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Influence of Rotation Crops on the Strawberry Pathogens *Pratylenchus penetrans, Meloidogyne hapla,* and *Rhizoctonia fragariae*

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Abstract: Field microplot, small plot, and greenhouse experiments were conducted to determine the effects of rotation crops on *Pratylenchus penetrans, Meloidogyne hapla,* and *Rhizoctonia fragariae* populations. Extraction of *P. penetrans* from roots and soil in microplots and field plots planted to rotation crops was highest for Garry oat, lowest for Triple S sorgho-sudangrass and Saia oat, and intermediate for strawberry, buckwheat, and canola. Isolation of *R. fragariae* from bait roots was highest for strawberry and canola after 2 years of rotation and lowest for Saia oat. Nematode extraction from roots of rotation crops in field soils was generally higher than from roots in microplots. Grasses were nonhosts of *M. hapla.* Strawberry, canola, and buckwheat supported root-knot populations over time, but there were no differences in nematode numbers regardless of crop after one season of strawberry growth. Garry oat, canola, and, to a lesser extent, buckwheat supported large populations of *P. penetrans* without visible root symptoms. Strawberry plants supported fewer nematodes due to root damage. Nematode numbers from soil were less than from roots for all crops. While there were similar trends for pathogen recovery after more than 1 year of strawberry growth following rotation, differences in pathogen density and fruit yield were not significant. In the greenhouse, *P. penetrans* populations in roots and soil in pots were much higher for Garry oat than for Saia oat. Total *P. penetrans* adult and juvenile numbers per pot ranged from 40 to 880 (mean = 365.6) for Garry oat and 0 to 40 (mean = 8.7) for Saia oat. Production of Saia oat as a rotation crop may be a means of managing strawberry nematodes and black root rot in Connecticut.

Key words: black root rot, buckwheat, canola, crop rotation, *Fragaria* × *ananassa,* lesion nematode, *Meloidogyne hapla,* nematode, oat, *Pratylenchus penetrans, Rhizoctonia fragariae,* sorgho-sudangrass, strawberry.

Strawberry is an important small fruit crop in the United States. Pick-your-own strawberry plantings are high-value crops and one of the most profitable choices for growers in the Northeast who want to expand or diversify their production.

Lesion nematodes, *Pratylenchus penetrans* (Cobb) Filipjev & Shuurmans Stekhoven, and northern root-knot nematodes, *Meloidogyne hapla* Chitwood, are common pathogens affecting perennial strawberry (*Fragaria* × *ananassa* Duch.) production systems in the northeastern United States (Chen and Rich, 1962; Goheen and Bailey, 1955; LaMondia and Martin, 1989; Townshend, 1963). These nematodes may cause stunting, poor vigor, and reduced fruit yield without producing diagnostic aboveground symptoms (Goheen and Bailey, 1955; Maas, 1984; Mai et al., 1977). In the absence of other pathogenic microorganisms, *P. penetrans* causes root necrosis and polyderm formation in the stele (Townshend, 1963). *Meloidogyne hapla* initiates root galls and swollen root tips (Maas, 1984). *Pratylenchus penetrans* has been associated with increased black root rot, a disease of complex etiology involving *Rhizoctonia fragariae* Hussain and McKeen, 1963 (binucleate *Rhizoctonia* spp. anastomosis group [AG] A, G, or I) (Chen and Rich, 1962; Goheen and Smith, 1956; Klinkenberg, 1955; LaMondia and Martin, 1989; 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.

Growers in the Northeast have cited black root rot as the most serious disease of strawberry over the last few years (Anonymous, 1991; Pritts and Wilcox, 1990). This disease causes extensive death of feeder roots as well as deterioration and death of the root cortex and reduces plant vigor, productivity, and

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winter survival (LaMondia and Martin, 1989; Maas, 1984).

Recommendations for growers with black root rot problems include pre-plant fumigation, 2-year rotations out of strawberry, and avoidance of wet compacted soils (Cooley and Schloemann, 1994; Pritts and Wilcox, 1990); however, these practices are only marginally effective. For example, while fumigation has been reported to reduce both nematodes and black root rot (Wolfe et al., 1990; Yuen et al., 1991), in some instances fumigation resulted in an increase in black root rot, perhaps by allowing low pathogen populations to proliferate in the absence of competitors (Maas, 1984). Nematode control by non-fumigant nematicides may increase yields but also may allow nematode populations to increase (LaMondia, unpubl.). The efficacy of crop rotation as a management practice is unknown because data concerning specific rotation crops have not been sufficiently evaluated for both nematodes and fungi. Current recommendations, unchanged since a 1932 Oregon bulletin concerning *Rhizoctonia* on strawberry (Zeller, 1932), suggest rotation into small grains for 2 years (Pritts and Wilcox, 1990; Schroeder, 1988). However, the lesion nematode has a wide host range (Mai et al., 1977), including most grains, and rotation with grains has been associated with increased *Pratylenchus* spp. damage to potato (Florini and Loria, 1990). Growers in Connecticut have alternated strawberry with grains and still observed poor plant growth and black root rot symptoms.

Two promising grain crops for rotation with strawberry are diploid 'Saia' oat (*Avena strigosa*) and 'Triple S' sorgho-sudangrass (*Sorghum bicolor* × *S. sudanense*). These crops have been reported to be poor hosts of the lesion nematode (Colbran, 1979; Elmer and LaMondia, 1999; Fay and Duke, 1977; Townshend, 1989). Other crops, such as canola (rapeseed, *Brassica napus* L. and *B. campestris* L.), have also been implicated in reducing soil densities of nematodes (Davis et al., 1989; Mojtahedi et al., 1993). These plants synthesize large quantities of sulfur-containing glucosinolates in all tissues (Sang et al., 1984). When these plants are incorporated into the soil as a green manure, the glucosinolates hydrolyze to fungicidal and nematicidal isothiocyanates (Ettlinger and Kjaer, 1968).

The objective of this research was to evaluate the impact of selected rotation crops on *P. penetrans, M. hapla,* and *R. fragariae* isolation from roots and soil under field and greenhouse conditions.

Materials and Methods

Ninety-six microplots, consisting of polyvinyl chloride (15 cm-diam. and 0.46 m long) pipe, were buried 0.9 m apart on center to a depth of 35 cm, and filled to within 5 cm of the top with Yalesville fine sandy loam (56.4% sand, 30.8% silt, 12.8% clay, pH 6.0) in Hamden, Connecticut, in 1992. The soil had been planted previously to strawberry with black root rot and was naturally infested with *P. penetrans* and *R. fragariae.* Additional nematode inoculum was prepared and applied to each microplot as a suspension of 20,000 individuals from carrot disk culture. *Rhizoctonia fragariae* inoculum, anastomosis groups (AG) A, G, and I, was prepared on autoclaved fescue seeds (Martin, 1988) and introduced on two colonized fescue seeds/AG/plot. Microplots were planted with one 1-year-old strawberry crown (cv. Honeoye) per plot or with eight seeds of either rye, Triple S sorgho-sudangrass, Humus canola, Garry oat, or Saia oat on 21 May 1992. On 12 May 1993, plots were seeded as before except that buckwheat was substituted for rye. There were 16 replicate microplots planted to each crop in a randomized block design. Plots were fertilized annually with 10-10-10 (N-P-K) at 56 kg N/ha; 50% was applied in June, and 50% was applied in August.

On 15 October 1992 and 14 October 1993, shoots of rotation crops were cut off within 2 cm of the soil surface and 4 cores (2.5-cm diam. × 15 cm deep) were removed from each plot. Nematodes were extracted from 50 cm^3 of soil containing root tissue over 10 days with a pie pan extraction method. *Rhizoctonia fragariae* was isolated from 40 cm^3 of soil in a 15-cm-diam. petri dish by baiting (Huang and Kuhlman, 1989). Roots of greenhouse-grown Alpine strawberry were surface-sterilized in 0.5% NaOCl for 1 minute, then rinsed with sterile distilled water. Eight 1-cm-long root segments were placed on the soil surface in each dish. Percent soil moisture averaged 20% by weight. Dishes were held at 20 °C for 24 hours, at which time bait roots were again surface-sterilized, rinsed, blotted dry on sterile paper towels, and placed on the surface of water agar plates amended with 0.3 g streptomycin sulfate/liter. Hyphal tips of visible fungi were transferred to potato dextrose agar for identification.

The soil in each microplot was mixed and replanted with one Honeoye strawberry crown per plot on 29 April 1994. Plots were fertilized annually with 10-10-10 (N-P-K) at approximately 120 kg N/ha; 25% was applied in April, and 75% was applied at renovation in July. Herbicides, insecticides, and fungicides were applied as necessary based on commercial practices. Runners were not allowed to root in the microplots in order to maintain single crowns of the same age. Ripe berries were harvested on five dates in June 1995, and plots were again sampled for pathogens on 11 July 1995.

An existing 3-year-old Honeoye strawberry field in Windsor, Connecticut (Merrimac sandy loam soil, 73.4% sand, 22.3% silt, 4.3% clay, pH 6.0), naturally infested with *P. penetrans* and *M. hapla,* was rototilled after harvest and planted with rotation crops on 23 July 1993. Humus canola, Triple S sorgho-sudangrass, buckwheat, Garry oat, or Saia oat rotation crops were seeded to 0.5 m × 1.2 m plots. Plots seeded to oats received 30 cm^3 seed/plot. All other rotation plots received 20 cm^3 seed/plot. Single-row strawberry plots (0.5 m × 1.2 m) were not tilled. There were 18 replicate plots of each treatment.

Root and soil samples were taken on 19 October 1993. *Pratylenchus penetrans* adults and juveniles and *M. hapla* second-stage juveniles were extracted from 2 g root tissue by shaker extraction in 50 ml water for 14 days, and from 50 cm^3 soil by sugar flotation-centrifugation. Plots were reseeded with rotation crops on 3 June 1994, as before. Samples were taken on 20 September 1994, and nematodes were extracted as before. Honeoye strawberry crowns were planted in each plot on 8 May 1995, and nematodes were collected from 2 g root taken from 2 crowns/plot on 20 September 1995.

To determine the range and extent of lesion nematode reproduction, 20 pots each of Saia or Garry oat were infested with 2,000 *P. penetrans* adults and juveniles/pot. Pots were maintained in the greenhouse and nematodes were extracted from 2 g roots and 50 cm^3 soil to determine total nematode population after 12 weeks.

All data were subjected to analysis of variance or to nonparametric Kruskal-Wallis analysis. Means were separated with LSD or the Kruskal-Wallis Z-Test.

Results

Numbers of *P. penetrans* from roots and soil in microplots planted to selected rotation crops were highest for Garry oat, lowest for Triple S sorgho-sudangrass and Saia oat, and intermediate for strawberry, buckwheat, and canola (Table 1). Isolation of *R. fragariae* from bait roots was highest for strawberry and canola after 2 years of rotation and lowest for Saia oat. While there were similar trends for pathogen isolation after more than 1 year of strawberry growth, differences in pathogen density and fruit yield were not significant.

Nematode numbers in roots of rotation crops in the field plots were generally higher than from microplots, but the effects of crop treatments on nematode numbers were similar (Table 2). Grasses were nonhosts of *M. hapla*. Strawberry, canola, and buckwheat supported *M. hapla* nematode populations over time, and there were no differences in numbers regardless of rotation crop after one season of strawberry growth. Garry oat, canola, and, to a lesser extent, buckwheat supported large populations of *P. penetrans* without visible symptoms on roots. Strawberry plants, while susceptible, were damaged and supported fewer nematodes. Saia

TABLE 1. Effects of strawberry and rotation crops on densities of *Pratylenchus penetrans* and *Rhizoctonia fragariae,* and yields of strawberry in field microplots, Hamden, Connecticut.

	P. penetrans per gram root			*R. fragariae* (infected bait roots)			Fruit weight (grams)
Crop	1992	1993	1995[a]	1992	1993	1995	1995
Strawberry	22.8	25.1	6.1	6.3	5.9	5.4	131.4
Canola	31.0	2.9	0.8	4.5	6.5	4.6	134.5
Garry oat	112.5	47.9	5.3	3.5	2.4	3.3	78.3
Saia oat	6.1	5.6	1.6	4.3	1.4	2.4	132.6
Rye	43.1	16.4	7.4	3.0	2.0	2.5	144.3
Sorgho-sudangrass	2.9	2.3	5.5	4.2	2.1	3.6	178.9
P	0.001	0.001	0.11	0.05	0.001	0.06	0.09
LSD	34.0	13.4		2.3	1.8		

[a] Pathogen isolation from strawberry crowns planted after previous rotation crops grown in 1992 and 1993.

oat and Triple S sorgho-sudangrass had the fewest *P. penetrans*. Nematode numbers from soil were much less than from roots.

In the greenhouse, *P. penetrans* populations in roots and soil in pots were higher for Garry oat than for Saia oat. Total *P. penetrans* adult and juvenile numbers per pot ranged from 40 to 880 (mean = 365.6) for Garry oat and 0 to 40 (mean = 8.7) for Saia oat ($P = 0.001$).

DISCUSSION

Pratylenchus penetrans and *M. hapla* are important pathogens of perennial strawberry plants in the northeastern United States. In addition, *P. penetrans* has been implicated as a component of the strawberry black root rot complex (Chen and Rich, 1962; Goheen and Smith, 1956; Klinkenberg, 1955; LaMondia and Martin, 1989). Preplant fumigation has been widely used to control black root rot, nematodes, fungi, soil-dwelling insects, and weeds. Rotation to small grains has been suggested as a component in an overall strategy to replace fumigation for control of *R. fragariae* and black root rot (Pritts and Wilcox, 1990; Schroeder, 1988). However, growers in Connecticut have rotated strawberry with grains and still observed severe black root rot symptoms. While the standard oat cultivar Garry (*Avena sativa*) reduced *M. hapla* population densities, and *R. fragariae* inoculum potential, it is a host of *P. penetrans* and increased lesion nematode densities in these experiments. These increased nematode densities may offset the suppressive effect of oat on *R. fragariae* and explain the lack of black root rot control after rotation with small grains.

On the other hand, Saia oat (*A. strigosa*) and Triple S sorgho-sudangrass were similar in effect to *A. sativa* in reducing *R. fragariae* inoculum potential in soil, but provided the

TABLE 2. Population dynamics of *Pratylenchus penetrans* and *Meloidogyne hapla* on rotation crops or strawberry in field soil, Windsor, Connecticut.

	P. penetrans per gram root			*M. hapla* per gram root		
Crop	1993	1994	1995[a]	1993	1994	1995[a]
Strawberry	97.7	80.6	18.3	559.6	172.0	22.5
Canola	516.7	786.7	52.4	1,032.6	2.0	65.8
Garry oat	831.5	576.5	55.0	0.0	0.0	22.8
Saia oat	38.6	5.0	6.1	4.2	0.0	28.9
Buckwheat	424.9	145.0	75.6	100.4	14.0	43.9
Sorgho-sudangrass	79.2	58.9	45.0	5.0	0.0	34.4
P	0.001	0.001	0.05	0.001	0.08	ns
LSD	516.3	430.6	55.8	743.2	124.5	

[a] Nematode extraction from strawberry crowns planted after previous rotation crops grown in 1993 and 1994.

added benefit of reducing populations of both *M. hapla* and *P. penetrans.* While diploid Saia oat does not produce high-quality grain, this crop may still be desirable for producing the straw used by many strawberry growers to protect plantings during winter. Grain or grass rotations and companion crops conserve soil, reduce compaction, and increase water infiltration into soil (Newenhouse and Dana, 1989). The use of oats and sorghum as allelopathic rotation or companion crops can suppress a number of weed species (Neustruyeva and Dobretsova, 1972; Putnam and DeFrank, 1983). Some oat accessions exuded up to three times as much scopoletin, a root growth-inhibiting compound, as standard Garry oat (Fay and Duke, 1977). Oat and sorghum also have been shown to produce fungicidal root exudates toxic to soilborne fungi such as *Fusarium* and *Gaumannomyces* (Crombie and Crombie, 1986; Odunfa, 1978). Recently, resistance to lesion nematodes has been associated with greater production of avenocin in Saia oat than in susceptible oat (B. B. Brodie, pers. comm.). The mode of action against lesion nematodes and *R. fragariae* was not investigated in these experiments.

Other crops, such as canola, also have been implicated in reducing soil densities of plant-parasitic nematodes. These plants synthesize large quantities of sulfur-containing glucosinolates in all tissues (Sang et al., 1984). When these plants are incorporated into the soil as a green manure, the glucosinolates hydrolyze to fungicidal and nematicidal isothiocyanates (Ettlinger and Kjaer, 1968). The incorporation of canola or sudangrass shoots to soils heavily infested with *Meloidogyne chitwoodi* (Johnson et al., 1992) reduced nematode populations more than fallow treatments (Mojtahedi et al., 1991, 1993), and the application of canola meal significantly reduced populations of *P. neglectus* and subsequent Verticillium wilt in potato (Davis et al., 1989). Canola supported reproduction of both *P. penetrans* and *M. hapla* in microplots and field plots, resulting in greater nematode populations than those on continuous strawberry. The incorporation of canola shoot tissues in October reduced both *P. penetrans* densities in microplots and *M. hapla* densities in field plots the following years. Results were somewhat inconsistent, however, as *P. penetrans* densities were unaffected in field plots.

The effects of rotation crops on nematode populations were not long-lasting. Populations of both *P. penetrans* and *M. hapla* rebounded fairly quickly during strawberry production. Only Saia oat resulted in a significant effect on *P. penetrans* populations after 1 year of strawberry growth. However, lesion nematode densities 1 year prior to harvest were better correlated with fruit yield than densities at later dates (LaMondia, unpubl.). Reduced pathogen populations at planting should result in increased initial growth and vigor, which may influence plant productivity beyond the time required for pathogen population increase. Weeds, which occurred to some extent in all plots, may have played a role in supporting *M. hapla* and *P. penetrans* populations during rotation. The wide host range of *P. penetrans* and *M. hapla* (Bendixen, 1988) and the large reproductive potential of *M. hapla* make it very difficult to eliminate nematode populations despite control in rotation crop roots below detection levels.

These findings underscore the lack of knowledge regarding crop rotation in strawberry root disease management, and emphasize the need for further determination of the influences that rotation crops and their residues have on pest populations and black root rot of strawberry.

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