Analysis of Crop Losses in Tomato Due to *Pratylenchus penetrans*

J. W. POTTER and TH. H. A. OLTHOF[1]

Abstract: The effects of *Pratylenchus penetrans* upon yields of 'Veebrite' tomato were studied at initial soil population densities (P_i) of 360, 2,010, 4,580, and 14,360 nematodes/kg of soil in 20-cm (i.d.) clay-tile microplots. The lowest P_i appeared to stimulate fruit production. Higher P_i's suppressed fruit production (total weight of marketable tomatoes and numbers of intermediate- and large-sized fruits), in comparison to control yields, the highest P_i resulted in 38% fewer fruits which weighed 44% less. These losses were at least partly due to a delay in fruit ripening, caused by the nematodes, which did not become apparent until the fourth week. Nematode populations in the soil increased at all but the highest P_i; final populations were around 7,000/kg of soil. Nematode populations in roots ranged from 230-590/gm of root at the completion of the experiment. Nematode control by fumigation would definitely be warranted at soil population densities of 2,000/kg or higher; with 500-2,000/kg, the decision to fumigate would depend on soil type and economic and biological factors. *Key Words:* root-lesion nematodes, populations, *Lycopersicon esculentum.*

Tomatoes, which had a farm value near $30 million in 1974 (8), are an important crop in Ontario. Fresh-market tomatoes account for 10% of the area's tomato production and 20% of the total farm value of the crop. Field tomatoes for processing make up the remaining area and farm value.

Root-lesion nematodes, *Pratylenchus* spp., are widespread in the tomato-growing areas of Ontario (12). Mountain and Fisher (5) found large numbers of *Pratylenchus penetrans* (Cobb) Filipj. & Shuurm.-Stekh. associated with stunted field tomatoes near Leamington, Ontario. Johnson and Boekhoven (2) detected *Pratylenchus* sp. in tomato greenhouse soils in the same area. In field experiments in the Netherlands, Oostenbrink et al. (9) found significant damage to tomatoes associated with initial densities of 400-1,800 root-lesion nematodes (predominantly *P. penetrans*)/kg of soil. Miller (4), in pot experiments, found an increase in root-browning and a decrease in plant height with increases in densities of *P. penetrans* up to 550/kg of soil. Estores and Chen (1) similarly demonstrated suppression of tomato growth by *P. penetrans.*

Previous studies in Ontario (6, 11) have shown that other vegetables suffer economic losses due to *P. penetrans,* but the relationship between nematode numbers and extent of loss in tomatoes was not established. Consequently, a detailed quantitative analysis of yield losses was undertaken to determine the nature and extent of losses due to *P. penetrans* in tomato and to define the economic loss thresholds required in connection with control recommendations.

MATERIALS AND METHODS

The nematode inoculum used in this study was reared on Vineland loam soil in greenhouse groundbeds. The root-lesion nematode, *P. penetrans,* came originally from rye (*Secale cereale* L. 'Tetra Petkus') and was increased on that crop. In April 1971, the number of nematodes in the groundbed soil was determined by the Baermann pan method (15). A microplot experiment was designed to determine the effects of four different initial population densities (P_i) of *P. penetrans* on tomato growth and yield. The design was a randomized block with 20 replicated microplots for each of the four P_i's and for the noninfested checks. The microplots were 20-cm i.d. x 30-cm long clay drainage tiles. These were plunged in the field in rows 1.5 m apart, spaced 1.2 m within the row, and filled with 10 kg of soil (6). Steam-treated (2 h at 104 C), nematode-free Vineland loam soil was used for the checks. Soil for each P_i was prepared by mixing groundbed soil with steam-treated soil for 5 min in a cement mixer; the different P_i's were

Received for publication 3 January 1977.

[1] Nematologists, Research Station, Agriculture Canada, Vineland Station, Ontario, L0R 2E0. We thank V. Rundans, C. Barber, and D. Keunen for technical assistance; P. Y. Jui, Statistical Research Service, Research Branch, Agriculture Canada, Ottawa, Ontario, for statistical analyses and advice; E. A. Kerr, Horticultural Research Institute of Ontario, Simcoe, Ontario, for Veebrite tomato seed and for helpful discussions; and E. A. Peterson, Chemistry & Biology Research Institute, Research Branch, Agriculture Canada, Ottawa, Ontario, for analysis of soil microflora.

obtained by adjusting the groundbed soil: steam-treated soil ratio.

One 6-week-old, 10- to 15-cm high tomato seedling (*Lycopersicon esculentum* Mill. 'Veebrite') was transplanted into each microplot. A two-core soil sample was taken from each of five microplots for each P_i to confirm the initial densities at transplanting. A 50-gm portion of air-dried groundbed soil was added to each check microplot to insure that all microplots had qualitatively the same microflora present. At transplanting, the soil in each microplot received a standard fertilizer application (6). Height of all plants was measured 23 and 31 days after transplanting. Soil samples were taken, to a depth of 15-20 cm from five microplots of each P_i 35 days after transplanting, to determine the nematode population densities at midseason. When the tomato vines first became prostrate, straw mulch was applied around each microplot to prevent ripening fruit from contacting the soil. Aphids and other insects were controlled with sprays, applied as required, of diazinon W50, 0.2 kg/100 liters of water. Resistance-block moisture-temperature sensors at depths of 15 and 30 cm in two microplots, one in each half of the block, indicated when irrigation was required.

Starting on 26 July (10 weeks after transplanting), ripe fruits were picked twice weekly and were individually weighed and graded to sizes as specified by the Farm Products Grades and Sales Act (13). At the end of the picking period (7.5 weeks), all remaining fruits were removed, weighed, and measured. Top weight and root weight were recorded for each microplot. The final nematode population in the soil (P_f) was determined for each microplot (15), and the nematodes were extracted from the roots (6). A composite soil sample was taken, and suitable dilutions of the soil were plated with glucose-peptone agar containing rose bengal and chlortetracycline (10) for isolation of fungi and with soil extract agar (3) for determination of number of bacteria. Plant-growth data and nematode counts were subjected to analysis of variance and Duncan's Multiple Range Test, and the weights and numbers of fruit were correlated with nematode numbers, times of fruit picking, and the size categories employed in the grading.

RESULTS

Population densities (P_i) at transplanting (360, 2,010, 4,580, and 14,360 larvae per kg of soil) had changed relatively little 5 weeks later at mid-season (Table 1). At termination of the experiment, ca. 18 weeks after transplanting, a trace nematode infestation was present in the check microplots, and P_f values in the other microplots were greater than all but the highest P_i.

A trace of *P. penetrans* was found in roots of check plants, whereas large numbers were extracted from the roots of all tomatoes grown in infested soil (Table 1). Highest populations, both per root system and per gm of root, were recovered from plants grown at a P_i of 2,010/kg of soil.

In comparison to control plants, 14,360 nematodes/kg of soil suppressed plant growth (height) by 16% and 35% at 23 and 31 days respectively after transplanting (Table 2). None of the other P_i's affected

TABLE 1. Population densities of *Pratylenchus penetrans* under Veebrite tomato[x].

Initial density no./kg soil (P_i)	Numbers/sampling time			
	Mid season[y] no./kg soil	Final[z] No./kg soil	Final[z] No./root system	Final[z] No./gm root
360	470	3,000a	17,820a	230a
2,010	1,670	6,390b	38,000b	590b
4,580	6,960	8,390c	20,490a	350c
14,360	13,660	7,330bc	11,220c	360c

[x]Column means followed by a letter in common do not differ, according to Duncan's Multiple Range Test ($P = 0.05$).
[y]Based on samples from 5 replicates.
[z]Based on samples from 20 replicates.

TABLE 2. Effects of *Pratylenchus penetrans* on vegetative growth of Veebrite tomato[y].

Initial density no./kg soil	Height (cm)		Plant weights (gm) at harvest		
(P_i)	23 days	31 days	Tops[z]	Roots	Total[z]
Check	17.6a	26.7a	980a	80ab	1,060a
360	16.7a	24.4a	970a	100a	1,070a
2,010	18.2a	25.7a	730b	70b	800b
4,580	17.3a	23.9a	670b	60b	730b
14,360	14.8b	17.5b	440c	40c	480c

[y]All data are means of 20 replicates. Column means followed by a letter in common do not differ, according to Duncan's Multiple Range Test ($P = 0.05$).
[z]Excluding fruit weight.

plant height during the first month. At termination of the experiment, top weights of plants, excluding fruit, and total plant weights were lower than the controls at P_i's of 2,010/kg of soil and greater (Table 2). Root weights at termination tended to be greater at a P_i of 360/kg in comparison with root weights of the checks, but at higher P_i's, root weights were progressively lighter with increasing P_i.

Both number and total weight of tomato fruit tended to decrease in all size categories (Fig. 1, 3) with increases in P_i; however, at the lowest density (P_i = 360

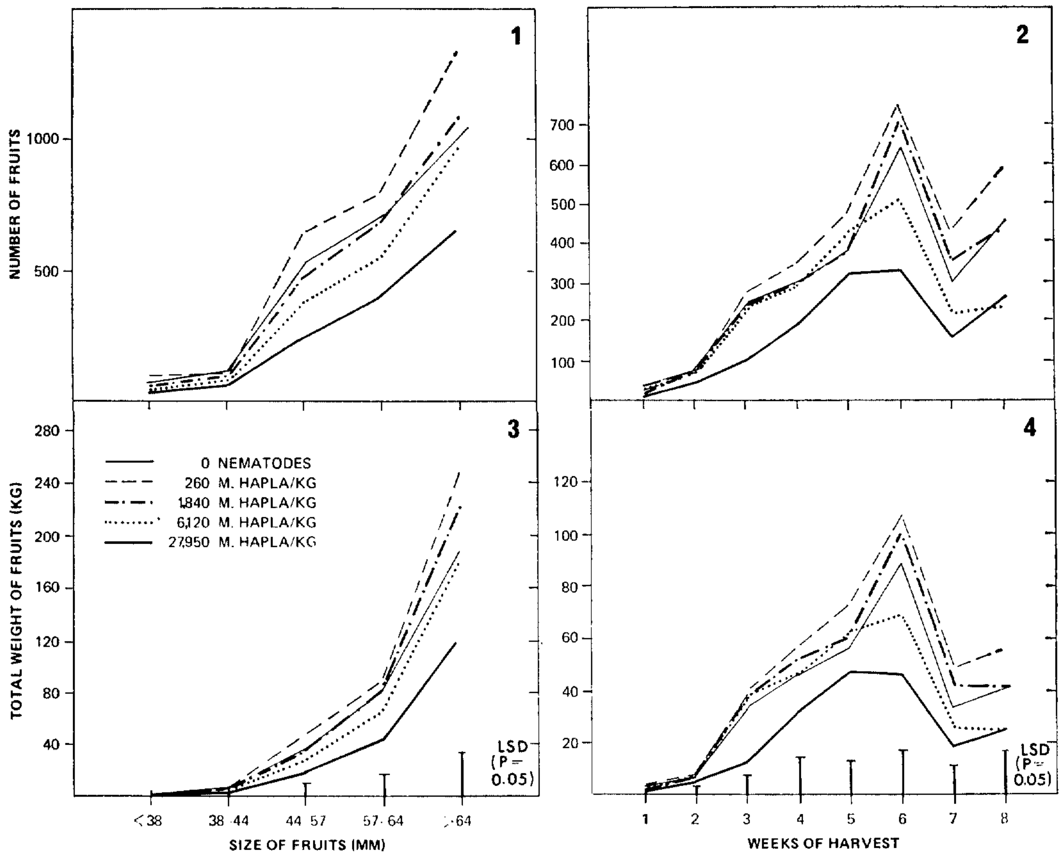

FIG. 1-4. Average yield of Veebrite tomato. *1)* Number fruits of each size range for each P_i of *Pratylenchus penetrans*. *2)* Number fruits per week of harvest for each P_i of *P. penetrans*. *3)* Total weight of fruits of each size range for each P_i of *P. penetrans*. *4)* Total weight of Veebrite tomato fruits per week of harvest for each P_i of *P. penetrans*.

per kg), numbers and weights of fruit were increased relative to those of the check.

The differences in total yield of fruit throughout the season are depicted as the cumulative numbers of fruits versus size (Fig. 5) and harvest period (Fig. 6), and as the cumulative total weight of fruit versus size (Fig. 7) and harvest period (Fig. 8). Yield of tomatoes was suppressed at high P_i's because fewer fruits of 44 mm diameter and larger were produced (Fig. 5) and consequently there was a lower total weight of fruit produced (Fig. 7).

Until the 4th week of harvest, only slight differences were observed in the numbers and weights of fruits produced weekly among the various nematode densities (Fig. 2, 4). From then until the 8th week, fruit production at the highest P_i was less than in other treatments. Maximum weekly production for the check and the two low densities (360 and 2,010 nematodes per kg) occurred during week 6, whereas at P_i = 4,580/kg, maximum production was reached at week 7; at P_i = 14,360/kg, the largest weight and number of fruits was produced in week 8 at the termination of the experiment.

The cumulative yields of fruit, both in numbers (Fig. 6) and in total weights (Fig. 8), were low at high P_i's from the 4th through the 8th week. At the highest P_i, final losses, relative to the check of numbers and of total weights, were 38% and 44%, respectively.

The fungi found in the soil were common saprophytes belonging to the same genera as listed previously (6); bacterial counts averaged 23 x 10^6/gm of soil. There were no apparent differences in microflora

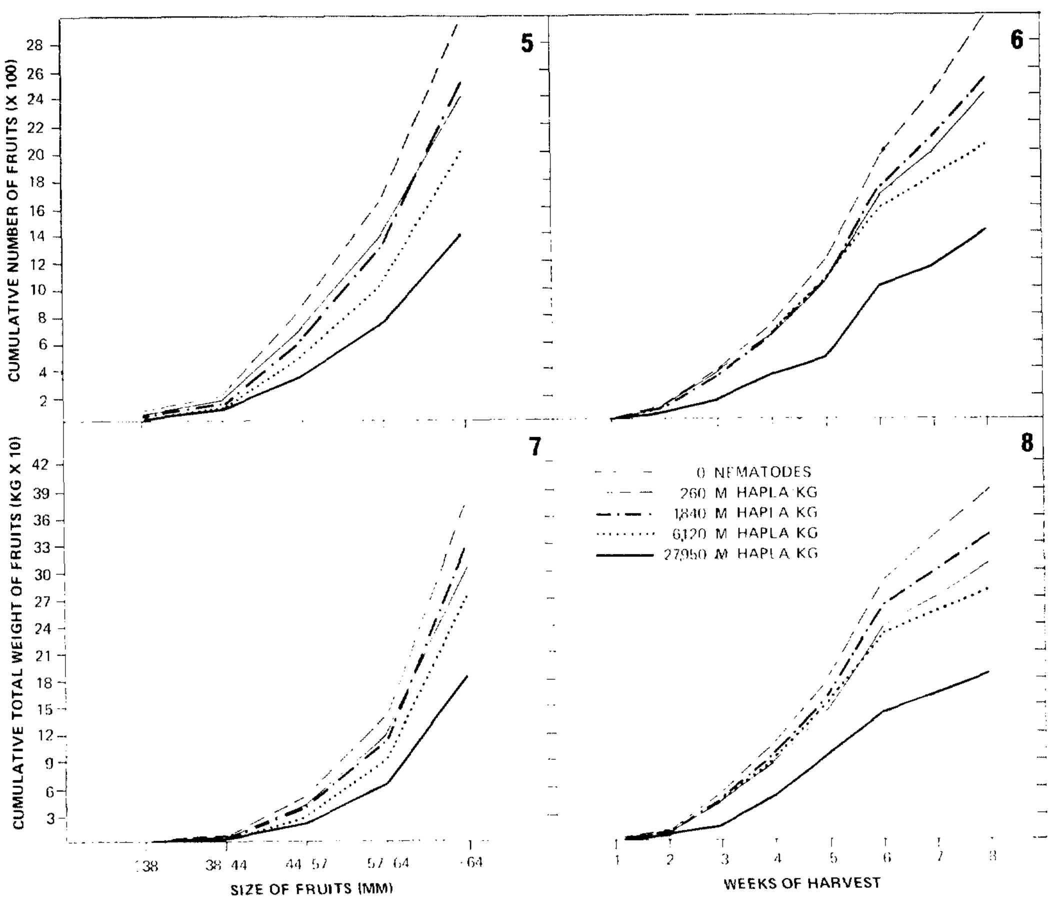

FIG. 5-8. Yield of Veebrite tomato. *5)* Number of fruits over all weeks of harvest for each P_i of *Pratylenchus penetrans. 6)* Total weight of fruits over all sizes for each P_i. *7)* Total weight of fruits over all sizes for each P_i. *8)* Total weight of fruits over all weeks of harvest for each P_i.

among the treatments.

Climatic conditions were favorable for plant growth during the experiment (Fig. 9); natural rainfall was supplemented with irrigation through May, after which rainfall alone was sufficient to maintain moisture near field capacity for the rest of the experiment.

DISCUSSION

High populations of *P. penetrans* affected yield of Veebrite tomato in this study by delaying fruit ripening. The result was fewer fruits which weighed less. No effect on fruit production was evident to the 3rd week of harvest, but differences at the two higher P_i's were apparent from the 4th week. These differences were mainly in smaller numbers and weights of the larger fruit, 44 mm or larger. The results represent the outcome of an interaction of plant growth rate with nematode attack and population increase. When high nematode population densities cause severe root destruction, plant development will be retarded with a subsequent loss in crop yield (7).

In our study, plant height within the first month after transplanting provided early evidence of growth retardation at the highest P_i; subsequently, this delay in growth and maturity resulted in yield losses. In southwestern Ontario, tomato blossoms must be set by 3 to 10 August to permit maturation of fruit (E. A. Kerr—personal communication). Moreover, tomato fruits fail to develop full color at temperatures below 15 C; thus a delay in fruit set could result in a loss in total yield over the season. In our work, the yield losses were probably not affected significantly by temperature, which was adequate during the fruiting period for fruit maturation and color development. The frequency of picking used in this experiment (two pickings/week over 8 weeks) was much higher than is usual in most experiments and with growers (two or three pickings per season). However, had the experiment been terminated sooner or been confined to a single picking, information on temporal yield patterns would have been lost. For example, the decline in the rate of fruit production beyond the sixth week with most P_i's would not have been observed, nor would the increase (indicating the delay of plant development) in fruit production rate at the highest P_i in the last 2 weeks have been noted.

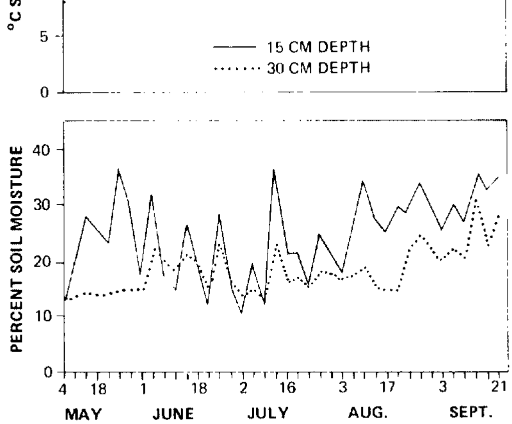

FIG. 9. Average biweekly soil temperature and moisture at two depths under Veebrite tomato.

The final densities (P_f) of *P. penetrans* increased by 10, 3, 2, and 0.5 x relative to the P_i's which converged to approximately 7,000/kg of soil. The results suggest that 8,000/kg appears to be the "equilibrium density" (14) with Veebrite tomato in our experiment. The root population densities at harvest reached a high of 38,000/root system at P_i = 2,010 and decreased at higher P_i's, probably because of root damage. A similar relationship was evident when the root populations were expressed as the number of nematodes/gm of root. With the two lowest P_i's (360 and 2,010) in our experiment, which were similar to those used by Miller (4) and Oostenbrink et al. (9), the root P_f, comparable with theirs (respectively 870-950 and 100-1,000/gm), ranged from 230-590/gm. However, when we used higher P_i's than were employed by other workers, we still found P_f's from 230-590/gm of root. Consequently, above a certain minimum soil P_i, there is apparently no direct relationship between the soil P_i and the root P_f. However, the root P_f is probably directly related to root weight, particularly where the destruction of roots (because of a high soil P_i) limits further nematode multiplication.

In 1970-1974, the value of tomatoes grown for the fresh market in Ontario was \$4,312/ha and for processing, \$2,178/ha. The cost of row fumigation at 45 liters of Vorlex/ha was approximately \$100/ha. The economic loss thresholds, as defined previously (6), were therefore, respectively 2.3% and 4.6% of the value of the crop. Initial nematode densities in excess of 360/kg of soil in this experiment caused percentage losses exceeding the economic loss thresholds. At P_i = 360, yield was increased by 8%, whereas a 12% loss was observed at P_i = 2,010. In view of this higher yield at the lowest P_i, fumigation would be inadvisable at P_i's at or below 360. The decision whether to fumigate or not at P_i's from 360-2,000/kg of soil would depend on whether processing or fresh market tomatoes were being grown, whether the crop was on a coarse-textured or a fine-textured soil, and on market tomato price levels and fumigant costs. At P_i's exceeding 2,000 nematodes/kg, fumigation would be both necessary and economically profitable.

This study has shown that *P. penetrans* causes significant losses to tomatoes at population densities comparable to those commonly found in coarse-textured soils in southwestern Ontario.

LITERATURE CITED

1. ESTORES, R. A., and T. A. CHEN. 1970. Interaction of Pratylenchus penetrans and Meloidogyne incognita acrita as cohabitants on tomatoes. Phytopathology 60:1291 (Abstr.).
2. JOHNSON, P. W., and L. W. D. BOEKHOVEN. 1969. Nematodes associated with tomato and cucumber greenhouse soils in Essex County, Ontario. Can. Plant Dis. Surv. 49:132-134.
3. LOCHHEAD, A. C., and F. E. CHASE. 1943. Qualitative studies of soil microorganisms. V. Nutritional requirements of the predominant bacterial flora. Soil Sci. 55:185-195.
4. MILLER, P. M. 1975. Effect of Pratylenchus penetrans on subsequent growth of tomato plants. Plant Dis. Rep. 59:866-867.
5. MOUNTAIN, W. B., and J. C. FISHER. 1954. Stunting of tomato associated with Pratylenchus penetrans, an apparent migrant from an adjoining peach orchard. Plant Dis. Rep. 38:809-810.
6. OLTHOF, T. H. A., and J. W. POTTER. 1973. The relationship between population densities of Pratylenchus penetrans and crop losses in summer-maturing vegetables in Ontario. Phytopathology 63:577-582.
7. OLTHOF, T. H. A., C. F. MARKS, and J. M. ELLIOT. 1973. Relationship between population densities of Pratylenchus penetrans and crop losses in flue-cured tobacco in Ontario. J. Nematol. 5:158-162.
8. ONTARIO MINISTRY OF AGRICULTURE AND FOOD. 1975. Agricultural statistics for Ontario. Publ. 20, Statist. Sect., Econ. Branch, Toronto, Ontario. 52 p.
9. OOSTENBRINK, M., J. J. S'JACOB, and K. KUIPER. 1957. Over de waardplanten van Pratylenchus penetrans. Tijdschr. Plantenziekten 63:345-360.
10. PETERSON, E. A. 1958. Observations on fungi associated with plant roots. Can. J. Microbiol. 4:257-265.
11. POTTER, J. W., and T. H. A. OLTHOF. 1974. Yield losses in fall-maturing vegetables relative to population densities of Pratylenchus penetrans and Meloidogyne hapla. Phytopathology 64:1072-1075.
12. POTTER, J. W., and J. L. TOWNSHEND. 1973. Distribution of plant-parasitic nematodes in field crop soils of southwestern and central Ontario. Can. Plant Dis. Surv. 53: 39-48.
13. QUEEN'S PRINTER AND PUBLISHER. 1970. The farm products grades and sales act and regulations respecting fruit and vegetables. Parliament Buildings, Toronto, Ontario. 144 p.
14. SEINHORST, J. W. 1966. The relationships between population increase and population density in plant parasitic nematodes. I. Introduction and migratory nematodes. Nematologica 12:157-169.
15. TOWNSHEND, J. L. 1963. A modification and evaluation of the apparatus for the Oostenbrink direct cottonwool filter extraction method. Nematologica 9:106-110.