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Article abstract

Experiments on the distribution and survival of pin nematode *Paratylenchus projectus* in potato growing systems and on its control by various mechanisms are described. Preferable management strategies for the pin nematode include the use of flax or a high-glucosinolate mustard or canola, the use of 'Trudan 8' sudangrass to add organic matter into the soil, and shallow but thorough tillage of a sandy soil in the fall or in early spring to disrupt the soil. In general, many grasses and legumes should be avoided as cover crops.

Fluctuations of populations of the pin nematode *Paratylenchus projectus* under selected potato management practices

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[Fluctuations des populations du nématode de goupille *Paratylenchus projectus* sous différents systèmes de production de pomme de terre]

Des expériences sur la distribution et la survie du nématode de goupille *Paratylenchus projectus* dans des systèmes de production de pomme de terre et sur son contrôle par divers mécanismes sont décrites. Les meilleures stratégies de gestion pour le nématode de goupille incluent l'utilisation du lin textile ou d'une moutarde ou canola à haut-glucosinolate, l'utilisation de 'Trudan 8' sudangrass comme ajout de matière organique dans le sol, et le labourage peu profond mais complet d'un sol sablonneux en automne ou au début du printemps pour perturber le sol. En général, plusieurs graminées et légumineuses devraient être évitées comme cultures de protection.

INTRODUCTION

Previously we reported on a series of experiments in which we explored the effects on yield of the potato (*Solanum tuberosum* L.) variety 'Superior' of several technologies for controlling the root-lesion nematode *Pratylenchus penetrans* Cobb, and on the degree of nematode control that these methods produced over time (McKeown and Potter 2001). In that report, we noted that choice of pre-potato cover-cropping, chemical fumigation, and soil disturbance by cultivation all affected the survival and parasitic abilities of the root-lesion nematode.

During the course of those studies, we became aware of a considerable presence of the pin nematode, *Paratylenchus projectus* Jenkins, in the test areas. This nematode is a common ectoparasitic inhabitant of Ontario crop soils (Potter and Townshend 1973; Townshend *et al.* 1973a) and has been detected in potato fields in New Brunswick (Kimpinski 1987) and Maine (Huettel *et al.* 1990). While generally consid-

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ered not to be a serious pathogen at population densities less than 5000 kg^{-1} soil in pure culture (Anonymous 1997), nevertheless the presence of this species was deemed to be worth monitoring in the event that population densities did exceed the accepted economic loss threshold at some point on the experiments. In addition, the biology of this nematode is imperfectly known in the agricultural systems of Ontario, in spite of its ubiquity. In a few circumstances, the species has proven to be moderately damaging to fleshy-rooted crops such as rhubarb (*Rheum rapronticum* L.) (Townshend *et al.* 1973b), and was considered to cause yield losses in gladiolus (*Gladiolus* spp.), where populations ranged as high as 80 000 kg^{-1} soil and were usually around 20 000 kg^{-1} soil (Potter, personal communication). Much of the known Canadian information on its reproductive capacity has been gained from greenhouse pot and field microplot experiments, using field crop hosts including clovers (Townshend and Potter 1976, 1982).

In other countries, *P. projectus* is known to be distributed in a variety of soil types, and is frequently found associated with forage grasses and legumes, along with a number of other host plants (Loof 1975). In the USA, Coursen and Jenkins (1958) found that tobacco (*Nicotiana tabacum* L.) and tall fescue (*Festuca arundinacea* L.) were good hosts, whereas McGlohon *et al.* (1961) found high numbers of the pin nematode associated with orchardgrass (*Dactylis glomerata* L.) and crabgrass (*Digitaria sanguinalis* [L.] Scop.). In some countries, rapid population increases to high densities have been commonly reported (Loof 1975), including reports of large numbers developing on red and Ladino clover (*Trifolium pratense* L., *T. repens* L.) (McGlohon *et al.* 1961; Rhoades and Linford 1961), which corroborate the Ontario experience (Townshend and Potter 1973, 1976). Evidence also suggests that the nematode can undergo a rapid population decline in the spring, then persist through the summer and fall, and probably multiplies best in spring and fall (McGlohon *et al.* 1961). Field population density has been correlated with two annual rainfall periods in Texas (Norton 1959), and with temperatures of 17-25°C in North Carolina (McGlohon *et al.* 1961). Townshend *et al.* (1973b) determined that *P. projectus* survived well in stored soil at 0-30°C and the population actually increased at 5-10°C while in storage, possibly from egg hatch. Ferris and Bernard (1971a, 1971b) concluded that *P. projectus* thrives in drier soils (silt-loams vs. silty clays) and thus survives better under dryland crops such as soybean (*Glycine max* L.) and legumes, as opposed to corn (*Zea mays* L.) which requires moister soils.

Our objective in this study was to assess the effects of reputed nematode-suppressive cover crop plants, soil fumigation, and depth of cultivation on the population density and persistence of the pin nematode, *P. projectus*, in a potato-cover crop system.

MATERIALS AND METHODS

The experiments were performed on the property of the University of Guelph Simcoe campus, Ontario, Canada, from 1993 to 1996. Additional details and description of the study plots and soil types, crops used, fumigation treatments applied, and plot maintenance with respect to fertilization and weed control were presented in a previous paper (McKeown and Potter 2001). Details relevant to the *P. projectus* study are summarized in the following paragraphs.

Fields used were in a potato-rye (*Secale cereale* L.)-potato rotation. Prior to and including the spring of 1994, red clover was used in the rotation by frost-seeding into the rye. Treatment cover crops were planted in the summer previous to potato; however, for clarity, the data will be presented by calendar yr of potato. Cover crops were planted following turn-down at or near maturity of the preceding rye cover crop. No fertilizer was applied prior to turn-down of the rye except for the 1996 crop yr, when 25 kg ha^{-1} N as 34-0-0 was applied prior to incorporation of the rye. Plots were arranged in a randomized complete block design with six replications, unless otherwise stated.

Cover crops as "biofumigants"

Series one

Initial comparisons of effects of late-summer-planted cover crops to fumigants were made in 1993 and 1994. 'Domo' mustard (*Brassica juncea* L.) was compared with rye plus under-seeded red clover, Vorlex Plus CP (methyl isothiocyanate/1,3-dichloropropene/ chloropicrin; Aventis CropScience Canada, Regina), Telone IIB (1,3-dichloropropene; Dow AgroSciences Canada Inc., Calgary), or a check (untreated bare soil - 1993; wheat [*Triticum aestivum* L.] - 1994). 'Domo' mustard cover crops were sown at 10 kg ha^{-1} on 1 September 1992 and 10 September 1993. Fumigants were applied on 23 April 1993 and 7 October 1993.

Series two

Comparisons of several late-summer-planted *Brassica* cover crops were made in 1992 and 1993. 'Domo' mustard (*Brassica juncea* L.), 'Westar' canola (*Brassica napus* L.), and 'Pigletta' oilseed radish (*Raphanus sativus* L. var. *oleifera*) were sown on 1 September 1992 and 10 September 1993 at 10 kg ha^{-1} to compare with rye plus under-seeded red clover as possible rotation crops prior to potatoes. Fumigants were as per Series one.

Series three

Sorghum-sudangrass (*Sorghum bicolor* [L.] Moench) hybrids 'Sordan 79' and 'Trudan 8', high-glucosinolate mustards 'Domo' (1993 only, as the line was discontinued) and 'Cutlass' (sister line of 'Domo' substituted after 1993), 'Forge' canola (*Brassica rapa* L.) and 'Norlea' flax (*Linum usitatissimum* L.) were compared with 'NK557' sorghum (*Sorghum bicolor* L.) as a lesion nematode host and Telone IIB (1994) or Vorlex Plus CP (225 L ha^{-1}) (1993, 1995) fumigants applied with a deep chisel applicator to 30 cm with a 45 cm tillage depth. Sorghum/ sorghum-sudangrass were planted at 14 kg ha^{-1}, Brassicas at 10 kg ha^{-1} and flax at 45 kg ha^{-1} with a grain drill. Planting dates for cover crops were: 30 August 1993, 12 July 1994, 28 June 1995. Sorghum and sudangrass hybrids were flail mowed prior to plowing, Brassicas were plowed under directly, at 15 cm height with plants in flower at time of plowing for the 1993 crop, but at the green pod stage of growth when plowed under in all other trials. Plots were rotovated to 15 cm deep on 4 November 1993 and mouldboard plowed to 15 cm on 3 November 1994 and 1995. Fumigation was applied on 8 October 1993, 16 August 1994 and 12 October 1995 when soil conditions were suitable; plots were rolled with a cultipacker after treatment to seal the soil surface.

Fumigation studies

Treatments consisted of shallow fumigation using Vorlex Plus CP to 15 cm, deep fumigation to 30 cm with a 45 cm tillage depth, shallow and deep non-fumigated controls and an untreated check. Fumigants were applied with a modified subsoiler with tines 45 cm apart. Fumigant was applied at 225 L ha^{-1} on the same dates as the ***Series three*** experiments. Plots were rolled immediately with a cultipacker after fumigation to seal the soil.

Nematodes

Nematode population density was estimated by soil sampling prior to planting potatoes (25 April 1993, 21 April 1994), during the season (23 June 1993, 13 July 1994) and near harvest (23 August 1993, 8 August 1994) for ***Series one*** and ***Series two***. For ***Series three***, samples for nematode analysis were collected near potato planting dates in spring (21 April 1994, 19 May 1995, 28 May 1996) and just prior to harvest (8 August 1994, 22 August 1995, 22 August 1996) in each yr. For the **fumigation studies**, preliminary samples were taken on 23 August 1993; the plots were intensively sampled on 15 June, 13 July, and 8 August 1994; on 19 May 1995 and 22 August 1995; and on 28 May 1996 and 22 August 1996.

For all studies, soil samples for nematode analysis were collected with a 2.5 cm x 45 cm Oakfield sampler, taking soil cores 15 cm deep in the middle row of each plot. Ten cores were collected from each plot to provide a 0.5 kg bulk sample. Nematodes were recovered from 50 g sub-samples by the Baermann pan method (Townshend 1963) and counted at 50X magnification with a stereoscopic microscope. Data were transformed using $\sqrt{(x+200)}$ prior to analysis; data presented are untransformed. Data were analysed using PC-SAS (SAS Institute, Cary, NC) using a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

Cover crops as "biofumigants"

Series one

In 1993 (the pre-potato year), the population density of pin nematode declined in all plots, although significantly more so in the bare-soil check than in other treatments (Table 1). A substantial population decrease of pin nematode in fallow soil has also been observed by McGlohon *et al.* (1961). Conversely, in the following yr under potato, the check treatment (under wheat) showed the greatest increase in numbers, whereas the population increased the least in plots previously fumigated with Telone. In spite of the evidence from greenhouse and field micro-plot studies that rye and red clover were good hosts of the nematode (Townshend and Potter 1976, 1982), the population density declined under rye plus red clover in 1993, although the highest fall numbers of pin nematode were found under this treatment. The population increased only moderately under rye plus red clover in 1994, but was second highest in that fall. The untreated check (under wheat) was the principal treatment in 1994 in which a significant population increase occurred; this result is consistent with the previous rating of wheat as a fair host for this nematode (Townshend and Potter 1976).

Series two

No significant differences in nematode numbers occurred among the cover crops in 1993 (Table 2). However, 'Domo' mustard was marginally better than the other crops in maintaining a low number of pin nematodes, as shown by the low levels at mid-season of the potato crop in 1994 (Table 2). In the three experiments in which 'Domo' mustard was included, pin nematode generally declined over the growing season, with a slight resurgence at the end of the season (Tables 1-3). Since 'Cutlass' mustard is a sister line of 'Domo' with equivalent glucosinolate content (Anonymous 1985), it was not surprising that the pin nematode also declined through the season in both

Table 1. Effect of fumigation and cover crops on populations of *Paratylenchus projectus*, Biofumigants Series one

	Nematode number kg^{-1} soil					
	1993			1994		
Treatments[a]	25 April	23 Aug.	Aug.-April[b]	21 April	8 Aug.	Aug.-April[b]
Telone IIB	868 bc[c]	260 b	-608 a	163 a	223 c	60 c
Vorlex Plus CP	67 c	307 b	-365 a	77 a	273 bc	196 bc
'Domo' mustard	1740 ab	627 ab	-1113 a	57 a	430 bc	373 abc
Rye plus red clover	1990 a	1067 a	-923 a	133 a	910 ab	767 ab
Check	2590 a	370 b	-2220 b	40 a	1163 a	1123 a

[a] Fumigants applied on 23 April 1993 and 7 October 1993; cover crops planted 1 September 1992 and 7 October 1993. Potatoes planted 7 May 1993 and 3 May 1994, and harvested 18 August 1993 and 19 August 1994.

[b] Increase (or decrease) in nematode population density from earlier date to later date (later minus earlier).

[c] Means of six replications. Numbers in the same column followed by the same letter are not different using Duncan's Multiple Range test at the 5% level.

Table 2. Effect of Brassicaceae cover crops on populations of *Paratylenchus projectus*, Biofumigants Series two

	Nematode number kg^{-1} soil					
	1993			1994		
Treatments[a]	25 April	23 Aug.	Aug.-April[b]	21 April	13 July	8 Aug.
Rye plus red clover	1523 a[c]	493 a	- 1030 a	313 bc	207 a	147 ab
'Pigletta' oilseed radish	1393 a	280 a	- 1113 a	1477 ab	83 ab	37 c
'Domo' mustard	957 a	190 a	- 767 a	1663 a	40 c	263 a
'Westar' canola	840 a	373 a	- 467 a	667 ab	70 bc	117 abc

[a] Cover crops planted 1 September 1992 and 7 October 1993. Potatoes planted 7 May 1993 and 3 May 1994, and harvested 18 August 1993 and 19 August 1994.
[b] Increase (or decrease) in nematode population density from April to August (Aug.-April).
[c] Means of six replications. Numbers in the same column followed by the same letter are not different using Duncan's Multiple Range test at the 5% level.

1995 and 1996 under this variety (Table 3). Although Coursen *et al.* (1958) regarded various brassica vegetable crops as hosts of the pin nematode, they did not name particular species or varieties of mustards or canolas. Garden radish (*R. sativus*) cvs. Cherry Belle and White Icicle were listed as hosts by Coursen *et al.* (1958), whereas *B. juncea* and *B. napus* were not studied and are not listed by Goodey *et al.* (1965) as hosts. Consequently a question still exists as to the efficacy of high-glucosinolate Brassicaceae in suppressing *P. projectus* while the crop is in vegetative growth.

Series three

There were no differences in the August populations of the pin nematode in 1994 and 1995, but a difference appeared under flax in August 1996 (Table 3). 'Trudan 8' sorghum-sudangrass produced a greater reduction from fall 1994 to spring in 1995 than any other treatment in that season. Otherwise, there were no remarkable reductions of the pin nematode by cover crops in any season. Fumigation significantly reduced populations in spring 1994 but produced no remarkable reductions thereafter. Although Coursen *et al.* (1958) reported an unnamed variety of sudangrass (*S. vulgare* var. *sudanense*) as being a host of pin nematode, we have no vindication of this, except the citation in Goodey *et al.* (1965). They also do not report flax as a host of *P. projectus*. In unpublished studies (Potter, personal communication), pin nematode declined under flax at two other locations on loamy sand and sandy loam soils, which tends to add credence to the notion of flax as a poor or non-host. As already noted with the Brassicas, further work on flax as a suppressor of pin nematode is indicated.

Fumigation studies

In August 1994, nematode populations were significantly decreased as a result of both deep and shallow fumigant application, and also as a result of the soil disturbance by shallow cultivation of the soil using the fumigator (Table 4); not surprisingly, populations in untreated check plots increased substantially during the period from August 1993 - June 1994, but declined thereafter until August 1994. By spring 1995, all treatments were not significantly different in numbers, a situation which had again changed by spring 1996, when the two treatments with added fumigant produced the lowest populations. Effects of soil disturbance on the nematode population continued to be noticeable through 1996, although the most obvious difference in 1996 was the difference between deep chiselling with and without fumigant being applied. Simply tilling the soil was apparently effective in reducing numbers of

Table 3. Populations of *Paratylenchus projectus* over time, following cover crops, fumigation and potatoes, Biofumigants Series three

	Nematode number kg^{-1} soil														
	1993		1994					1995					1996		
Treatments[a]	Fall	Spring 94 -Fall 93[b]	April	Aug.	Aug.-April[b]	Fall	Spring 95 -Fall 94[b]	May	Aug.	Aug.-May[b]	Fall	Spring 96 -Fall 95[b]	May	Aug.	Aug.-May[b]
Sorghum 'NK557'	650 a[c]	40 a	690 a	20 a	-670 b	252 a	-195 ab	57 c	3 a	-54 ab	124 a	901 b	1025 a	28 ab	-997 b
'Sordan 79' sorghum-sudangrass	2413 a	-1773 a	680 a	20 a	-660 b	620 a	-598 ab	22 c	7 a	-15 a	158 a	814 ab	972 a	18 ab	-954 b
'Trudan 8' sorghum-sudangrass	1417 a	-774 a	643 a	30 a	-613 b	2905 a	-2870 a	35 c	3 a	-32 ab	55 a	865 b	920 a	17 ab	-903 b
'Domo' mustard	1597 a	-940 a	657 a	33 a	-624 b	–[d]	—	—	—	—	—	—	—	—	—
'Cutlass' mustard	—	—	—	—	—	185 a	413 b	598 ab	50 a	-548 bc	115 a	400 ab	515 ab	62 a	-453 ab
'Forge' canola	—	—	—	—	—	658 a	239 b	898 a	23 a	-875 c	125 a	273 ab	398 b	38 ab	-360 ab
'Norlea' flax	1153 a	-646 a	507 a	100 a	-407 b	1242 a	-1015 ab	227 abc	50 a	-177 ab	98 a	887 ab	985 ab	10 b	-975 b
Vorlex Plus CP	1090 a	-1057 a	33 b	20 a	-13 a	1583 a	-1489 bc	94 bc	15 a	-79 ab	95 a	138 a	232 b	32 ab	-200 a

[a] Fumigant applied on 8 October 1993, 16 August 1994 and 12 October 1995. Cover crops planted 30 August 1993, 12 July 1994 and 28 June 1995. Potatoes planted on 29 April 1994, 4 May 1995 and 15 May 1996, and harvested on 9 August 1994, 24 August 1995 and 28 August 1996.

[b] Increase (or decrease) in nematode population density from earlier date to later date (later minus earlier).

[c] Means of six replications. Numbers in the same column followed by the same letter are not different using Duncan's Multiple Range test at the 5% level.

[d] No data taken. 'Domo' mustard not available after 1994; replaced by 'Cutlass' mustard in 1995, 1996; 'Forge' canola added in 1995, 1996.

Table 4. Effect of fumigation method on *Paratylenchus projectus* populations, Fumigation Studies

	Nematode number kg^{-1} soil									
	1993		1994				1995	1996		
Treatments[a]	Aug.	June 94 - Aug. 93[b]	June	July	Aug.	Aug. - June[b]	May	May	Aug.	Aug. - May[b]
Check	3640 a[c]	5977 a	9617 ab	1188 ab	762 a	-8855 a	267 a	275 ab	12 a	- 263 ab
Deep chisel	3196 a	-1856 b	1340 b	417 b	260 ab	-1080 b	217 a	847 a	47 a	- 800 b
Deep chisel + fumigation	3544 a	-2135 b	1409 b	177 b	170 b	-1239 b	65 a	190 b	18 a	- 172 a
Shallow chisel	4280 a	-2967 b	1313 b	277 b	195 b	-1118 b	163 a	468 ab	44 a	- 424 ab
Shallow chisel + fumigation	2184 a	-541 ab	1643 b	242 b	125 b	-1518 b	113 a	103 b	17 a	- 86 a

[a] Fumigant applied 8 October 1993, 16 August 1994 and 12 October 1995. Potatoes planted 28 April 1994, 29 April 1995 and 16 May 1996, and harvested 9 August 1994, 24 August 1995 and 28 August 1996.

[b] Increase (or decrease) in nematode population density from earlier date to later date (later minus earlier).

[c] Means of six replications. Numbers in the same column followed by the same letter are not different using Duncan's Multiple Range test at the 5% level.

the pin nematode, as we have demonstrated previously with respect to the root-lesion nematode *Pratylenchus penetrans* (McKeown and Potter 2001; McKeown *et al.* 1998). As in the situation with the root-lesion nematode, we regard the activity of tillage or subsoiling as being sufficiently beneficial to be worth performing, even if no fumigant is required.

Considering the overall changes in populations of *Paratylenchus projectus* in our present work on various management plans for cover cropping, rotation and fumigant use, red clover, wheat, 'Westar' canola and 'NK557' sorghum all appear to be poor choices for cover or rotation crops for potato cropping in pin nematode-infested soils. Preferable non-chemical management strategies for the pin nematode would seem to be the use of flax or a high-glucosinolate mustard or canola, the use of 'Trudan 8' sudangrass if a high quantity of organic matter is required to be added into the soil, and shallow but thorough tillage of a sandy soil to disrupt the soil either in the fall or in early spring. The literature also suggests that, in general, many grasses should be avoided as covers (Townshend and Potter 1973, 1976) if pin nematode populations are high. Potato growers should also be aware of the overwintering capacity of the nematode (Townshend *et al.* 1973b), and avoid fields where grasses, forages, or cereals have been fall-plowed.

Although potato apparently is not seriously damaged by pin nematode (MacGuidwin 1993), the information of Norton (1959) suggests that an irrigated potato crop might be more at risk, which contrasts with Ferris and Bernard (1971a, 1971b) whose work implies a risk in dryland potato farming. However, potato does not seem to be a good host and it does not appear that the pin nematode increases in numbers on potatoes; decreases were observed on most of the potato crops examined in the current study. Previous authors (Coursen *et al.* 1958; Goodey *et al.* 1965; Loof 1975) do not mention potato as a host for *P. projectus*. Instead, it would appear that the rotation crop or cover crop is the greater culprit in maintaining a nematode presence, and that a careful selection of rotation crop or cover crop could obviate the need for chemical control of this nematode. The situation may be analogous to the rotation system in flue-cured tobacco production of alternating yr of rye and tobacco, in which it is known that the *Pratylenchus penetrans* population increases on the rye cover crop but more severely attacks the tobacco (Olthof 1971). However, the pin nematode, *P. projectus* apparently shows low damage potential on potatoes (MacGuidwin 1993), perhaps because of its ectoparasitic feeding habit, and promotes tillering of tall fescue and tobacco roots (Coursen and Jenkins 1958), so perhaps the comparison between ectoparasitic and migratory endoparasitic nematodes is not reasonable. While there appears to be little direct effect of pin nematodes on potatoes, the ecological interrelationship of pin nematode and potato and other crops in rotation with potato requires further study.

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