.		2,690	1,920	3,570

Column means followed by common letters a–f and row means followed by common letters x and y are not significantly different ($P = 0.05$), according to Duncan's multiple-range test on data subjected to a log (x + 200) transformation. Standard Error of Means (S.E.M.) were calculated on untransformed data.

TABLE 2. Soil population densities of *Pratylenchus penetrans* in nematicide-treated and control Russet Burbank potato plots at Alliston, Ontario, at planting, mid-season, and harvest 1984. Data are means of five replications.

Treatment	Rate product/ha	No. *P. penetrans*/kg soil At planting (Pi) (24 May)	At mid-season (Pm) (11 July)	At harvest (Pf) (2 October)
Vorlex + Temik 10 G	55 liters + 22 kg	330 c x	500 d x	2,000 d x
Vorlex	55 liters	400 c z	6,570 bc y	10,440 c x
Telone II B	75 liters	2,180 b z	6,340 bc y	14,200 abc x
Temik 10 G	22 kg	35,600 a x	2,860 c z	10,140 c y
Vydate	18 liters	34,730 a x	6,140 bc y	16,680 abc x
Vydate	9 liters	47,520 a x	10,440 b y	13,630 bc y
Furadan 10 G	33 kg	45,480 a x	11,190 b y	25,740 a x
Check		50,880 a x	36,140 a xy	24,620 ab y
S.E.M.		4,280	1,860	1,530

Column means followed by common letters a–d and row means followed by common letters x–z are not significantly different ($P = 0.05$), according to Duncan's multiple-range test on data subjected to a log (x + 200) transformation. Standard Error of Means (S.E.M.) were calculated on untransformed data.

stage. Visual inspections throughout the growing season failed to reveal symptoms associated with *Verticillium dahliae* in any of the plots.

In 1983, Vorlex + Temik 10 G reduced the Pi to 100/kg from 25,150/kg, the density before treatment on 25 April (Table 1). Vorlex alone and Telone reduced the respective Pi from 25,430 and 23,620/kg soil before treatment to 350 and 260/kg. Temik, Vydate at both rates, and Furadan, applied at planting, resulted in significant decreases by mid-season. At harvest, population densities with the combination Vorlex + Temik had increased but were still only 720 *P. penetrans*/kg soil. Population densities with Vorlex alone, Telone, and Temik were still significantly lower than the check at harvest. Population densities in the remaining treatments had increased at harvest and differed significantly from those at mid-season but were not different from the untreated check.

In 1984, Vorlex + Temik 10 G and Vorlex alone were equally effective in reducing the respective Pi from 38,520 and 52,080/kg soil before treatment to 330 and 400/kg (Table 2). Telone was also quite effec-

TABLE 3. Effect of nematicides on yield of Russet Burbank potatoes in *Pratylenchus penetrans*-infested field plots at Alliston, Ontario, in 1983 and 1984. Data are means of five replications.

Treatment	Rate product/ha	Yield (t/ha)			
		Marketable (> 7.0 cm)		Total	
		1983	1984	1983	1984
Vorlex + Temik 10 G	55 liters + 22 kg	20.7 a	15.5 a	23.5 a	29.9 a
Vorlex	55 liters	17.3 b	14.1 a	20.2 b	27.2 ab
Telone II B	75 liters	15.9 b	13.9 a	19.7 b	25.5 bc
Temik 10 G	22 kg	7.5 c	11.6 a	10.0 c	21.5 cd
Vydate	18 liters	6.9 cd	9.8 a	9.4 c	22.7 cd
Vydate	9 liters	6.4 cd	9.8 a	9.3 c	22.4 cd
Furadan 10 G	33 kg	5.8 cd	11.0 a	8.4 cd	18.8 d
Check		4.7 d	11.2 a	6.3 d	19.0 d
S.E.M.		0.73	0.60	0.87	0.77

Values in each column followed by the same letter are not significantly different ($P = 0.05$) according to Duncan's multiple-range test. Standard Error of Means (S.E.M.) were calculated on untransformed data.

tive with 2,180/kg, down from 51,480/kg on 25 April. At mid-season, all treatments contained lower Pm than the check. Densities in the Vorlex + Temik, Vydate 9, and check did not change from mid-season to harvest; the other treatments were higher at harvest.

In 1983, marketable yield of potatoes grown with Vorlex + Temik was highest followed by Vorlex alone and Telone (Table 3). Treatment with Temik also resulted in an increase in marketable yield, but treatments with the remaining compounds did not. Increases in total yield in 1983 paralleled those for marketable yields except that only Furadan did not bring about an increase as compared with the check. In 1984, none of the compounds significantly increased the marketable yield; however, total yields were increased by the three fumigant treatments.

DISCUSSION

In both years, the fumigants Vorlex and Telone II B were most effective in suppressing population densities of *P. penetrans* to almost negligible levels at planting. One exception in 1984 was Telone II B which was 95% effective but still left a Pi of 2,180/kg soil (Table 2). The systemic compounds Temik, Vydate, and Furadan, applied at planting, suppressed Pm (Tables 1, 2). In both years, however, the suppression obtained with the combination Vorlex + Temik (and with Telone in 1983) at mid-season was still greater than that achieved with the systemic compounds. The Pf in the soil treated with Vorlex + Temik was quite low compared with the other treatments and the check. In both years, all treatments except Vydate and Furadan showed lower Pf at harvest than the check. In 1984, Telone II B also failed to lower the Pf relative to the check. Other workers (13) reported that Telone and Furadan suppressed *P. penetrans* up to harvest time; however, they used much higher rates.

The differences in nematode population densities in the middle of July of both years were generally related to plant vigor rated at mid-season. An exception was the Vorlex treatment in 1983 when insufficient aeration of the soil, as sensed by smell at planting, caused some initial stunting. Also, Vydate at 18 liters/ha caused some growth retardation during the first few weeks as was observed earlier (20).

Regression analyses between the log (x + 200) transformation of Pi, Pm, Pf, and the total yield showed a significant ($P = 0.05$) negative correlation in both 1983 and 1984 (Fig. 1). The slopes were flatter, however, for the Pi ($b = -1.7745$) and Pm ($b = -2.5984$) in 1984 than in 1983. The observation that early suppression of the root-lesion nematode results in maximum crop protection has also been observed in flue-

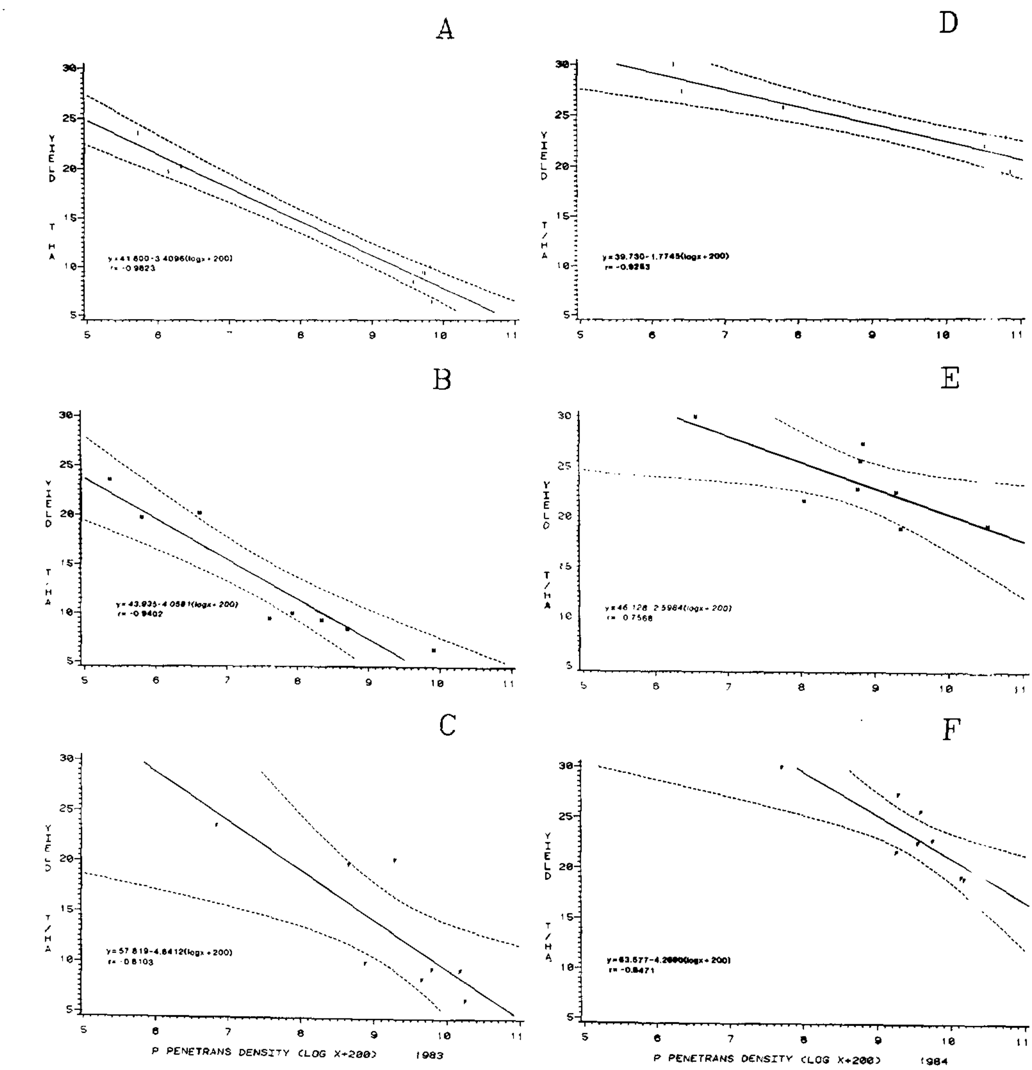

FIG. 1. Linear regression with 95% confidence intervals between the log (x + 200) transformation of soil population densities of *Pratylenchus penetrans* and total potato tuber yields in t/ha. A, D) Initial densities. B, E) Mid-season densities. C, F) Final densities. A–C) 1983. D–F) 1984.

cured tobacco (19). With that crop the nematode causes most of its damage by destroying parts of the young root system. In vitro studies with alfalfa (14) showed that the increased resistance or tolerance of plants to nematode damage as the plant becomes older is related to a decrease in nematode penetration with increase in age of root tissue.

Total yields were lower in 1983 than in 1984, as were the differences attributed to nematode control. The importance of drought in exacerbating the effect of *P. penetrans* has been noted elsewhere (2,8,11). Although the total amount of rainfall was 29% less than the long-term average in both years (Table 4), the somewhat drier condition in June 1983 may have aggravated the damage caused in the early stages of root development more so than in 1984. In addition, the potato plants did not receive any irrigation in 1983 because the plots were located in a large field cropped to small grains. In 1984, however, the experimental plots received supplementary irrigation as applied to the surrounding

TABLE 4. Summer rainfall (mm) and mean daily average temperature (C) at Alliston, Ontario, in 1983 and 1984.

	1983		1984	
	Amt	Dev†	Amt	Dev
Rainfall				
June	28.5	−29.7	35.7	−22.5
July	43.8	−26.1	26.4	−43.5
August	70.6	+14.4	80.8	+24.6
Total	142.9	−41.4	142.9	−41.4
Temperature				
June	18.4	+1.0	18.7	+1.3
July	22.1	+2.5	20.0	+0.4
August	21.0	+2.2	20.8	+2.0

† Deviation from long-term Environment Canada weather averages (1).

commercial potato crop. The data support Kimpinski's observations (7) that potato plant root systems damaged by root-lesion nematodes are much less able than healthy plants to cope with moisture stresses.

High-temperature stress during tuberization exacerbated yield losses due to *P. penetrans* in Ohio (24,25). In Alliston, temperatures were above normal during June, July, and August, both in 1983 and 1984 (Table 4). According to Burton (4), under typical field conditions, net assimilation for potato plants falls to zero at about 30 C. During June, July, and August 1983, the daily maxima exceeded 30 C on 22 days, compared with only 11 days during the same period in 1984 (1). The greater heat stress in 1983 may have contributed to the lower yields in that year.

The timing of the moisture and temperature stresses on the potato crop may account for the fact that the marketable tubers (> 7 cm) in 1983 accounted for 80% of the total numbers vs. only 52% in 1984. Based on commercial grading, which depends on cultivar, destination, and socioeconomic factors, there were no statistically significant differences in marketable potato yields due to nematicidal treatments in 1984. However, the degree of control in 1984, based on total yield, which is probably a better criterion than marketable yield from a biological standpoint, closely followed the ranking observed in 1983, with the fumigants giving best protection.

In a previous study (20), Vydate L applied preplant in-furrow at 9 liters/ha, followed by five foliar sprays at 9 liters/ha total resulted in a 9.5 t/ha (44.4%) increase in marketable yield of Russet Burbank potatoes, and five foliar sprays only at 18 liters/ha increased yields 8.4 t/ha (39.3%) compared with the check grown in soil with an initial infestation of 10,700 *P. penetrans*/kg. Other recent work (9) also showed the effectiveness of aldicarb and oxamyl in the control of *P. penetrans* on potato in Canada.

The present study has clearly shown that the use of fumigants, preferably combined with a systemic pesticide such as Temik, is superior to single applications of systemic compounds alone. Similar results were obtained in the control of *Meloidogyne chitwoodi* in Russet Burbank potatoes in Washington (23). Although orthogonal comparisons revealed significant differences ($P = 0.05$) in population densities and total yields between the combination of Vorlex and Temik and the sum of the effects of these two compounds applied singly, inspection of the data (Tables 1–3) does not suggest a potential synergism.

In 1983, the costs of the chemicals per ha were $420 (Can.) for the combination of Vorlex + Temik, $310 for Vorlex alone, $185 for Telone II B, $110 for Temik, $190 for Vydate 18 L, $95 for Vydate 9 L, and $85 for Furadan. Based on the above costs, and at a return of $100/t, a grower would have benefited greatly from using fumigants or Temik in 1983, but little, if at all, in 1984. The data suggest that proper irrigation measures could reduce or negate the necessity of chemical control by reducing moisture stress.

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