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Effects of *Pratylenchus penetrans* and *Rhizoctonia fragariae* on Vigor and Yield of Strawberry

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Abstract: Microplot and small field-plot experiments were conducted to determine the effects of *Pratylenchus penetrans* on strawberry yield over several seasons and to evaluate the effects of nematode control on strawberry vigor and yield. *Pratylenchus penetrans* alone or in combination with the black root rot pathogen, *Rhizoctonia fragariae,* reduced strawberry yield in microplots over time. There were no differences in effects on yield among *R. fragariae* anastomosis groups A, G, or I. The interaction of the two pathogens appeared to be additive rather than synergistic. In field plots infested with *P. penetrans* alone, plant vigor and yield were increased by the application of carbofuran and fenamiphos nematicides. Nematode control was transitory, as *P. penetrans* populations were initially suppressed but were not different in samples taken 10 months after treatment. These data highlight the error in associating causality between plant damage and nematode populations based on a correlation of root disease with nematode diagnostic assays from severely diseased plants. These findings may help to explain how nematode numbers can sometimes be higher in healthy plants than in severely diseased plants that lack sufficient roots to maintain nematode populations. Because nematode populations from up to a year before harvest are better correlated with berry yield, preplant nematode diagnostic assays taken a year in advance of harvest may be superior in predicting damage to perennial strawberry yield.

Key words: black root rot, disease complex, *Fragaria* × *ananassa,* lesion nematode, nematode, *Pratylenchus penetrans, Rhizoctonia fragariae.*

The lesion nematode, *Pratylenchus penetrans* (Cobb) Filipjev & Shuurmans Stekhoven, is one of the most important and common soilborne pathogens affecting perennial strawberry (*Fragaria* × *ananassa* Duch.) production in the northeastern United States (Chen and Rich, 1962; DiEdwardo, 1961; Goheen and Bailey, 1955; LaMondia and Martin, 1989; Townshend, 1963). These nematodes may reduce crown vigor and fruit yield without producing diagnostic aboveground symptoms (Mai et al., 1977). In the absence of other pathogenic microorganisms, *P. penetrans* causes root necrosis and polyderm formation in the stele (Townshend, 1963). In strawberry fields, *P. penetrans* has been associated with extremely low plant vigor (Braun and Keplinger, 1960), stunting (Goheen and Bailey, 1955), and increased black root rot. Black root rot is a disease of complex etiology involving *Rhizoctonia fragariae* Hussain & McKeen, 1963 (Chen and Rich, 1962; Goheen and Smith, 1956; Hussain and McKeen, 1963; Klinkenberg, 1955; LaMondia and Martin, 1989), which comprises binucleate anastomosis groups (AG) A, G, or I (Martin, 1988). In controlled growth chamber experiments, LaMondia and Martin (1989) demonstrated an interaction of *P. penetrans* and *R. fragariae* resulting in an increase in the severity of black root rot. The reduction in root growth as a result of high *P. penetrans* and *R. fragariae* populations can result in increased winter injury and crown death (unpubl.). *Pratylenchus penetrans* may remain active in roots at low temperatures and continue to cause plant injury in late fall and early spring (Ferris, 1970).

The objectives of this research were to: (i) determine the effects of *P. penetrans* and *R. fragariae* on yield in microplots over several seasons of a perennial strawberry planting and (ii) evaluate the effects of nematode control on strawberry vigor and yield under field conditions.

Materials and Methods

Forty-eight field microplots were arranged in a factorial design with six replications at two sites in Windsor and Hamden Connecti-

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cut. Microplots were established in 1987 in Hamden, sampled for pathogens, and replanted in 1988. Microplots were established in 1988 in Windsor. Microplots consisted of polyvinyl chloride (15 cm diam., 0.46 m long) pipe buried 0.9 m apart on center to a depth of 35 cm and filled with methyl bromide-fumigated soil (Merrimac sandy loam soil: 73.4% sand, 22.3% silt, 4.3% clay, pH 5.9 in Windsor, or Yalesville fine sandy loam: 56.4% sand, 30.8% silt, 12.8% clay, pH 6.0 in Hamden). Soil in each plot was infested or not infested with nematodes and (or) *Rhizoctonia fragariae.* Nematode inoculum was applied as a suspension of 20,000 individuals per plot recovered from carrot disk culture by blending and sieving. Inoculum of *R. fragariae* AG A, G, or I was prepared on autoclaved fescue seeds (Martin, 1988). *Rhizoctonia fragariae* was introduced on 2 g of colonized fescue seed. Uninfested plots received a suspension from carrot disks without nematodes or 2 g sterile autoclaved fescue seeds. Microplots were planted with one 1-year-old strawberry crown (cv. Honeoye) per plot. Plots were fertilized annually with 10-8-10 at approximately 120 kg N/hectare; 25% was applied in April, and the remainder was applied at renovation in July. Herbicides and fungicides were applied as necessary based on commercial practices. Runners were not allowed to root in the microplots in order to maintain plants of the same age over the length of the experiment. Ripe berries were harvested three times per week in June 1989, 1990, 1991, and 1992. *Rhizoctonia fragariae* and *P. penetrans* were collected from inoculated strawberry roots in microplots sampled in 1988. *Rhizoctonia fragariae* was isolated from surface-sterilized roots (exposed to 0.5% NaOCl for 30 seconds) placed on acidified water agar for 48 hours. Nematodes were extracted from 2 g root tissue placed in a flask containing 50 ml water and shaken for 7 days using a wrist-action shaker. Fruit yield over time was analyzed by repeated measures analysis of variance, and total berry yield over the course of the experiment was analyzed by analysis of variance.

The effects of carbofuran (Furadan 4F 44% a.i., FMC, Philadelphia, PA) and fenamiphos (Nemacur 3 ES 35% a.i., Bayer, Kansas City, MO) nematicides were evaluated in 5.0-m^2 field plots that had three rows with 10 crowns/row. The soil was naturally infested with *P. penetrans.* Strawberry cv. Honeoye crowns were transplanted into 18 plots in April 1990. Six replicate plots were treated at renovation on 29 July 1991 with water only, 2.2 liters ai/ha of Furadan 4F, or 2.1 liters ai/ha of Nemacur 3 in 400 liters/ha water as a soil drench over the row. Nematodes were extracted from four plants taken from the outer two rows of each plot in July 1991 before treatment and in September 1991, May 1992, and August 1992. Nematodes were extracted from 2 g root tissue in water in a shaker for 14 days. Plots received 2.5 cm water from overhead irrigation 31 July 1991. Berries were harvested from the center row of each plot on five occasions from 10 June to 19 June 1992 and on six occasions from 7 June to 21 June 1993. Numbers of crowns per harvest row were counted on 30 June of 1992 and 1993. Data were subjected to analysis of variance.

The effect of nematode densities on Honeoye strawberry yield was determined in 1994 in eighteen 0.3-m^2 single-matted row plots that had been established for 3 years. Plots were monitored for lesion nematodes in spring and fall of each year from 1992 to 1994 by removing two crowns per plot and counting the number of nematodes extracted from 2 g roots/plant after 1 week on a wrist-action shaker. Correlation analyses were performed between nematode densities at each sampling time and 1994 yield.

Results

Rhizoctonia fragariae and *Pratylenchus penetrans* were collected from inoculated strawberry roots in microplots sampled in 1988. Nematode lesions and cortical root rots were evident on roots of inoculated plants in 1988 and at the conclusion of the experiments. *Rhizoctonia fragariae* was consistently isolated from inoculated plants, and an average of 20 (range 0 to 128) *P. penetrans*/g root were extracted from inoculated plants.

Rhizoctonia fragariae isolation from uninoculated plants was very low. *Pratylenchus penetrans* densities ranged from 0 to 7/g root, mean = 1. Berry yield tended to decline each year. Compared to non-infested plots, yield was reduced in plots that had been infested with the pathogens (Tables 1 and 2). Because there were no differences in yield among plots treated with the different *R. fragariae* anastomosis groups, AG groups were combined for analyses. Both *P. penetrans* and *R. fragariae* significantly reduced yield as evidenced by repeated measure analysis. Total yield over the course of the experiment was also reduced by each pathogen in Hamden (*P. penetrans* $P = 0.001$; *R. fragariae* $P = 0.02$). In Windsor, only *R. fragariae* reduced yields ($P = 0.01$), although *P. penetrans* effects were marginally significant ($P = 0.07$). The effects of inoculation with both pathogens were additive rather than synergistic.

Nematode densities in nematicide experimental plots ranged from 0 to more than 1,500 *P. penetrans*/g root in July 1991. Densities of *P. penetrans* were suppressed in September after fenamiphos application. However, application of carbofuran resulted in greater nematode extraction from treated roots than from untreated plants. Although the nematicides did not result in long-term suppression of this nematode, fruit yields, plant size, and runner numbers (reflected in number of crowns in 1993) were increased in 1992 by the application of nematicides in 1991 (Table 3). While berry yield was still larger in 1993, yield from nematicide-treated plots was not significantly different from untreated plots in the second fruiting year after application. Summer 1992 was hot and dry, with 22 days between June and September at or above 32 °C. June was especially dry, with only 3.3 cm of rain. Strawberry crowns with restricted root systems were stressed and grew poorly, perhaps resulting in the lower yields seen in 1992. In contrast, summer 1993 was cool and moist, with only 3 days all summer at or above 32 °C. Berry weight in 1994 was more highly correlated to lesion nematode populations sampled in Spring 1993 than to populations sampled in the year of harvest (Table 4).

Discussion

Pratylenchus penetrans is a common pathogen of perennial strawberry (Goheen and Bailey, 1955; Townshend, 1962). Black root rot is generally accepted as a disease of complex etiology (Maas, 1984), and *P. penetrans* has been repeatedly associated with severe root rot (Chen and Rich, 1962; Klinkenberg, 1955; LaMondia and Martin, 1989; Townshend, 1962). Soil fumigation to control nematodes in strawberries may also control a number of soilborne pathogens (Wolfe et al., 1990; Yuen et al., 1991), including *R. fragariae*. It has therefore been difficult to determine the effects of each pathogen on field-grown strawberry fruit yield.

In past surveys, strawberry roots were sampled from the margins of stunted areas and adjacent (about 1 m away) vigorous plants in eight fields on three farms in Connecticut (LaMondia, 1994). *Rhizoctonia fragariae* was isolated from all plants sampled, but root symptoms were more severe and lesion nematode numbers were greater from plants in the margins of stunted areas than from nearby healthy plants ($P = 0.05$; stunted mean = 146, SE = 53; healthy mean

TABLE 1. Combined and individual effects of *Pratylenchus penetrans* and binucleate *Rhizoctonia fragariae* on strawberry fruit yield in microplots (Hamden, CT).

Treatment	Fresh berry weight (g) per microplot			
	1989	1990	1991	Sum
No pathogens	65.5	87.3	64.5	217.3
R. fragariae	48.2	37.6	33.7	119.4
P. penetrans	54.9	20.4	12.3	87.6
P. penetrans + *R. fragariae*	37.7	24.9	14.2	76.8

TABLE 2. Combined and individual effects of *Pratylenchus penetrans* and binucleate *Rhizoctonia fragariae* on strawberry fruit yield in microplots (Windsor, CT).

Treatment	Fresh berry weight (g) per microplot				Sum
	1989	1990	1991	1992	
No pathogens	81.9	80.2	61.9	31.2	238.6
R. fragariae	83.4	37.8	51.7	33.5	206.5
P. penetrans	71.8	58.1	53.6	38.4	221.9
P. penetrans + *R. fragariae*	80.3	32.0	46.1	25.6	184.0

= 19, SE = 11). These observations should be considered when sampling for *P. penetrans* in strawberry fields affected by black root rot.

Pratylenchus penetrans and *R. fragariae* reduced strawberry yield in microplots. The interaction of the two pathogens was additive rather than synergistic. Martin (1988) found that there were no differences in effect among *R. fragariae* anastomosis groups A, G, and I—the three groups associated with strawberry black root rot. In field plots infested with nematodes alone, plant vigor and yield were increased by the application of carbofuran and fenamiphos nematicides. The data indicated that nematode control may be transitory, as *P. penetrans* populations were not different in samples taken 10 months after treatment.

Other researchers have found that single applications of carbofuran and fenamiphos to strawberry were associated with greater populations of the root-knot nematode *Meloidogyne hapla* (Crow and MacDonald, 1986), and that while fenamiphos or oxamyl controlled root-knot and sting nematodes in strawberry, there were no effects on annual strawberry yield 26 weeks after treatment (Overman, 1984). These results are consistent with observations made here that nematode populations are best correlated with perennial strawberry yield about 1 year after sampling. Perennial strawberry crowns set fruit buds in the fall, which determines yield potential for the next June crop (Maas, 1984). It may not be surprising, then, that the influence of nematode-induced stress may not be reflected in yield until the next year.

In other perennial crops, carbofuran reduced *P. penetrans* populations in alfalfa for only about 6 weeks (Thies et al., 1992), and fenamiphos did not affect *P. penetrans* populations in most years but still resulted in increased yield in apple (Santo and Wilson, 1990). Concentrations of fenamiphos available under field conditions may not kill nematodes but may reduce activity for a period of time (Bunt, 1987). The half-life of fenamiphos may range from 1 week to 2 months, depending on environmental conditions (Hague and Gowen, 1987). Alternatively, these nematicides may have other growth-promoting benefits.

Results of this investigation also demonstrate some of the difficulties associated with evaluating the effects of nematodes in perennial strawberry. Lesion nematodes are obligate parasites and cannot survive and re-

TABLE 3. Effects of nematicides on *Pratylenchus penetrans* populations, strawberry yield, and crown number in field plots.

Treatment (kg a.i. per ha)	*P. penetrans* per gm of root			Berry weight (kg)		Crown number	
	1991	1992	1993	1992	1993	1992	1993
None	181.3	205.7	340.0	0.6	2.8	31.3	66.5
Carbofuran (Furadan 2.2)	237.0	293.8	283.8	2.1	3.5	35.8	108.5
Fenamiphos (Nemacur 2.1)	22.9	107.8	161.2	2.7	3.9	44.5	128.0
LSD ($P = 0.05$)	140.2	ns	ns	1.6	ns	ns	57.1

TABLE 4. Correlation of 1994 strawberry yield with *Pratylenchus penetrans* density in field plots.

Sampling time	Correlation coefficient
Spring 1992	−0.33
Fall 1992	−0.57*
Spring 1993	−0.71*
Fall 1993	−0.51*
Spring 1994	−0.38

produce in the absence of host roots. In our plots, declining strawberries had poor root systems, reduced yields, and lower numbers of nematodes. These findings may help to explain how nematode numbers can sometimes be higher in healthy plants than in severely diseased plants, which lack sufficient roots to maintain nematode populations. Associating a lack of causality between *P. penetrans* and root disease based on a correlation of nematode density and disease severity, without accounting for the relationship between root health and nematode population, may lead to inconsistencies. For example, Wing et al. (1995) concluded that *P. penetrans* was not a component of the strawberry black root rot problem in New York based on a correlation of root disease with nematode assays taken from severely diseased plants. Nematode distribution is more widespread and population estimation is better in established plantings than in newly planted plots. Because nematode populations from up to a year earlier may be better correlated with current berry yield, preplant nematode diagnostic assays taken a year in advance of harvest may be superior for predicting damage to perennial strawberry fields than assays taken during the harvest season.

In summary, *P. penetrans* alone or in combination with root-rotting pathogens, such as *R. fragariae,* reduces strawberry vigor and yield over time. However, nematode control, even if temporary, can result in increased vigor and yield but can also increase the potential for increased nematode populations. Repeated applications of nematicides or alternate methods for suppressing nematode populations may be required to maintain plant health and productivity over time.

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