Yield of ‘Superior’ potatoes (*Solanum tuberosum*) and dynamics of root-lesion nematode (*Pratylenchus penetrans*) populations following “nematode suppressive” cover crops and fumigation

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Résumé de l’article

De 1992 à 1996, des études ont été menées à Simcoe, Ontario, pour évaluer diverses espèces de cultures de couverture comme alternatives possibles à la fumigation précédant la culture de la pomme de terre (*Solanum tuberosum*). Le seigle (*Secale cereale*), une culture de couverture hivernante fréquente dans les systèmes de production de légumes, est un excellent hôte pour le nématode des lésions racinaires (*Pratylenchus penetrans*) et lui procure un hôte convenable pour hiverner dans les sols sableux grossiers. Les fumigants Vorlex Plus CP et Telone IIIB ont été comparés à la moutarde ‘Domo’ (*Brassica juncea*) pour les années 1993 et 1994 de production de pommes de terre. Le seigle mélangé au trèfle rouge (*Trifolium pratense*) a été inclus en tant que système connu de culture de couverture hôte. Les plantes cyanogénétiques telles la moutarde ‘Domo’ (1994) ou la moutarde ‘Cutlass’ (1995, 1996), le canola ‘Forge’ (*Brassica rapa*), les hybrides sorgho/sorgho herbacé ‘Sordan 79’ et ‘Trudan 8’ (*Sorghum bicolor*) et le lin (*Linum usitatissimum*) ont été comparées au fumigant Vorlex Plus CP et au sorgho ‘NK55’ (*Sorghum vulgare*) quant à leurs effets sur les rendements de la pomme de terre et sur les nématodes. Une fumigation superficielle (15 cm) et une en profondeur (45 cm) avec le Vorlex Plus CP ont aussi été comparées pour les années 1994 à 1996 de production de pommes de terre. Il y avait peu de différence de décelable entre tous les traitements en pourcentage ou en jours pour atteindre 50 % d’émergence des pommes de terre. Les rendements totaux et vendables les plus élevés ont été obtenus avec la fumigation au Telone IIIB, puis avec la fumigation au Vorlex Plus CP et la moutarde ‘Domo’, suivis du traitement témoin et de la culture de seigle et de trèfle rouge. Les populations de nématodes ont dépassé le seuil de 1000 kg⁻¹ de sol pour tous les traitements et étaient les plus élevées pour les pommes de terre qui suivaient la culture de seigle et de trèfle rouge. Les rendements et la répression des nématodes avec les hybrides sorgho/sorgho herbacé et les moutardes semblaient intermédiaires entre la fumigation et la non-fumigation. Toutes les cultures de couverture semblaient être des hôtes au champ pour le nématode des lésions racinaires et la réduction des niveaux des populations n’apparaît que lorsque intervient la destruction par l’hiver. La mortalité des nématodes était excellente avec la fumigation et n’était surpassée que par la mortalité hivernale après incorporation de ‘Sordan 79’. L’emploi du ‘Sordan 79’ pendant au moins une partie de l’été suivi de son incorporation a été une alternative à la fumigation précédant la culture de la pomme de terre. Le passage en profondeur d’un chisel semble réduire les populations de nématodes probablement par un effet physique. Là où les populations de nématodes le justifient, une fumigation en profondeur avant la culture de la pomme de terre semble de mise.
Yield of ‘Superior’ potatoes (Solanum tuberosum) and dynamics of root-lesion nematode (Pratylenchus penetrans) populations following “nematode suppressive” cover crops and fumigation

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Studies were conducted at Simcoe, Ontario from 1992 to 1996 to evaluate various cover crop species as possible alternatives to fumigation prior to potatoes (Solanum tuberosum). Cereal rye (Secale cereale), a common overwinter cover crop in vegetable production systems, is an excellent host for the root-lesion nematode (Pratylenchus penetrans) and provides a suitable overwintering host on coarse sandy soils. Vorlex Plus CP and Telone IIB fumigants were compared to ‘Domo’ mustard (Brassica juncea) for the 1993 and 1994 potato crop years. Rye plus red clover (Trifolium pratense) was included as a known host cover crop system. Cyanogenic plants including ‘Domo’ mustard (1994) or ‘Cutlass’ mustard (1995, 1996), ‘Forge' canola (Brassica rapa), ‘Sordan 79’ and ‘Trudan 8’ sorghum-sudangrass hybrids (Sorghum bicolor), and flax (Linum usitatissimum) were compared to Vorlex Plus CP fumigant and ‘NK557’ sorghum (Sorghum vulgare) for effects on potato yield and nematodes. Shallow (15 cm) and deep (45 cm) fumigation with Vorlex Plus CP were also compared prior to potatoes for the 1994 to 1996 crop years. There was little detectable difference in percent or days to 50% emergence of potatoes following any treatment. Highest total and marketable yields resulted from Telone MB fumigation, then Vorlex Plus CP fumigation and ‘Domo’ mustard, followed by control and rye plus red clover cover. Populations of nematodes surpassed the threshold of 1000 kg⁻¹ soil in all treatments and were highest in potatoes following rye plus red clover. Yield and nematode control following sorghum-sudangrass hybrids and mustards appeared to be intermediate between fumigated and not fumigated. All of the cover crops appeared to be root-lesion nematode hosts in the field, and reduction of population levels appeared to result after incorporation or nematode winterkill. Nematode mortality was excellent with fumigation and next best from kill over the winter after ‘Sordan 79’ incorporation. ‘Sordan 79’ grown over at least part of the summer followed by incorporation was an alternative to fumigation. Deep chiselling appears to reduce nematode population,

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possibly by physical action. Where nematode populations warrant, deep fumigation prior to potatoes appears to be of merit.

[Rendement de la pomme de terre (Solanum tuberosum) ‘Superior’ et dynamique des populations du nématode des lésions racinaires (Pratylenchus penetrans) à la suite de cultures de couverture « répressives de nématodes » et de fumigation]

De 1992 à 1996, des études ont été menées à Simcoe, Ontario, pour évaluer diverses espèces de cultures de couverture comme alternatives possibles à la fumigation précédant la culture de la pomme de terre (Solanum tuberosum). Le seigle (Secale cereale), une culture de couverture hivernante fréquente dans les systèmes de production de légumes, est un excellent hôte pour le nématode des lésions racinaires (Pratylenchus penetrans) et lui procure un hôte convenable pour hiverner dans les sols sableux grossiers. Les fumigants Vorlex Plus CP et Telone IIB ont été comparés à la moutarde ‘Domo’ (Brassica juncea) pour les années 1993 et 1994 de production de pommes de terre. Le seigle mélangé au trèfle rouge (Trifolium pratense) a été inclus en tant que système connu de culture de couverture hôte. Les plantes cyanogénétiques telles la moutarde ‘Domo’ (1994) ou la moutarde ‘Cutlass’ (1995, 1996), le canola ‘Forge’ (Brassica rapa), les hybrides sorgho/sorgho herbacé ‘Sordan 79’ et ‘Trudan 8’ (Sorghum bicolor) et le lin (Linum usitatissimum) ont été comparées au fumigant Vorlex Plus CP et au sorgho ‘NK557’ (Sorghum vulgare) quant à leurs effets sur les rendements de la pomme de terre et sur les nématodes. Une fumigation superficielle (15 cm) et une en profondeur (45 cm) avec le Vorlex Plus CP ont aussi été comparées pour les années 1994 à 1996 de production de pommes de terre. Il y avait peu de différence de décelable entre tous les traitements en pourcentage ou en jours pour atteindre 50 % d’émergence des pommes de terre. Les rendements totaux et vendables les plus élevés ont été obtenus avec la fumigation au Telone IIB, puis avec la fumigation au Vorlex Plus CP et la moutarde ‘Domo’, suivis du traitement témoin et de la couverture de seigle et de trèfle rouge. Les populations de nématodes ont dépassé le seuil de 1000 kg⁻¹ de sol pour tous les traitements et étaient les plus élevées pour les pommes de terres qui suivaient la couverture de seigle et de trèfle rouge. Les rendements et la répression des nématodes avec les hybrides sorgho/sorgho herbacé et les moutardes semblaient intermédiaires entre la fumigation et la non-fumigation. Toutes les cultures de couverture semblaient être des hôtes au champ pour le nématode des lésions racinaires et la réduction des niveaux des populations n’apparaît que lorsque intervient la destruction par l’hiver. La mortalité des nématodes était excellente avec la fumigation et n’était surpassée que par la mortalité hivernale après incorporation de ‘Sordan 79’. L’emploi du ‘Sordan 79’ pendant au moins une partie de l’été suivi de son incorporation a été une alternative à la fumigation précédant la culture de la pomme de terre. Le passage en profondeur d’un chisel semble réduire les populations de nématodes probablement par un effet physique. Là où les populations de nématodes le justifient, une fumigation en profondeur avant la culture de la pomme de terre semble de mise.
INTRODUCTION

An overwinter cover crop of cereal rye, *Secale cereale* L., planted in autumn after harvest is an important component of potato (*Solanum tuberosum* L.) and other vegetable production systems in Ontario. Rye is winterhardy and establishes quickly to form a soil cover but, unfortunately, is a good to excellent host for the northern root-lesion nematode *Pratylenchus penetrans* Cobb (Dunn and Mai 1973; OIthof 1980), but not for *Meloidogyne hapla* Chitwood (Potter and OIthof 1993). Thus a rye-host crop rotation contributes to root lesion nematode problems. Many weed, agronomic and vegetable species grown in Ontario, including potatoes, are good to excellent hosts for the root-lesion nematode (Potter and OIthof 1993; Townshend and Davidson 1960). Furthermore, sandy soils where potatoes are typically grown provide an ideal physical environment for *P. penetrans* (Potter and OIthof 1993) over other related species (Florini *et al.*1987; Huettel *et al.*1990). Combining an ideal physical environment and wide host range with a well-adapted pest creates a crop management dilemma in any cropping system. The potato cv. Superior is very susceptible to root-lesion nematodes (OIthof 1986), making it suitable as an assay plant for studies to evaluate remedial treatments or systems.

Soil fumigation for nematode control is usually applied only for high value crops, as the cost outweighs the returns on many crops. Non-chemical, relatively inexpensive remedial options for other crops or organic systems would be valuable. Fumigation is typically applied to the top 15 cm of soil but, because root-lesion nematodes may inhabit soil to the depth of rooting, reinfestation could easily occur. Even with suppressive cover crops, remedial effects are only to the zone of incorporation (Mojtahedi *et al.* 1993). Deeper fumigation may eliminate this possibility. Additionally, reduced soil compaction from chisel-style tillage increases potato yield (Pierce and Chase 1987; Sojka *et al.* 1993) and may provide an additional benefit. However, there is concern about loss of fumigants due to regulatory action. Thus, options other than fumigants for nematode management would be beneficial.

Crops that suppress plant-parasitic nematodes would be an asset in crop production systems for use as cover crops provided they were adapted to local climate, soils, and production systems, and were not phytotoxic to the subsequent crop. Some plants or plant parts can suppress various nematode species (Akhtar and Mahmood 1994; Chitwood 1993; Davis *et al.* 1989, 1991; Dunn and Mai 1973; Rodriguez-Kabana 1986). Selected high glucosinolate cultivars of *Brassica* spp. (Grossman 1993; Mojtahedi *et al.* 1991), and selected cyanogenic sorghum-sudangrass grass (*Sorghum bicolor* (L.) Moench) cultivars (Dunn and Mai 1973; Mojtahedi *et al.* 1993) appear interesting as potential cover crops to suppress nematodes. Mowing the cover crop was reported to enhance efficacy (Grossman 1993). Most of the reported works were on species other than *P. penetrans* and not in soils and climate/soil environment similar to Ontario. Asparagus (Potter and OIthof 1993), and several local native prairie plant species (McKeown *et al.* 1994) are non-hosts to *P. penetrans* but are more suitable as long term crops than as cover crops or short term rotational crops. Thus, there is a need to find adapted plant species/cultivars that fit into our production system, reduce nematode populations, and increase yield of subsequent crops.

Our objectives were to use the potato-cover crop system to: 1) compare efficacy of reputed nematode-suppressive cover-crop species to soil fumigation; 2) compare efficacy of shallow and deep fumigation on nematode populations; 3) assess the impact of cover crops and fumigation on emergence and yield of subsequent potato crops.

MATERIALS AND METHODS

Plots were located at the University of Guelph Simcoe campus, Ontario, Canada. Fields used were in a potato-rye-potato rotation. Prior to and including
the spring of 1994, red clover (*Trifolium pratense* L.) 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 “fumigants”**

**Series one**

Initial comparisons of late-summer-planted cover crops to fumigants were made in 1993 and 1994. ‘Domo’ mustard (*Brassica juncea* L.) was compared to Vorlex Plus CP (methyl isothiocyanate/1,3-dichloropropene/chloropicrin; AgrEvo Canada Inc., Regina [now Aventis CropScience Canada, Regina]) or Telone II (1,3-dichloropropene; DowElanco Canada Inc., Calgary [now Dow AgroSciences Canada Inc., Calgary]), rye plus under-seeded red clover (good host combination), or untreated bare soil (1993) or 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**

Sorghum-sudangrass 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 râpa* L.) and ‘Norlea’ flax (*Linum usitatissimum* L.) were compared to ‘NK557’ sorghum (*Sorghum vulgare* L.) as a nematode host and Telone II (1994) or Vorlex Plus CP (225 L ha\(^{-1}\)) fumigants applied with a deep chisel applicator to 30 cm with a 45 cm tillage depth. Mow/no-mow treatments were included in a randomized complete block factorial design with eight treatments and six replications in the last 2 yr of this study.

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, and 28 June 1995. For the 1995/1996 cropping yr, one-half of the cover crop plots were mowed (17 August 1994 and 16 August 1995) and allowed to regrow. Sorghum and sudan-grass hybrids were flail mowed prior to plowing, brassicas were plowed under directly. Growth of mustard reached 15 cm in height for the 1993 crop but was in flower at time of incorporation. In all other trials, brassicas were at the green pod stage of growth when incorporated. Plots were rotated 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 correct; 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 two experiments. Plots were rolled immediately with a cultipacker after fumigation to seal the soil.

**Potatoes**

Cut, suberized seed pieces of cv. Superior potatoes weighing approximately 65 g were used in each yr. Plots consisted of three rows 10 m long with the centre row harvested. Between row spacing was 1.0 m and the in-row spacing 0.25 m. Planting dates were: \textit{Series one}, 7 May 1993, 3 May 1994; \textit{Series two}, 29 April 1994, 4 May 1995, and 15 May 1996. Fumigation trials were planted on 28 April 1994, 29 April 1995, and 16 May 1996. Shoots were counted three times per wk, and days to 50% emergence and percent emergence calculated. Plots were harvested as follows: \textit{Series one}, 18 August 1993, and 19

Fumigation studies plots were harvested on 9 August 1994, 24 August 1995, 28 August 1996. After harvest, potatoes were held in storage at 10°C until grading. Potatoes were graded on a Treeways (Treeways Engineering, Hastings, New Zealand) computerized weight grader. Marketable tubers were greater than 45 mm using the Ontario Summer #1 size (O.M.A.F.R.A. grade standards).

Soil types

Weed control was attained using herbicides as follows: 1993, 1994: preplant incorporated metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide], Novartis Canada, Mississauga, at 1.92 kg a.i. ha\(^{-1}\) followed by metribuzin [4-Amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one], Dupont Canada, Mississauga, at 1.2 L a.i. ha\(^{-1}\) post emergence; 1995 and 1996, Eptam (s-ethyl dipropylthiocarbamate), Syngenta Canada, Calgary, 4.25 L a.i. ha\(^{-1}\) preplant incorporated followed by 1.2 L a.i. ha\(^{-1}\) post emergence. Pest management practices for potatoes followed Ontario recommendations. Plots were irrigated as required.

Nematodes
Nematode population density was estimated 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. 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. For series two and the fumigation studies, samples for nematode analysis were collected near potato planting dates in spring (21 April 1994, 19 May 1995 and 28 May 1996) and just prior to harvest (8 August 1994, 22 August 1995, 22 August 1996) in each yr. 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 retransformed. Data were analysed using PC-SAS (SAS Institute, Cary, NC) using a significance level of \(P < 0.05\).

RESULTS AND DISCUSSION

Emergence and plant growth
Cover crop or fumigant had no observable effect on emergence or growth of cv. Superior potatoes in 1994 (data not shown). There was no consistent practical effect on percent emergence in any trial. Fumigated crops emerged one to 2 d earlier in 1995 and 1996 compared to some cover crops. Emergence was less than 5% lower in unfumigated, unchiselled plots in 1994 and 1996. No visual evidence attributable to deleterious effects of treatments on crop growth was observed in any yr.

Yield and nematodes
Series one
Yields were lower in 1993 than in 1994. For both yr, highest total and market-
able yields followed Telone IIB fumigation (Table 1), with Vorlex Plus CP and 'Domo' mustard being similar, suggesting that 'Domo' mustard could have a positive effect on yield. There was no difference among spring populations of root-lesion nematodes in 1993 or 1994 with spring populations much higher in 1994 (Table 2). Highest post harvest nematode populations followed potatoes grown in the rye plus red clover plots in 1993. Telone IIB-treated plots had the least increase in population over the summer. High populations in the spring of 1994 were above the threshold of 1000 kg$^{-1}$ soil (in pure cultures in sterilized soil) for injury (Potter and Olthof 1977), but there were no differences among treatments. Evidently, the 1993 winter and 1994 growing seasons were very favourable to root-lesion nematodes. The gain in population over the summer of 1994 was lower than 1993. Rye plus red clover rotations should probably not be used on sands infested with root-lesion nematodes prior to nematode sensitive vegetables.

**Series two**

Mowing was reported to increase efficacy of cover cropping (Grossman 1993) but had no effect in our study on emergence, yield or nematode populations; consequently the data for mowed and no-mowed treatments were pooled. Fumigation, followed by 'Domo' mustard and 'Sordan 79', resulted in the highest yields compared to 'NK557', 'Trudan 8', and flax cover crops (Table 3) in 1994. Fumigation resulted in higher yields in 1995 and there was no difference among cover crops. In 1996, lowest total yield among the cover crops was observed for 'Sordan 79', 'Cutlass' mustard and 'Norlea' flax. There was no difference among treatments in marketable yields.

### Table 1. Effect of fumigation and cover crops on the yield of cv. Superior potatoes (1993-1994)*

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Marketable</td>
<td>Non-</td>
<td>Total</td>
<td>Marketable</td>
<td>Non-</td>
<td>Total</td>
<td>Marketable</td>
<td>Non-</td>
<td>Marketable</td>
</tr>
<tr>
<td>Telone IIB</td>
<td>15.4 a</td>
<td>11.3 a</td>
<td>4.0 bc</td>
<td>25.9 a</td>
<td>23.7 a</td>
<td>2.1 a</td>
<td>15.4 a</td>
<td>11.3 a</td>
<td>4.0 bc</td>
<td>25.9 a</td>
</tr>
<tr>
<td>Vorlex Plus CP</td>
<td>13.0 ab</td>
<td>9.7 ab</td>
<td>3.4 b</td>
<td>24.5 ab</td>
<td>22.6 ab</td>
<td>1.9 a</td>
<td>13.0 ab</td>
<td>9.7 ab</td>
<td>3.4 b</td>
<td>24.5 ab</td>
</tr>
<tr>
<td>'Domo' mustard</td>
<td>12.7 ab</td>
<td>9.5 ab</td>
<td>4.2 b</td>
<td>22.7 abc</td>
<td>20.8 abc</td>
<td>1.9 a</td>
<td>12.7 ab</td>
<td>9.5 ab</td>
<td>4.2 b</td>
<td>22.7 abc</td>
</tr>
<tr>
<td>Rye plus red clover</td>
<td>10.2 b</td>
<td>4.6 c</td>
<td>5.6 a</td>
<td>16.8 c</td>
<td>14.5 c</td>
<td>2.3 a</td>
<td>10.2 b</td>
<td>4.6 c</td>
<td>5.6 a</td>
<td>16.8 c</td>
</tr>
<tr>
<td>Bare soil 1993, Wheat (1994)</td>
<td>11.1 b</td>
<td>7.4 bc</td>
<td>3.7 b</td>
<td>19.1 bc</td>
<td>16.7 bc</td>
<td>2.4 a</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* Means of six replications. Means 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 fumigation and cover crops on Pratylenchus penetrans populations (number kg$^{-1}$ soil)*

<table>
<thead>
<tr>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Telone IIB</td>
<td>173 a</td>
<td>977 b</td>
<td>804 b</td>
<td>2360 a</td>
<td>2983 a</td>
<td>623 a</td>
</tr>
<tr>
<td>Vorlex Plus CP</td>
<td>467 a</td>
<td>1713 ab</td>
<td>1246 ab</td>
<td>2100 a</td>
<td>2037 a</td>
<td>-63 a</td>
</tr>
<tr>
<td>'Domo' mustard</td>
<td>427 a</td>
<td>2210 ab</td>
<td>1783 ab</td>
<td>2018 a</td>
<td>2197 a</td>
<td>179 a</td>
</tr>
<tr>
<td>Rye plus red clover</td>
<td>393 a</td>
<td>2227 a</td>
<td>1834 a</td>
<td>3407 a</td>
<td>3697 a</td>
<td>290 a</td>
</tr>
<tr>
<td>Untreated</td>
<td>463 a</td>
<td>1693 ab</td>
<td>1230 ab</td>
<td>2547 a</td>
<td>3517 a</td>
<td>970 a</td>
</tr>
</tbody>
</table>

* Means of six replications. Means in the same column followed by the same letter are not different using Duncan's Multiple Range Test at the 5% level.

*b Increase in nematode density from spring to August.
Table 3. Effect of various cover crops or fumigation on yield of cv. Superior potatoes

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yield (t ha⁻¹)</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Marketable</td>
<td>Non-Marketable</td>
<td>Total</td>
</tr>
<tr>
<td>Fumigation</td>
<td>19.7 a</td>
<td>16.9 a</td>
<td>2.8 ab</td>
<td>35.0 a</td>
</tr>
<tr>
<td>Sorghum ‘NK557’</td>
<td>12.3 b</td>
<td>9.9 b</td>
<td>2.4 ab</td>
<td>23.4 b</td>
</tr>
<tr>
<td>‘Sordan 79’</td>
<td>14.2 ab</td>
<td>11.7 ab</td>
<td>2.5 ab</td>
<td>22.1 b</td>
</tr>
<tr>
<td>‘Trudan 8’</td>
<td>11.9 b</td>
<td>9.8 b</td>
<td>2.2 b</td>
<td>20.5 b</td>
</tr>
<tr>
<td>‘Domo’ mustard</td>
<td>16.0 ab</td>
<td>13.0 ab</td>
<td>3.0 a</td>
<td>-</td>
</tr>
<tr>
<td>‘Forge’ canola</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>21.1 b</td>
</tr>
<tr>
<td>‘Cutlass’ mustard</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>20.9 b</td>
</tr>
<tr>
<td>‘Norlea’ flax</td>
<td>11.2 b</td>
<td>8.7 b</td>
<td>2.5 ab</td>
<td>23.2 b</td>
</tr>
</tbody>
</table>

* Means of six replications. Means in the same column followed by the same letter are not different using Duncan’s Multiple Range Test at the 5% level.

Cover crops were sampled in August of the cover crop planting yr to obtain overwintering nematode populations (Table 4). Highest nematode populations in the fall of 1993 (pre fumigation) were recorded in ‘Domo’ mustard treatment suggesting that it is a host for *P. pennetaurus*. All cover crops tested appear to be hosts under local field conditions for root-lesion nematodes. It may be that the crop has to be incorporated for any effect on the pests. Populations decreased over winter in 1993-1994 with the greatest loss in fumigated plots; however populations increased in ‘Trudan 8’ plots. The largest spring/summer increase came from potatoes in the fumigated plots with lower increases following cover crops suggesting some residual cover crop effect.

Fall 1994 populations were high and did not differ among treatments. There was a large overwinter drop in populations, without statistical differences among treatments. However, populations exceeded the threshold of 1000 kg⁻¹ soil in all treatments in spring 1995, indicating that single fumigation or these cover crop treatments grown for one-season only do not provide control to below threshold levels if populations are high enough.

Populations declined precipitously for the fall 1995 and the subsequent 1996 crop yr. There were no differences in the fall, but fumigated plots had the lowest populations by spring, with little recovery of the populations during growth of the potato crop. This may explain the higher yields and lack of effect of treatments observed in 1996. In previous work at this location, a similar overwinter situation was observed with *Meloidogyne hapla* Chitwood followed by a slow increase in population (McKeown et al. 1998). We suspect these declines are at least in part a result of winter kill and, while beneficial for crop production, make comparison between treatments difficult. Nematode populations appear to be quite dynamic over time. Looking at percent population change from fall to spring following fumigation, winter mortality resulted in 92.3, 79.4, and 81.2% kill for 1994 to 1996 respectively. The next best winter population reductions were following ‘Sordan 79’ cover crops.

**Fumigation methods**

Highest yields followed deep chisel, deep and shallow fumigation in 1994 (Table 5). Yields were much higher in 1995 and both fumigation treatments had the highest total yields with deep fumigation resulting in the highest marketable yields. In 1996, shallow chisel+fumigation resulted in the highest yields. Lowest marketable yields were from control plots in all 3 yr. This indicates that the physical shattering of the soil was beneficial, and is consistent with our previous findings (McKe-
Table 4. Populations of *Pratylenchus penetrans* over time, following cover crops, fumigation and potatoes

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Fumigation</td>
<td>1217 ab</td>
<td>93 b</td>
<td>1124 a</td>
<td>1120 a</td>
<td>1027 a</td>
<td>4910 a</td>
<td>1010 a</td>
<td>3900 a</td>
<td>1566 a</td>
</tr>
<tr>
<td>Sorghum 'NK557'</td>
<td>1557 ab</td>
<td>943 a</td>
<td>614 abc</td>
<td>797 a</td>
<td>-146 b</td>
<td>5370 a</td>
<td>2786 a</td>
<td>2584 a</td>
<td>4028 a</td>
</tr>
<tr>
<td>'Sordan 79'</td>
<td>1523 ab</td>
<td>483 ab</td>
<td>1040 ab</td>
<td>1003 a</td>
<td>520 ab</td>
<td>4340 a</td>
<td>1706 a</td>
<td>2634 a</td>
<td>3670 a</td>
</tr>
<tr>
<td>'Trudan 8'</td>
<td>667 b</td>
<td>1133 a</td>
<td>-466 c</td>
<td>1277 a</td>
<td>144 b</td>
<td>4922 a</td>
<td>1944 a</td>
<td>2978 a</td>
<td>4500 a</td>
</tr>
<tr>
<td>'Dom'</td>
<td>1897 a</td>
<td>1043 a</td>
<td>854 abc</td>
<td>1460 a</td>
<td>417 ab</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cutlas</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>'Forge' canola</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>'Norle' flax</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Means of six replications. Means in the same column followed by the same letter are not different using Duncan's Multiple Range Test at the 5% level.*

*Difference in nematode population from fall to spring.*

*Increase in nematode population from spring to August.*
Table 5. Yield (t ha\(^{-1}\)) of cv. Superior potatoes following deep or shallow fumigation\(^a\)

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Marketable</td>
<td>Total</td>
</tr>
<tr>
<td>Untreated</td>
<td>10.5 b</td>
<td>7.2 c</td>
<td>31.1 b</td>
</tr>
<tr>
<td>Deep Chisel</td>
<td>14.3 a</td>
<td>9.7 ab</td>
<td>32.4 b</td>
</tr>
<tr>
<td>Deep Chisel + Fumigation</td>
<td>14.7 a</td>
<td>11.6 a</td>
<td>41.2 a</td>
</tr>
<tr>
<td>Shallow Chisel</td>
<td>10.9 b</td>
<td>7.4 b</td>
<td>35.2 b</td>
</tr>
<tr>
<td>Shallow Chisel + Fumigation</td>
<td>14.1 a</td>
<td>9.2 bc</td>
<td>42.2 a</td>
</tr>
</tbody>
</table>

\(^a\) Means of six replications. Means in the same column followed by the same letter are not different using Duncan’s Multiple Range Test at the 5% level.

own et al. 1998) and reported effects of zone tillage or chisel plowing to reduce soil compaction (Leach et al. 1993; Pierce and Chase 1987; Sojka et al. 1993). Additionally, diseases tend to be reduced in well structured soils and roots encountering compacted soils may become predisposed to infection (Leach et al. 1993). All treatments resulted in reduced root-lesion nematode populations compared to the untreated control in the spring of 1994 (Table 6), indicating that the physical action alone could reduce numbers of nematodes. Populations were much higher in 1995 but were lower in fumigation treatments. As with the series two above, populations declined to below threshold over the winter of 1995/1996 and there were no differences among treatments in 1996. Populations recovered slower in the plots that had been fumigated. The deep fumigation treatments in this work were essentially subsoiling and fumigation in one pass, and should be considered when fumigation is warranted.

Nematicidal chemistry including nitrogenous soil amendments has been reviewed by several authors (Akhtar and Mahmood 1994; Chitwood 1993; Rodriguez-Kabana 1986; Rodriguez-Kabana et al. 1987); however, many reports are on species other than *P. penetrans*. The possibility that *P. penetrans* is not controlled or is poorly controlled directly by the cover crops tested, is consistent with our results. In this work, control was probably from breakdown of cover crop residues, tillage, and winter conditions. Possibly, to improve action of similar cover crops, they need to be incorporated at peak content of the active ingredient so that sufficient active ingredient to achieve kill must be

Table 6. Effect of fumigation method on *Pratylenchus penetrans* populations\(^a\).

<table>
<thead>
<tr>
<th>Treatments</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Spring</td>
<td>Aug. - Spring</td>
<td>Spring</td>
</tr>
<tr>
<td>Untreated</td>
<td>1620 a</td>
<td>1543 bc</td>
<td>3545 a</td>
</tr>
<tr>
<td>Deep Chisel</td>
<td>707 b</td>
<td>2157 a</td>
<td>3760 a</td>
</tr>
<tr>
<td>Deep Chisel + Fumigation</td>
<td>388 b</td>
<td>1007 c</td>
<td>1907 b</td>
</tr>
<tr>
<td>Shallow Chisel</td>
<td>803 b</td>
<td>1212 bc</td>
<td>3343 a</td>
</tr>
<tr>
<td>Shallow Chisel + Fumigation</td>
<td>930 b</td>
<td>1643 ab</td>
<td>1555 b</td>
</tr>
</tbody>
</table>

\(^a\) Means of six replications. Means in the same column followed by the same letter are not different using Duncan’s Multiple Range Test at the 5% level.
present. Rapid, inexpensive chemical
tests for the active compound(s) would
be an asset in management. Sufficient
volume of crop residues would be re-
quired, along time to decompose
and kill the nematodes, and for the toxic
byproducts to dissipate to prevent sub-
sequent crop damage. Volume (1% v:v
minimum) and a narrow C:N ratio
around 20:1 of the amendment are cru-
cial factors in the efficacy of organic
amendments to control nematodes
through general stimulation of soil
microorganisms (Rodriguez-Kabana

Based on our experiments, use of the
rye plus red clover combination is risky
on sands where P. penetrans is present
but may be successful in heavier soils
where P. penetrans is less prevalent
(Potter and Olthof 1993). The suppos-
edly suppressive crops appear to be
hosts in situ, and suppression occurs
after incorporation. Suppression may
be easier to demonstrate on heavier
soils where the nematode is not well
adapted (Potter and Olthof 1993). Inter-
estingly, rye cover and rotation result-
ed in highest tomato yields on this site
(McKeown et al. 1998), indicating that
different cover or rotation patterns are
needed for individual crops. While not
as good as fumigation, ‘Sordan 79’ or
one of the high glucosinolate Brassica
spp. could be useful in soil/nematode
management for potatoes and low val-
ue crops, for organic production, or
where time permits as in the case of
early vegetables or after grains. If fumi-
gation usage were to be restricted, the
cover crops used would become very
attractive options compared with the
alternative of no chemical control.
Winter kill may be a major factor in nema-
tode mortality, suggesting that treat-
ments designed to weaken nematodes
prior to winter would be beneficial. If
the production system in the field could
be managed to weaken the nematodes
in the previous summer, winter kill
might be enhanced. Yield increases
resulting from deep fumigation or till-
age indicate that the physical action of
deep tillage adds to efficacy of treat-
ments, thus summer subsoiling may be
beneficial. The limitation of the cover
crops system in the current work is that
there was no overwinter cover crop for
erosion control. Currently, we know of
no winter-hardy covercrop which is not
a host of P. penetrans, yet is adaptable
for overwinter use in vegetable systems.
A winter-hardy cover crop for late plant-
ing to replace rye is still required, as it
was also pointed out by Dunn and Mai
(1973). If nematode-suppressive factors
could be added to winter rye or other
crops, it would be an asset for vegeta-
ble management systems. There is
potential to improve or maintain soil
productivity and manage nematodes via
certain cover crops, however, an inte-
grated management approach is re-
quired for success.

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