RESEARCH/INVESTIGACIÓN

MANAGEMENT OF LESION AND DAGGER NEMATODES WITH ROTATION CROPS

J. A. LaMondia*

Connecticut Agricultural Experiment Station, Valley Laboratory, Windsor, CT 06095; *Corresponding author: James.LaMondia@ct.gov

---

ABSTRACT

LaMondia, J. A. 2021. Management of lesion and dagger nematodes with rotation crops. Nematropica 51:9-16.

Annual rotation green manure crops of selected brassicas, buckwheat, forage pearl millet, forage radish, black-eyed Susan, sesame, sudangrass, and velvetbean were evaluated to determine impacts on lesion nematode *Pratylenchus penetrans* and dagger nematode *Xiphinema americanum* populations densities. Canadian forage pearl millet '101'and 'Tifgrain 102' millet effectively controlled *P. penetrans* but increased population densities of *X. americanum*. Black-eyed Susan (*Rudbeckia hirta*) and sudangrass 'Trudan 8' also reduced *P. penetrans* densites but not *X. americanum*. Rapeseed and other brassicas as a green manure reduced *X. americanum* densities but did not suppress *P. penetrans*. *Brassica juncea* 'Pacific Gold', *B. napus* 'Dwarf Essex', but not mustard 'Caliente' resulted in low densities of *X. americanum* in soil. Velvetbean and sesame increased both *P. penetrans* and *X. americanum* population densities. A moderately suitable host plant such as buckwheat was ineffective in managing both *P. penetrans* and *X. americanum* populations. These results emphasize that suppressive effects of any given cover crop are nematode-specific, and that within a group of cover crops, e.g., the Brassicaceae, species and varieties can vary substantially in their effectiveness. If the rotation crop chosen is a good host for the nematodes present, it may exacerbate the problem instead of controlling it.

Key words: black-eyed Susan, *Brassica juncea*, *B. napus*, buckwheat, Camelina, *Fagopyrum esculentum*, green manure, millet, *Mucuna* sp., *Pennisetum glaucum*, *Pratylenchus penetrans*, rapeseed, *Raphanus sativus* var. *niger*, *Rudbeckia hirta*, sesame, *Sesamum indicum*, *Sorghum vulgare* var. *sudanense*, sudangrass, velvetbean, *Xiphinema americanum*

RESUMEN

LaMondia, J. A. 2021. Manejo de los nematodos lesionador y daga con cultivos de rotación. Nematropica 51:9-16.

La rotación anual con cultivos considerados abono verde como Brassicas seleccionadas, trigo sarraceno, forraje mijo perla, rábano forrajero, Susan de ojos negros, sésamo, pasto Sudán, y frijol terciopelo fueron evaluados para determinar el impacto sobre poblaciones del nematodo lesionador *Pratylenchus penetrans* y el nematodo daga *Xiphinema americanum*. Los forrajes mijo perla Canadiense '101' y mijo 'Tifgrain 102' controlaron efectivamente *P. penetrans* pero incrementaron los nematodos de *X. americanum*. Rapeseed y otras Brassicas como abono verde redujeron *X. americanum* pero no suprimieron *P. penetrans*. *Brassica juncea* 'Pacific Gold', *B. napus* 'Dwarf Essex', pero no mostaza 'Caliente' resultaron en bajas densidades de *X. americanum* en el suelo. El Frijol terciopelo y el sésamo incrementaron ambas poblaciones de *P. penetrans* y *X. americanum*. Una planta moderadamente hospedera como el trigo sarraceno fue ineficaz en el manejo de ambas poblaciones de *P. penetrans* y *X. americanum*. Estos resultados enfatizan que los efectos supresores de cualquier cultivo de cobertura son específicos de nematodos, y que dentro de un grupo de cultivos de cobertura, e.g. especies y variedades de Brassicaceae pueden variar sustancialmente en su eficacia. Si el cultivo de rotación seleccionado es un buen hospedero para los nematodos presentes, puede agravar el problema en lugar de controlarlo.

Palabras clave: Susan de ojos negros, *Brassica juncea*, *B. napus*, trigo sarraceno, Camelina, *Fagopyrum esculentum*, abono verde, mijo, *Mucuna* sp., *Pennisetum glaucum*, *Pratylenchus penetrans*, rapeseed, *Raphanus sativus* var. *niger*, *Rudbeckia hirta*, sésamo, *Sesamum indicum*, *Sorghum vulgare* var. *sudanense*, pasto Sudán, frijol terciopelo, *Xiphinema americanum*

INTRODUCTION

Plant-parasitic nematodes can be important limiting factors in vegetable and fruit production in the Northeast United States. Two common and important plant-parasitic nematodes are the lesion nematode *Pratylenchus penetrans* and the dagger nematode *Xiphinema americanum*. *P. penetrans* is associated with poor root health, stunting, and interactions with other pathogens to result in complex diseases such as potato early dying (MacGuidwin *et al.*, 2012, Orlando *et al.*, 2020) black root rot of strawberry (LaMondia, 2003) and orchard replant disease (Jaffee *et al.*, 1982; Mazzola *et al.*, 2009). *X. americanum* causes root damage, stunting and is an efficient vector of tomato ring spot virus (Pinkerton *et al.*, 2008).

For decades, farmers have relied on fumigant and non-fumigant nematicides for nematode control as few effective nonchemical tactics are available. Rotation has often been advised (Halbrendt and LaMondia, 2004), but both *P. penetrans* and *X. americanum* have wide host ranges (Belair *et al.*, 2007; Forge *et al.*, 2000; Miller, 1980). Research is needed to determine appropriate rotational crops. Rotation crops can provide many benefits including suppressing weeds, controlling erosion, replenishing organic matter, reducing soil compaction and improving soil microbial activity (Ball *et al.*, 2005; Halbrendt, 1996; Welker and Glenn, 1988). For rotation crops to be practical and acceptable to growers, the seed must be commercially available, and the crop must be inexpensive and relatively easy to grow. Research on nematode suppressive or allelopathic plants holds a great deal of promise. For example, rapeseed (*Brassica napus*) used as a green manure biofumigation crop has been identified as a good method to suppress *P. penetrans* and *X. americanum* (Avato *et al.*, 2013; Halbrendt, 1996; Matthiessen and Kirkegard, 2006). However, rapeseed is not a perfect rotation crop, it can be a host for *P. penetrans*, and if the biofumigation effect is not optimized, it may not effectively control nematodes (Belair *et al.*, 2007).

A number of potential rotation crops or green manure crops have been suggested to reduce populations of plant-parasitic nematodes, including velvetbean and sesame (McSorley and Dickson, 1995), pearl millet (Belair *et al.*, 2005; MacGuidwin *et al.*, 2012), brassicas (Mazzola *et al.*, 2009; Zasada and Ferris, 2004), sudangrass (Viaene and Abawi, 1998), and *Rudbeckia* (LaMondia, 2006; De Viala *et al.*, 1998). The objective of this research was to evaluate the effects of potential non-host, antagonistic or biofumigant rotation crops on management of *P. penetrans* or *X. americanum* in the Northeastern United States.

MATERIALS AND METHODS

Field trials were established at the Connecticut Agricultural Research Station Valley Laboratory Research Farm in Windsor, CT. All experimental plots were 3 m by 3 m with 1 m vegetation free border between plots, replicated four times, and the experiments were planted in a randomized complete block design. Plots were established in an area where a standard Macintosh apple orchard (approx. 30 years old) had been removed and left in a grass fallow for three years. Both *Pratylenchus penetrans* and *Xiphinema americanum* were present in the soil. Plots were pre-plant fertilized with 10:10:10 NPK broadcast incorporated annually at a rate of 56 kg N/ha just prior to planting. Weeds were controlled in brassica plots with Treflan (trifluralin, Dow AgroSciences, Indianapolis, IN) at 1.5 l/ha, in tomatoes with Prowl (pendimethalin, BASF, Research Triangle Park, NC) at 1.2 l/ha, in buckwheat and velvetbean with Poast (sethoxydim, BASF) at 1.2 l/ha, and in other crops by hand weeding. Border areas were tilled as needed. Nematodes were enumerated from soil samples taken from ten 2.5 cm diam. 15-cm deep cores per plot. Soil was bulked, mixed and nematodes extracted from a 50 cm^3 subsample by sugar centrifugation and reported as a standardized number of nematodes per 100 cm^3 soil. Nematodes were extracted from plant roots by shaker extraction of 2 g blotted dry fresh weight roots per plot in 50 ml water using a wrist action shaker for 7 days and reported as a standardized number per gram of root. Nematodes were counted under a dissecting microscope at 20 to 30× magnification.

Different rotation crops were evaluated over four years to attempt to identify effective rotation crops against both nematodes and to screen plants reported to have potential efficacy in the scientific or popular literature. Trials were conducted in the same field over the four years with plots randomized each year. Buckwheat was grown each year as a control treatment moderately susceptible to both nematodes. A number of different brassicas were grown, including rapeseed, arugula, camelina, forage radish, and two mustards, as well as millets, sudangrass, *Rudbeckia*, and sesame.

2006

Canadian forage pearl millet (*Pennisetum glaucum*) '101', velvet bean (*Mucuna pruriens*), rapeseed (*Brassica napus*) 'Dwarf Essex' and buckwheat (*Fagopyrum esculentum*) no variety stated) were evaluated. Buckwheat, rapeseed Dwarf Essex, Canadian forage pearl millet 101, and velvetbean were seeded at rates of 56, 10, 12, and 45 kg seed/ha, respectively, on 9 May. Seeds were broadcast onto loose soil, raked to cover, and rolled. Plots were irrigated as needed to ensure germination. Soil samples were collected prior to planting, from crop roots and soil at the end of the season prior to mowing and rototilling (21 September), from soil two weeks after the crop was incorporated as a green manure, and from soil and roots of a rye (*Secale cereal*) winter cover crop planted 6 October and sampled on 20 November. Nematodes were extracted and enumerated as described above.

2007

Canadian forage pearl millet '101', velvetbean, rapeseed 'Dwarf Essex', buckwheat, mustard (*B. juncea*) 'Pacific Gold', sudangrass (*Sorghum vulgare* var. sudanense) 'Trudan 8', grain millet (*Pennisetum glaucum*) 'Tifgrain 102', and tomato (*Solanum lycopersicon*) 'Rutgers' were evaluated as rotation or green manure crops. Plots were planted at rates of 12, 45, 10, 56, 10, 12, and 12 kg seed/ha. Tomatoes were planted as transplants. Brassica crops were seeded on 25 May, and all other plants seeded on 30 May except velvetbean, which was seeded on 14 June. Tomatoes were transplanted on 30 May in three rows of six plants each. Nematodes were sampled from soil prior to planting, and from crop roots and soil at the end of the season prior to mowing and tilling to incorporate as a green manure on 21 September. A rye winter cover crop was planted 22 October, and on 20 November, soil and roots from the rye cover crop were sampled for nematodes. Nematodes were extracted and enumerated as described above.

2008

Camelina (*Camelina sativa*), and rapeseed 'Dwarf Essex' were planted on 2 June at rates of 10 kg seed/ha. Buckwheat, grain millet hybrid 'Tifgrain 102', and sesame (*Sesamum indicum*) were planted on 5 June at rates of 56, 12, and 12 kg seed/ha, respectively. Black-eyed Susan, (*Rudbeckia hirta*a) was planted as transplants on 24 June in five rows of six plants each. Nematodes were sampled from soil pre-plant, from crop roots and soil mid-season 31 July prior to mowing and tilling to green manure incorporation on 20 August, and from soil and roots of a rye winter cover crop planted 10 September and sampled on 4 December. Nematodes were extracted and enumerated as described above.

2009

Arugula (*Arugula sativa*) 'Nemat', camelina, and mustard (*B. juncea*) 'Caliente199' were seeded at rates of 10 kg seed/ha and buckwheat, Canadian forage pearl millet '101', and forage radish (*Raphanus sativus* var. *niger*) 'Daikon' were seeded at rates of 56, 12, and 10 kg seed/ha, respectively on 19 June 2009. Samples were collected from soil pre-plant, from crop roots and soil mid-season on 29 July prior to mowing and tilling for green manure incorporation on 26 August, and from soil and roots of a rye winter cover crop planted 10 September and sampled on 29 September. Initial *P. penetrans* populations in plots on 19 June 2009 were different among crop treatments, the only time that this occurred over the experiments, so *Pratylenchus* population change for that year was expressed as the ratio of the final to initial population (Pf/Pi), and data were arcsine transformed for statistical analysis. The final population sample was taken 29 September and consisted of the sum of *P. penetrans* recovered from roots and soil.

Data were tested for normality and analyzed by Analysis of Variance. Means were separated by Fisher's LSD Multiple Comparison Test (NCSS 2007 Statistical Software, Kaysville, UT). Ratio (Pf/Pi) data from 2009 were arcsine transformed prior to statistical analysis.

RESULTS

2006

Annual rotation crops of Canadian forage pearl millet '101', velvetbean, rapeseed 'Dwarf Essex', and buckwheat had different impacts on *P. penetrans* and *X. americanum* populations (Table 1). Initial nematode numbers in plots ranged from 32 to 50 *Xiphinema* and 5 to 10 *Pratylenchus*/100 cm^3 soil with no significant differences between treatment plots. End of season *P. penetrans* and

Figure 1. Rotation crops prior to incorporation as a green manure, 2006.

X. americanum numbers in soil prior to crop incorporation (5, 8, 15, and 45 *Pratylenchus* and 60, 24, 13, and 140 *Xiphinema*/100 cm^3 soil for buckwheat, millet, rapeseed and velvetbean, respectively) did not differ between rotation crops (data not shown). Numbers of *Pratylenchus* per gram root were lower in pearl millet and buckwheat compared to velvetbean. Plots were weed free and had sufficient biomass for green manure effects after incorporation (Fig. 1). After crop incorporation, numbers of *P. penetrans* and *X. americanum* in soil were higher in velvetbean plots than all other treatments. *P. penetrans* extracted from roots of the subsequent rye cover crop were also lower for pearl millet and buckwheat than for rapeseed and velvetbean.

2007

There were no differences among cover crop

Table 1. Lesion (*Pratylenchus penetrans*) and dagger (*Xiphinema americanum*) nematode populations in soil and roots of rotation crops immediately prior to mowing and rototilling on 21 September, or in roots of rye winter cover crop planted 6 October and sampled 20 November 2006.

	Nematodes/100 cm^3 soil[y]		*Pratylenchus*/g root	
Rotation crop	*Pratylenchus*	*Xiphinema*	Crop plant[y]	Rye cover
Buckwheat	12.0 a[z]	41.3 a	39.0 a	137 a
Pearl Millet 101	3.8 a	29.5 a	7.5 a	94 a
Rapeseed Dwarf Essex	35.8 a	19.5 a	144.4 ab	563 b
Velvetbean	97.5 b	79.5 b	358.2 b	649 b
P =	0.01	0.01	0.01	0.01

[y]Samples taken prior to rotation crop incorporation as a green manure on 21 September.
[z]Means within columns followed by the same letter are not different according to Fisher's LSD at *P* = 0.05. The level of significance between means is indicated by the P value in each column.

treatments in preplant nematode densities in soil (*P. penetrans* and *X. americanum* ranged from 10 to 35 and 20 to 195/100 cm^3 soil, respectively). *P. penetrans* and *X. americanum* numbers in soil prior to crop incorporation did not differ between rotation crops (data not shown). *P. penetrans* populations in rotation crop roots sampled just prior to crop incorporation were lowest for the two millets, buckwheat and sudangrass, and highest for velvetbean (Table 2). After incorporation, populations of *P. penetrans* extracted from roots of the rye cover crop were higher than from soil. *P. penetrans* population densities in rye roots were similar to those in roots of the rotation crop, millets and sudangrass resulted in lower numbers than the brassicas, velvetbean, buckwheat or tomato. *X. americanum* numbers in soil after incorporation of the rotation crop were lowest after the rapeseed 'Dwarf Essex' and yellow mustard 'Pacific Gold'. The highest *X. americanum* populations were observed after both millets, sudangrass, and buckwheat. Plots are shown in Figure 2.

Figure 2. Rotation crops prior to incorporation as a green manure, 2007.

2008

There were no differences in preplant nematode densities in soil (*P. penetrans* and *X. americanum* ranged from 0 to 8 and 0 to 61 per 100 cm^3 soil, respectively). *P. penetrans* populations in rotation crop roots sampled just prior to crop incorporation did not differ among treatments (Table 3). *P. penetrans* and *X. americanum* numbers in soil prior to crop incorporation did not differ between rotation crops. *X. americanum* numbers in soil were lowest after incorporation of Camelina and rapeseed 'Dwarf Essex' (Table 3). *P. penetrans* populations in rotation crop roots and sampled from rye roots were higher from sesame than all other rotation crops. No *P. penetrans* were detected in roots or soil from *R. hirta* plots, while *X. americanum* numbers in soil were relatively high after *R. hirta*. Plots are shown in Figure 3.

2009

Preplant nematode densities in soil ranged from 0 to 43 for *P. penetrans* and 0 to 2 *X. americanum* per 100 cm^3 soil. In this year, there were differences in initial densities of *P. penetrans*, so reproduction was evaluated Pf/Pi ratio. Forage radish and Caliente mustard supported the highest *P. penetrans* increase and pearl millet '101' supported the lowest population increase (Table 4). *X. americanum* population

Table 2. Lesion (*Pratylenchus penetrans*) and dagger (*Xiphinema americanum*) nematode populations in soil and roots of rotation crops on 21 September or rye cover crops on 20 November following rotation crop incorporation, 2007.

	Pf nematodes/100 cm^3 soil[y]		*Pratylenchus*/g root	
Rotation crop	*Pratylenchus*	*Xiphinema*	Crop plant[y]	Rye cover
Buckwheat	2.3 a[z]	56.0 bcd	9.4 a	116.3 ab
Pearl Millet 101	1.3 a	68.3 cd	5.6 a	5.7 a
Rapeseed Dwarf Essex	10.5 a	7.8 a	63.8 a	159.4 b
Velvetbean	6.0 a	34.8 abc	136.9 b	156.7 b
Grain Millet Tifgrain 102	2.3 a	91.0 d	9.4 a	20.4 a
Sudangrass Trudan 8	3.5 a	69.3 cd	23.3 a	38.4 a
Tomato Rutgers	1.5 a	22.3 abc	90.0 ab	69.8 ab
Mustard Pacific Gold	43.3 b	12.5 ab	82.5 ab	176.4 b
P =	0.01	0.01	0.04	0.02

[y]Samples taken prior to rotation crop incorporation as a green manure on 21 September.
[z]Means within columns followed by the same letter are not different based on Fisher's LSD at *P* = 0.05 level.

Figure 3. Rotation crops prior to incorporation as a green manure, 2008.

densities were generally quite low, but Caliente mustard resulted in significantly higher populations than other crops.

DISCUSSION

Many field soils, including vegetables, small fruit and orchard sites in the Northeast United States are commonly infested with *P. penetrans* and *X. americanum*. Both nematodes have the potential to damage a wide range of plants including vegetables as well as small and tree fruits. Although nematicides can be effective at lowering nematode populations, there are many reasons to consider using nematode suppressive rotation crops rather than nematicides as a nematode management strategy. Rotations break the cycle of monoculture after years of fruit or vegetable production thus changing the soil biology which helps to alleviate a number of soil-borne disease problems (Grabau *et al.*, 2017). Rotation crops provide an opportunity to get problem weeds under control, increase soil organic matter and correct for pH and nutritional problems that may be present (Ball *et al.*, 2005). Rotation crops also offer a sustainable alternative for organic growers.

A number of potential rotation crops or green manure crops have been suggested to reduce populations of plant-parasitic nematodes, including velvetbean and sesame (McSorley and Dickson, 1995), pearl millet (Belair *et al.*, 2005; MacGuidwin *et al.*, 2012), brassicas (Mazzola *et al.*, 2009; Zasada and Ferris, 2004), sudangrass (Viaene and Abawi, 1998), and *Rudbeckia* (LaMondia, 2006; De Viala *et al.*, 1998). However, as this research demonstrates, it is important to know which nematode species are present in a site and what effect a rotation crop may have on the populations. Canadian forage pearl millet consistently controlled *P. penetrans* but may increase a *X. americanum* nematode population on the same site. 'Tifgrain 102' millet was only evaluated for one year but appeared to suppress *P. penetrans* similarly to the forage pearl millet. 'Tifgrain 102' had been previously shown to reduce populations of *Pratylencvhus brachyurus* (Timper and Hanna, 2005). Lesion nematode populations increased in roots of Sudangrass 'Trudan 8' but subsequent incorporation of plant residue lowered populations to pre-plant levels (Forge *et al.*, 2000). In this study, 'Trudan 8' suppressed *P. penetrans* but not *X. americanum*.

Table 3. Lesion (*Pratylenchus penetrans*) and dagger (*Xiphinema americanum*) nematode populations in soil and roots of rotation crops sampled 20 August or rye cover crops sampled 4 December following rotation crop incorporation, 2008.

	Pf Nematodes/100 cm^3 soil[y]		*Pratylenchus*/g root	
Rotation crop	*Pratylenchus*	*Xiphinema*	Crop plant[y]	Rye cover
Buckwheat	4.3	1.5	2.7	27.0 a[z]
Pearl Millet 101	1.8	2.5	5.1	37.2 a
Rapeseed Dwarf Essex	11.3	0.3	15.5	62.6 a
Camelina sativa	4.3	0.0	1.0	10.6 a
Rudbeckia hirta	0.0	14.0	0.4	0.0 a
Sesame	24.8	12.5	12.0	821.7 b
P =	ns	0.08	ns	0.01

[y]Samples taken prior to rotation crop incorporation as a green manure on 20 August.
[z]Means within columns followed by the same letter are not different based on Fisher's LSD at *P* = 0.05 level.

Table 4. Lesion (*Pratylenchus penetrans*) and dagger (*Xiphinema americanum*) nematode populations in soil and roots of rye cover crops planted 10 September and sampled 29 September following rotation crop incorporation on 26 August, 2009.

Rotation crop	*Pratylenchus* Pf/Pi ratio	*Xiphinema* per 100 cm^3 soil
Buckwheat	42.4 ab[z]	4.8 a
Pearl Millet 101	6.6 a	3.3 a
Arugula Nemat	27.4 ab	4.3 a
Camelina sativa	51.5 ab	4.5 a
Mustard Caliente	85.1 bc	14.8 b
Forage radish Daikon	107.1 c	2.0 a
P =	0.03	0.02

[z]Means within columns followed by the same letter are not different (*Pratylenchus* analysis after arcsine transformation) based on Fisher's LSD, at *P* = 0.05 level.

In fact, sudangrass may be used as a host plant for increasing *Xiphinema* populations in the greenhouse (J. Halbrendt, personal communication). *Rudbeckia hirta* reduced *P. penetrans* numbers in previous studies (LaMondia, 2006; Potter and Mckeown, 2002) and in this experiment, but *X. americanum* were high after this rotation crop. Similarly, rapeseed and other brassicas as green manures can be used to manage *X. americanum* nematodes (Aballay *et al.*, 2004), but may not suppress *P. penetrans*. Not all brassicas may have the same impact, in our experiments, 'Dwarf Essex', camelina, 'Pacific Gold', arugula and forage radish all resulted in low densities of *X. americanum* in soil, but Caliente mustard did not. Environmental conditions are not always suitable for biofumigation after green manure incorporation. The use of brassica seed meal soil amendments is a means of utilizing the biofumigant properties of brassicaceous plant tissues but without the risk of increasing *P. penetrans* nematode populations in roots of the growing Brassica plants. *Brassica juncea* 'Pacific Gold' seed meal was demonstrated to be more effective in reducing *Pratylenchus* populations than other brassica seed meals (Mazzola *et al.*, 2009). Velvetbean and sesame, used for control of root-knot nematodes (McSorley and Dickson, 1995), grew well in Connecticut but may greatly increase both *P. penetrans* and *X. americanum* problems.

These results emphasize the importance of conducting a preplant nematode assay to determine potential nematode problems. If a problem exists, a rotation crop must be selected to manage the specific nematode population present. However, if multiple species of plant-parasitic nematodes are present, it is likely that a rotation cover crop chosen to suppress one of the species could facilitate population growth of the other species.

ACKNOWLEDGMENTS

The authors thank J. Canepa-Morrison, M. Salvas and J. Preste for technical assistance.

LITERATURE CITED

Aballay, E., R. Sepulveda, and V. Insunza. 2004. Evaluation of five nematode-antagonistic plants used as green manure to control *Xiphinema index* Thorne et Allen on *Vitis vinifera* L. Nematropica 34:45-51.

Avato, P., T. D'Addabbo, P. Leonetti, and M. P. Argentieri. 2013. Nematicidal potential of Brassicaceae. Phytochemistry Reviews 12:791-802.

Ball, B. C., I. Bingham, R. M. Rees, C. A. Watson and A. Litterick. 2005. The role of crop rotations in determining soil structure and crop growth conditions. Canadian Journal of Soil Science 85:557-577.

Belair, G., N. Dauphinais, D. L. Benoit, and Y. Fournier. 2007. Reproduction of *Pratylenchus penetrans* on 24 common weeds in potato fields in Quebec. Journal of Nematology 39:321-326.

Belair, G., N. Dauphinais, Y. Fournier, O. P. Dangi, and M. F. Clement. 2005. Effect of forage and grain pearl millet on *Pratylenchus penetrans* and potato yields in Quebec. Journal of Nematology 37:78-82.

De Viala, S. S., Brodie, B. B., Rodríguez, E., and D. M. Gibson. 1998. The potential of thiarubrine C as a nematicidal agent against plant-parasitic nematodes. Journal of Nematology 30:192-200.

Forge, T. A., R. E. Ingham, D. Kaufman, and J. N. Pinkerton. 2000. Population growth of *Pratylenchus penetrans* on winter cover crops grown in the Pacific Northwest. Journal of Nematology 32:42-51.

Grabau, Z. J., Z. T. Z. Maung, D. C. Noyes, D. G. Baas, B. P. Werling, D. C. Brainard, and H. Melakeberhan. 2017. Effects of cover crops on *Pratylenchus penetrans* and the nematode community in carrot production. Journal of Nematology 49:114-123.

Halbrendt, J. M. 1996. Allelopathy in the management of plant parasitic nematodes. Journal of Nematology 28:8-14.

Halbrendt, J. M., and J. A. LaMondia. 2004. Crop rotation and other cultural practices. Pp. 909-930 *in* Z. X. Chen, S. Y. Chen, and D. W. Dickson, eds. Nematology, Advances and Perspectives. CABI, DOI 10.1079/9780851996462.0909

Jaffee, B. A., G. S. Abawi, and W. F. Mai. 1982. Role of soil microflora and *Pratylenchus penetrans* in an apple replant disease. Phytopathology 72:247-251.

LaMondia, J. A. 2006. Management of lesion nematodes and potato early dying with rotation crops. Journal of Nematology 38:442-448.

LaMondia, J. A. 2003. Interaction of *Pratylenchus penetrans* and *Rhizoctonia fragariae* in strawberry black root rot. Journal of Nematology 35:17-22.

MacGuidwin, A. E., D. L. Knuteson, T. Connell, W. L. Bland, and K. D. Bartelt. 2012. Manipulating inoculum densities of *Verticillium dahliae* and *Pratylenchus penetrans* with green manure amendments and solarization influence potato yield. Phytopathology 102:519-527.

Matthiessen, J. N., and J. A. Kirkegaard. 2006. Biofumigation and enhanced biodegradation: Opportunity and challenge in soilborne pest and disease management. Critical Reviews in Plant Sciences 25:235-265.

Mazzola, M., J. Brown, A. D. Izzo, and M. F. Cohen. 2009. Mechanism of action and efficacy of seed meal-induced pathogen suppression differ in a Brassicacae species and time-dependent manner. Phytopathology 97:454-460.

McSorley, R., and D. W. Dickson. 1995. Effect of tropical rotation crops on *Meloidogyne incognita* and other plant parasitic nematodes. Journal of Nematology 27:535-544.

Miller, P. M. 1980. Reproduction and survival of *Xiphinema americanum* on selected woody plants, crops and weeds. Plant Disease 64:174-175.

Orlando, V., I. G. Grove, S. G. Edwards, T. Prior, D. Roberts, R. Neilson, and M. Back. 2020. Root-lesion nematodes of potato: Current status of diagnostics, pathogenicity and management. Plant Pathology 69:405-417.

Pinkerton, J. N., J. Kraus, R. R. Martin, and R. P. Schreiner. 2008. Epidemiology of *Xiphinema americanum* and Tomato ringspot virus on Red Raspberry, *Rubus idaeus*. Plant Disease 92:364-371.

Potter, J. W., and A. W. Mckeown. 2002. Inhibition of *Pratylenchus penetrans* by intercropping of *Rudbeckia hirta* and *Lycopersicon esculentum* in pot cultivation. Phytoprotection 83:115-120.

Timper, P., and W. W. Hanna. 2005. Reproduction of *Belonolaimus longicaudatus*, *Meloidogyne javanica*, *Paratrichodorus minor*, and *Pratylenchus brachyurus* on pearl millet (*Pennisetum glaucum*). Journal of Nematology 37:214-219.

Viaene, N. M., and G. S. Abawi. 1998. Management of *Meloidogyne hapla* on lettuce in organic soil with sudangrass as a cover crop. Plant Disease 82:945-952.

Welker, W. V., Jr., and D. M. Glenn. 1988. Growth responses of young peach trees and changes in soil characteristics with sod and conventional planting systems. Journal of American Horticulture 113:652-656.

Zasada, I. A., and H. Ferris. 2004. Nematode suppression with brassicaceous amendments: Application based upon glucosinolate profiles. Soil Biology and Biochemistry 36:1017-1024.

Received: *9/XI2020*

Accepted for publication: *26/I/2021*

Recibido:

Aceptado para publicación: