SURVEY OF LESION AND NORTHERN ROOT-KNOT NEMATODES ASSOCIATED WITH VEGETABLES IN VERMONT

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ABSTRACT

Bao, Yong, and Deborah A. Neher. 2011. Survey of lesion and northern root-knot nematodes associated with vegetables in Vermont. Nematropica 41:100-108.

Although crop damage due to plant-parasitic nematodes in Vermont vegetable fields has been suspected, no formal statewide nematode survey has been conducted. A survey was conducted to determine the frequency, abundance and distribution of nematodes associated with selected vegetables in 2008. A total of 66 soil samples were collected from tomato, green bean and lettuce fields on 36 vegetable farms across Vermont in spring and fall. The number of fields sampled in each county was based proportionately on the vegetable acreage in the county. Each sample was collected as a composite of 20 cores (20 cm deep, 2 cm diameter) of soil in a systematic pattern from each field. The farmer managing each field provided data including cropping history, pest management, and crop rotations. Soil nematodes were extracted by wet-tray-sieving, preserved, identified to genus, and enumerated. Additionally, bioassays with indicator plants of soybean and lettuce were conducted in a greenhouse to visually assess the infestation level of lesion and northern root-knot nematodes in soil samples, respectively. *Pratylenchus, Meloidogyne, Paratylenchus, Criconemoides, Heterodera, Helicotylenchus,* and *Hoplolaimus* spp. were found in this survey. Lesion nematode was encountered most frequently (97% of sampled fields), with fifty percent of the fields were heavily infested by the end of the growing season. The soil bioassay with soybean suggested that the number of lesions caused by lesion nematodes on primary roots was correlated positively to soil infestation levels. Northern root-knot nematode occurred only sparingly and in only a few fields, but one field had densities exceeding the established economic threshold (100 individuals/100 cm^3 dry soil). Lesion nematode is widespread and may cause significant vegetable yield losses in Vermont.

Key words: plant-parasitic nematodes, soil bioassay, indicator plants, green bean, lettuce, tomato

RESUMEN

Bao, Yong, and Deborah A. Neher. 2011. Muestreo de nematodos lesionadores y agalladores en hortalizas en Vermont. Nematropica 41:100-108.

Aunque se ha sospechado daño económico causado por nematodos fitoparásitos en hortalizas en Vermont, no se ha efectuado un muestreo formal en el estado. Se condujo un muestreo para determinar la frecuencia, abundancia y distribución de nematodos asociados a ciertas hortalizas en Vermont en el año 2008. Se colectaron 66 muestras de suelo de cultivos de tomate, habichuela y lechuga en 36 fincas en Vermont en la primavera y el otoño. La cantidad de muestras en cada condado se determinó de manera proporcional con base en el área sembrada con hortalizas en cada condado. Cada muestra estuvo compuesta de 20 submuestras (20 cm de profundidad, 2 cm de diámetro) de suelo colectadas en un patrón sistemático en cada lote. Se obtuvo información de los agricultores respecto al manejo, incluyendo información de cultivos anteriores, manejo de plagas y rotaciones de cultivos. Se extrajeron los nematodos del suelo con el método de tamiz y bandeja, y se contaron e identificaron hasta género. También se condujeron bioensayos en invernadero con plantas indicadoras de soya y lechuga para medir el nivel de infestación con nematodos lesionadores y agalladores de las muestras de suelo. Se encontraron *Pratylenchus, Meloidogyne, Paratylenchus, Criconemoides, Heterodera, Helicotylenchus,* y *Hoplolaimus* spp. en las muestras. El nematodo lesionador fue el más frecuente (97% de los lotes muestreados), con infestación alta en 50% de los lotes al final de la temporada. El bioensayo con soya indicó que la cantidad de lesiones causadas por Pratylenchus en raíces primarias se correlacionó positivamente con los niveles de infestación del suelo. Se encontró Meloidogyne hapla en baja frecuencia en unas pocos lotes, pero en un lote se encontraron densidades por encima del umbral económico (100 individuos/100 cm^3 suelo seco). El nematodo lesionador se encuentra ampliamente distribuido y puede causar daños significativos a las hortalizas en Vermont.

Palabras clave: bioensayo de suelo, habichuelas, lechuga, nematodos fitoparásitos, plantas indicadoras, tomate.

INTRODUCTION

Vegetable production in Vermont is valued at $10 million including melons, potatoes and sweet potatoes (Vermont State and County Profiles, 2002). Most widespread and economically important nematode species in the northeast region of the U.S. include northern root-knot (*Meloidogyne hapla* Chitwood, 1949), lesion (*Pratylenchus penetrans* (Cobb, 1917) Chitwood & Oteifa, 1952), and cyst (*Heterodera* spp.) nematodes (Mai *et al*., 1960). Northern root-knot and lesion nematode cause significant damage on vegetables throughout production areas of New York (Mitkowski, 2002). Yield loss by lesion nematode has been recorded previously in commercial potato (*Solanum tuberosum* L.) fields of Maine (Huettel *et al*., 1990) and Quebec (Belair *et al*., 2005). Cyst nematode (*Globodera rostochiensis* Wollenweber, 1923) was found in potato fields in New York (Mai *et al*., 1960). Similar plant-parasitic nematodes are likely present in Vermont or could be introduced from the adjacent states and provinces, given similarities in crops, climate and soils. Although crop damage due to nematodes in Vermont vegetable fields has been suspected and sampled occasionally, no formal statewide nematode survey has yet been reported. In a regional survey of stylet-bearing nematodes, only one Vermont soil sample was analyzed, with two species of lesion nematodes reported: *P. penetrans* and *P. pratensis* (de Man, 1889) Filipjev, 1936 (Mai *et al*., 1960). According to the 2002 Census of Agriculture, only one Vermont grower applied nematicide to his fields within Vermont (Vermont State and County Profiles, 2002).

The objective of this nematode survey was to verify the presence of economically important species and their abundance and distribution in Vermont vegetable fields. Specifically, we hypothesized the occurrence and damage of lesion and northern root-knot nematodes increased on vegetables in Vermont. We also investigated the potential association of plant-parasitic nematode abundance and nematode community indices with on-farm practices, which could be useful to develop appropriate management strategies.

MATERIALS AND METHODS

Field selection:

Soil samples were collected from 36 vegetable farms among 13 Vermont counties. The number of fields sampled in each county was proportional to its respective vegetable acreage (Vermont State and County Profiles, 2002). In total, 36 and 30 composite soil samples were collected from tomato (*Solanum lycopersicum* L.), green bean (*Phaseolus vulgaris* L.) and lettuce fields across Vermont in spring and late fall 2008, respectively. The farmer managing each field provided data including cropping history, pest management, and crop rotation options. More than 90% of the collaborative vegetable fields in the study were on certified organic farms or practicing organic methods if not yet certified. Field sizes ranged from 0.2 to 32 hectares with varied cropping history of 2 to 40 years. Insecticides, bactericides, or fungicides were used on 56% of the investigated fields, and two of the fields were fumigated with nematicide in the past 10 years. Only two of 36 fields had used herbicide in the past 10 years. The prevalent organic amendments applied in the vegetable fields were compost, crop residue, and (or) animal manure. Winter rye (*Secale cereale* L.), oat (*Avena sativa* L.), vetch (*Vicia villosa* Roth), clover (*Trifolium angustifolium* L.), peas (*Pisum sativum* L.), and sudangrass (*Sorghum bicolor* subsp. *Drummondii* (Steud.) de Wet ex Davidse) were common over-winter cover crops in the surveyed vegetable fields.

Experimental design:

Composite soil samples were collected by means of a modified sampling method (Neher and Campbell, 1996) from 36 fields in spring and fall 2008. In early spring, after plowing but prior to planting, 20 cores (2-cm diameter and 20-cm deep) of soil along a 100-m transect with a random starting point, within 10 cm of the plant stem were collected. The location was recorded so the same region of the field was sampled again in the fall. The cores were homogenized gently by hand in a bucket and stored in a plastic bag in an insulated container at 15°C until nematodes could be extracted.

Nematode extraction and identification:

Nematodes were extracted from 185-g soil with a modified Cobb's decanting and sieving method (Whitehead and Hemming, 1965). Soil was saturated with water, gently stirred for 30s, and then decanted with duplicate passes over a series of sieves in the order of 600, 250, 150, 75, and 44-µm pores. Nematodes and soil debris caught on the sieves were backwashed into a metal basin and poured onto a cotton filter suspended above a collecting tray. After 48 hours, the cotton filter was removed and the nematodes in the water beneath the filter were collected and settled into 100-mL bottles. Nematodes were counted from 10 mL of a well-mixed 100 mL solution in bottles and assumed to be 10% of the initial sample. Nematodes from the original sample were settled and concentrated into a 15-mL conical tube, then killed and fixed by addition of 10 mL hot 8% formalin. Several days later, depending on the estimated number of nematodes in a sample, 5 to 10 slides were prepared by placing small aliquots of concentrated nematodes onto slides inside a paraffin wax ring. A cover slip was applied and the slide was gently heated to melt the paraffin, which after cooling sealed the nematodes on the slide. For each soil sample, approximately 150 nematodes were identified to genus according to Bongers (1987), Bongers and Ferris (1999), Hunt (1993), Nickle (1991), Goodey (1963), and Maggenti et al. (1983, 1987, 1991). Taxonomic genera were assigned to a trophic group according to Yeates *et al*. (1993). Shannon's diversity (Shannon and Weaver, 1949), Simpson's dominance (Simpson, 1949), richness of genera (Hill, 1973), and ∑MI indices of both plant-parasitic and free-living genera (Yeates, 1994) were calculated (Table 1). A 50-g subsample of soil was used to determine soil gravimetric moisture and standardize nematode abundance per gram of dry soil.

Soil bioassays:

A sub-sample from each field was tested for the presence of lesion and cyst nematodes with indicator host plants, separately (Gugino *et al*., 2006, 2008): soybean for lesion nematode and lettuce for root-knot nematode. Each soil sample with each indicator plant was replicated four times. Approximately 200 cm^3 of soil was placed in each of four cone-tubes that had a cotton ball blocking the holes in the bottom to allow water drainage but prevent soil loss. Two seeds of an indicator plant were planted in each tube. The tubes were arranged on plastic holders, and maintained in the greenhouse at 20-25°C. Water was supplied daily to maintain soil moisture near field capacity. A standard fertilizer (17N-4P-17K) was applied once per week. Root systems were harvested 4 to 6 weeks after planting, and washed free of soil. Lesions on tap roots and root galls on the entire root systems were counted on soybean and lettuce, respectively.

Statistical analysis:

Repeated measures, three-way analysis of variance was performed using the MIXED procedure in SAS software version 9 (SAS Institute, Cary, NC). Dependent variables included the abundances of total nematodes and lesion nematodes, and the index values of nematode community diversity, richness, dominance, and maturity (Table 1). Independent variables were season, pesticide, and manure. Multiple comparisons among means were made with Fisher's protected Least Significant Difference (LSD) Test. Prior to analysis; abundance of nematodes was transformed to $\log_{10}$ to meet assumptions of normality and equal variances. Canonical correspondence analysis (CCA) was employed to identify multidimensional patterns among abundance of nematodes by genus and contrasting on-farm practices including pesticide, manure, vetch, sudangrass, and clover. Canonical correspondence analysis was performed using Canoco Version 4.5 software (ter Braak and Smilauer, 1998).

RESULTS

Nematode genera and abundance:

This survey revealed the presence of 20 families and 34 genera of nematodes associated with mixed vegetable production in Vermont (Table 2). Nematode populations in the investigated fields had a range of 719 to 3,578 individuals/100 cm^3 of dry soil. Seven genera of plant-parasitic nematodes were identified:

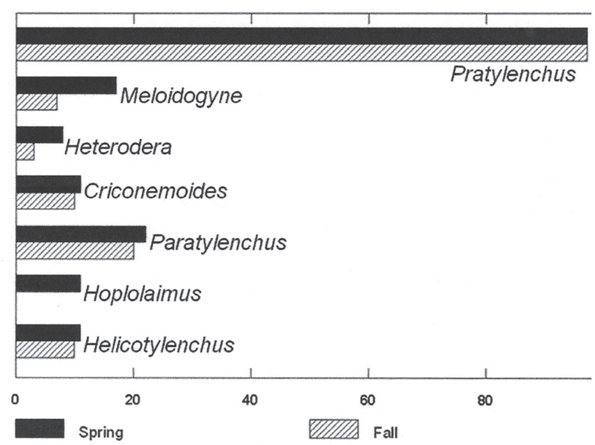

Fig. 1. Incidence of plant-parasitic nematodes from Vermont nematode survey. Illustrated as a percentage of the 36 fields sampled.

Table 1. Indices used in nematode community analysis

Name	Equation	Reference
Shannon's diversity	$H' = -\sum (p_i^{x} \ln p_i)$	Shannon and Weaver (1949)
Simpson's dominance	$D = \sum p_i^2$	Simpson (1949)
Richness	$R = S^y$	Hill (1973)
Maturity index	$\sum MI = \sum (v_i^{z} * f_i^{u}) / n$	Yeates (1994)

$^x p_i$ is the relative abundance of taxon i.
^{y}S is the total number of genera present in soil.
$^z v_i$ = c-p value (1-5) assigned to family
$^u f_i$ = frequency of taxon i in sample
^{v}n = total number of individuals in a sample

Pratylenchus, Meloidogyne, Paratylenchus, Criconemoides, Heterodera, Helicotylenchus and *Hoplolaimus* (Fig. 1). Among plant-parasitic nematodes, lesion nematode was encountered most frequently, with detection in 97% of sampled fields in both spring and fall (Fig. 1). However, lesion nematode abundance varied among fields, with means of 148 and 224 individuals/100 cm^3 dry soil in spring and fall, respectively. Furthermore, lesion nematode occurred at population levels above the economic threshold (100 individuals/100 cm^3 dry soil) in 47% of sampled fields in spring and increased to 70% in fall (Fig. 2). About 19 % of sampled fields were infested heavily (>200 individuals/100 cm^3 dry soil) with lesion nematode in spring, while fifty percent of the sampled fields were infested heavily in fall (Fig. 2). Root-knot nematode was observed in 17% and 7% of soil samples in spring and fall, respectively (Fig. 1), and only one field in fall contained a density above the established economic threshold (100 individuals/100 cm^3 dry soil). The remaining genera of plant-parasitic nematodes: (*Paratylenchus, Criconemoides, Heterodera, Helicotylenchus, Hoplolaimus*) were collected from soil samples occasionally with relatively low abundance. *Hoplolaimus* spp. were detected in the soils only in fall. In terms of geographical distribution, lesion nematode was distributed unevenly across Vermont. The highest incidence occurred in the north-central region in spring, and then occurred over the entire state in fall (Fig. 3).

Soil bioassays:

The results of soil bioassay with soybean plants indicated that the number of lesions caused by lesion nematodes on primary roots was correlated positively to their abundance in the bulk soils (Fig. 4). However, an association between the galls on the lettuce roots and the infestation level of root knot nematode in bulk soil was not attempted because only 10% of roots were infested by root-knot nematodes.

Management effects:

Based on our survey, a dramatic increase in lesion nematode abundance and smaller value of the Maturity Index was observed in fall (Table 3). Pesticide treatment corresponded with the less abundance of nematodes, reduced the value of diversity index, and increased the value of dominance index simultaneously (Table 3). However, we did not observe any significant statistical differences for nematode communities among fields with incorporation of

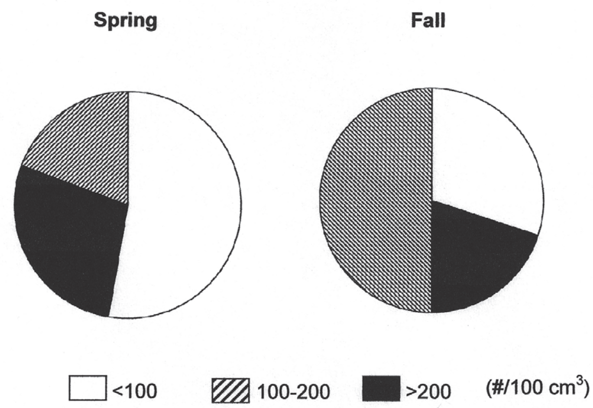

Fig. 2. The percentage of infestation level of lesion nematode, *Pratylenchus* spp., in spring and fall 2008. Populations > 100 lesion nematodes per 100 cm^3 dry soil is damaging to vegetable crops; populations > 200 individuals per 100 cm^3 dry soil indicate a heavy infestation and action is needed.

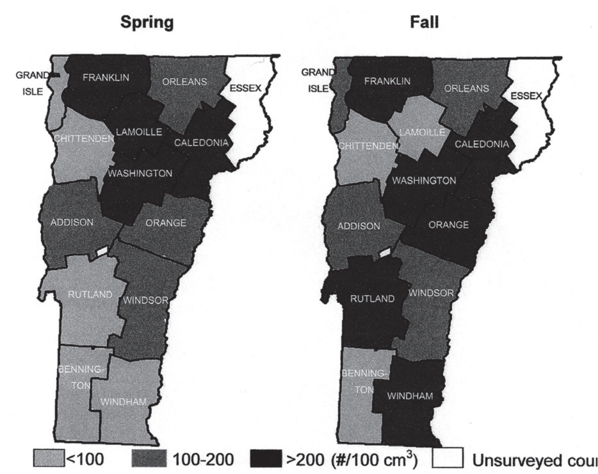

Fig. 3. Level of infestation and distribution of lesion nematodes, *Pratylenchus* spp., in spring and fall 2008. Populations > 100 lesion nematodes per 100 cm^3 dry soil is damaging to vegetable crops; populations > 200 individuals per 100 cm^3 dry soil indicate a heavy infestation and action is needed.

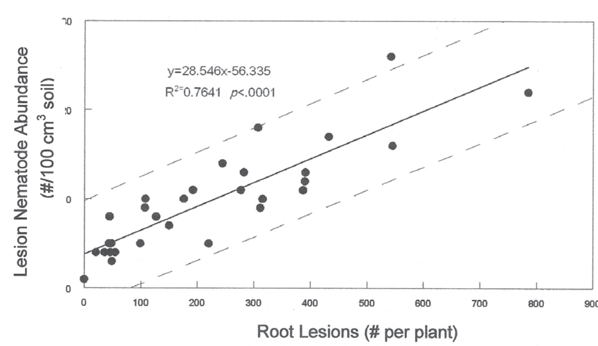

Fig. 4. Linear regression between number of lesions and abundance of lesion nematode, *Pratylenchus* spp., in soil.

Table 2. Nematode genera found in Vermont vegetable fields in 2008. Families were assigned to feeding types according to Yeates *et al*. (1993) (in alphabetical order). Abundance illustrated as the mean of 36 fields sampled in spring and 30 fields in fall 2008 (n = 66).

Feeding Group	Family	Genus	Abundance (individuals/100 cm^3 dry soil)
Bacterivores	Cephalobidae	*Acrobeles*	28±56
		Acrobeloides	82±108
		Acrolobus	29±40
		Cephalobus	265±195
		Cervidellus	5±15
		Encephalous	235±152
		Metacrolobus	3±10
		Panagroteratus	2±7
	Leptolaimidae	*Chronogaster*	3±7
	Monhysteridae	*Eumonhystera*	4±12
	Panagrolaimidae	*Panagrellus*	5±14
		Panagrolaimus	3±13
	Plectidae	*Plectus*	14±26
		Wilsonema	4±9
	Prismatolaimidae	*Prismatolaimus*	25±36
	Rhabditidae	*Mesorhabditis*	173±139
Fungivores	Aphelenchidae	*Aphelenchus*	224±149
	Aphelenchoididae	*Aphelenchoides*	11±20
	Tylenchidae	*Filenchus*	143±128
Herbivores	Criconematidae	*Criconemoides*	2±7
	Heteroderidae	*Heterodera*	1±6
	Hoplolaimidae	*Helicotylenchus*	4±16
		Hoplolaimus	1±5
	Meloidogynidae	*Meloidogyne*	11±61
	Paratylenchidae	*Paratylenchus*	9±26
		Pratylenchus	183±182
Predators/Omnivores	Aporcelaimidae	*Aporcelaimus*	39±65
	Dorylaimidae	*Discolaimus*	1±4
		Epidorylaimus	9±17
		Eudorylaimus	29±43
		Prodorylaimus	2±7
	Neodiplogasteridae	*Pristionchus*	21±90
	Qudsianematidae	*Microdorylaimus*	14±26
		Thonus	4±12

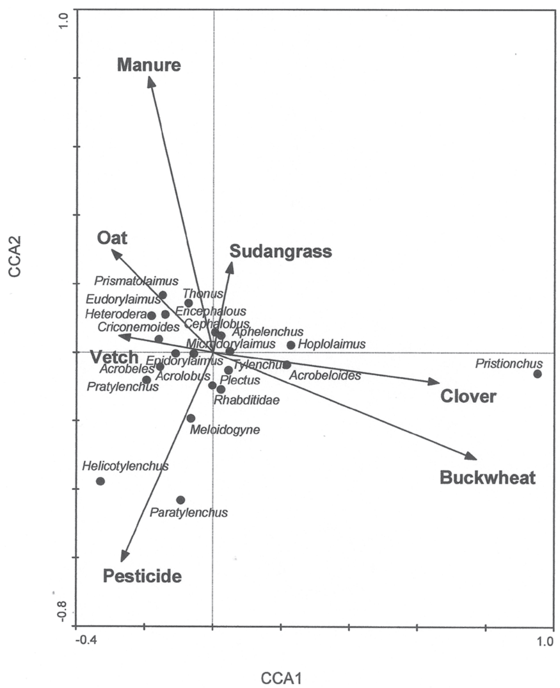

Fig. 5. Nematode community composition from Vermont nematode survey in spring. Canonical correspondence biplot of CCA1 (*x*-axis) and CCA2 (*y*-axis) are illustrated. Environmental vectors represent treatment combination of farming practices. Points represent relative abundance of nematode genera. Eigenvalues (lambda) are 1.13 (p = 0.0160), 0.049, 0.047, and 0.032 for first (horizontal), second (vertical), third and fourth axes, respectively.

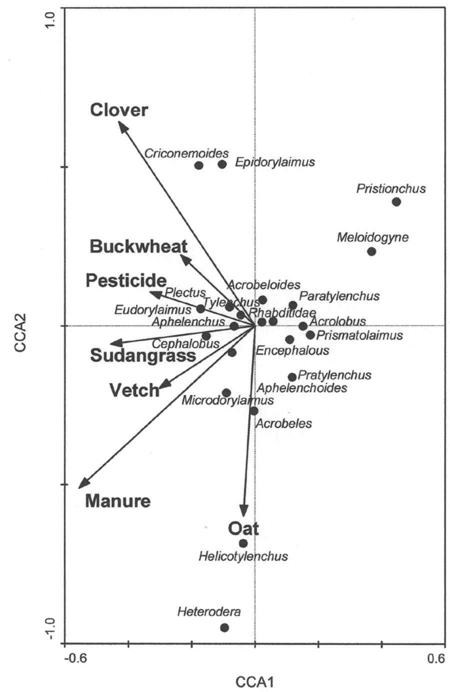

Fig. 6. Nematode community composition from Vermont nematode survey in fall. Canonical correspondence biplot of CCA1 (*x*-axis) and CCA2 (*y*-axis) are illustrated. Environmental vectors represent treatment combination of farming practices. Points represent relative abundance of nematode genera. Eigenvalues (lambda) are 1.051 (p = 0.9900), 0.042, 0.039, and 0.032 for first (horizontal), second (vertical), third and fourth axes, respectively.

Table 3. Effect of season and management on nematode communities in vegetable fields of Vermont 2008. Statistical differences were analyzed as repeated measures three-way analysis of variance.

Effect		Total Nematode[w]	Lesion Nematode[w]	Diversity[y]	Dominance[z]	Richness[u]	∑MI[v]
Season	Spring	1518±179a[x]	36±53a	2.04±0.05a	0.15±0.01a	13.58±0.82a	2.17±0.06a
	Fall	1498±177a	118±53b	2.00±0.05a	0.15±0.01a	13.04±0.81a	2.08±0.06b
Pesticide	No	1709±194a	81±58a	2.06±0.06a	0.14±0.01a	13.53±0.89a	2.17±0.06a
	Yes	1308±166b	73±49a	1.97±0.05b	0.16±0.01b	13.09±0.76a	2.08±0.05a
Manure	No	1432±178a	94±53a	2.02±0.05a	0.15±0.01a	12.93±0.81a	2.14±0.06a
	Yes	1585±187a	61±56a	2.01±0.05a	0.15±0.01a	13.69±0.85a	2.10±0.06a

[w]The abundance of total nematode and lesion nematode were calculated as nematode/100 cm^3 dry soil.
[x]Multiple comparisons among means were made with Fisher's protected Least Significant Difference (LSD) Test. Means with different letters (within a column) indicate contrasting means within an effect ($p < 0.05$).
[y]Diversity = Shannon diversity index
[z]Dominance = Simpson dominance index
[u]Richness = richness index
[v]∑MI = maturity index of both plant-parasitic and free-living genera

manure (Table 3). The CCA bi-plots showed that using clover as overwinter cover crop reduced the occurrence of *Pratylenchus* in soils in both spring and fall (Fig. 5, 6). *Helicotylenchus, Meloidogyne* and *Paratylenchus* occurred, when the pesticides were applied in spring (Fig. 5). *Paratylenchus* and *Meloidogyne* were absent only when animal manure was added in fall (Fig. 6). The other two plant-parasitic nematodes: *Heterodera* and *Criconemoides* were present only when vetch occurred in spring (Fig. 5).

DISCUSSION

The genera of plant-parasitic nematodes found in this survey were consistent with those reported from neighboring northeastern states (Mai, 1960; Huettel, 1991; Mitkowshi, 2002), in that, lesion nematode was the predominant plant-parasitic nematode in vegetable fields of Vermont. Although we did not identify the lesion nematode to the species level, *P. penetrans* and *P. pratensis* are the most probable species, both of them were identified previously from Vermont soils in a regional nematode survey (Mai, 1960). Furthermore, *P. penetrans* and *P. crenatus* were the two major plant-parasitic nematode species associated with potato that caused substantial yield reductions in an adjacent state, Maine (Huettel, 1991). *P. penetrans* had also caused serious damage on vegetables and berries in second adjacent state, New York (Mitkowshi, 2002). During this survey, we observed above-ground symptoms possibly associated with lesion nematodes such as wilting, stunting, chlorosis, curled leaves and fewer fruits on plants in some vegetable fields.

Our survey detected root-knot nematodes (*Meloidogyne*) in several fields but only one field was heavily infested and occurred in Orange County. Northern root-knot nematode (*Meloidogyne hapla*) has been identified in New York as the most important economic plant-parasitic nematode (Viaene and Abawi, 1998; Mitkowski, 2002). Nematode taxa that were not recovered in soil samples do not necessarily mean they do not occur and infest the plants in Vermont. Our sampling was limited to only soils with tomato, green beans, and lettuce plants that is an incomplete list of plant hosts. Alternatively, nematodes may feed on the roots of crops in rotation other than the one present at the time the sample was taken. For example, a previous nematode survey (Mai, 1960) reported *Xiphinema* in the soils from Vermont, but we did not find any in our samples.

Soil bioassays with indicator plants have been developed as an integrated pest management (IPM) tool for nematode infestation assessment in New York (Gugino *et al*., 2006, 2008). The bioassays provide a simple method to determine whether plant-parasitic nematodes occur within specific fields; and whether nematode population densities exceed economic thresholds. For example, lettuce (*Lactuca sativa* L.) is very susceptible to root knot nematode infections and the resultant galls on the roots are distinct and visible to the naked eye, making it an ideal soil bioassay indicator. The number of galls developed on lettuce bioassay plants have been shown previously to be closely related to soil infestations with root-knot nematodes and a good predictor of the impact of cover and rotational crops on the root knot nematode population (Viaene and Abawi, 1998; Widmer and Abawi, 2000). Similarly, feeding by lesion nematodes results in dark lesions along the primary root of soybean, which make it an ideal candidate for soil bioassay with lesion nematode. Our result confirmed a positive correlation of lesion nematode density in soil and the number of diagnostic lesions observed on soybean roots. We observed that lesions formation on the soybean roots was often masked by the symptoms from other soil-borne root pathogens. Gugino *et al*. (2006) recommended the development of a new indicator plant for the bioassay that would not be susceptible to the confounding soil-borne pathogens. Duncan (1991) recommended bioassays due to their sensitivity for detecting low nematode densities through reproduction over time.

Damage thresholds (i.e., economic thresholds) for lesion and northern root-knot nematodes on vegetables we used in our survey were defined under New York conditions, as thresholds have not been developed for Vermont crops. Thresholds may vary annually with changes in weather conditions, crop cultivars, and other factors (Ferris, 1978). Lesion nematode densities above the assumed economic threshold of 100 individuals/100 cm^3 soil were common at harvest time, but the effect of these densities on vegetable yield and quality has not been assessed in Vermont.

Rotation to non-host crops can substantially reduce the nematode population (Viaene and Abawi, 1998). It was demonstrated that adding barley into rotation of carrot cropping system was extremely effective in reducing root-knot nematode levels (Belair, 1996). However, practicing crop rotation becomes challenging because both lesion and northern root-knot nematodes have a wide host range. Plant hosts exceed 350 species including most cultivated crops and numerous weeds including dandelion (*Taraxacum* officinale F.H. Wigg), purslane (Portulaca oleracea L.), and mallow (*Malva rotundifolia* L.). Current crop rotation practices used by Vermont vegetable growers as management tools for general soil-borne diseases are ineffective as most crops grown in vegetable rotations (e.g., lettuce, snap beans, tomato, carrots, onion (*Allium cepa* L.) are susceptible to lesion nematodes. Winter rye has been grown as a rotation crop or winter cover crop in Vermont, but it is a good host for lesion nematodes. Lesion nematodes can overwinter successfully in soil, living at a reduced metabolic rate, on stored food supplies. Therefore, the use of rye as cover winter crop could increase nematode pressure on subsequent crops, potentially reduce yield. While vetch has several beneficial effects such as controlling soil erosion and improvement of soil quality as a cover crop, it is an excellent host for *P. penetrans* (Abawi and Ludwig, 1995). In contrast, cover crop and green manure amendments of sudangrass and rapeseed (*Brassica napus* L.) decreased root-galling ratings and the reproduction of northern root-knot nematodes (Viaene and Abawi, 1998; Chen *et al*., 1999). In this survey, we detected a reduction in occurrence of lesion nematodes in soils with clover, suggesting that clover has the potential as a suppressive agent for lesion nematode control in vegetable fields. Eberlein *et al*. (1997, 1998) reported that the incorporation of white clover and sorghum sudangrass improve the control of nematodes and soilborne diseases in the potato fields.

Although not significant statistically, our results show the trend of applications of animal manure associated with a reduction of lesion nematode abundance, which supports the previous studies (Mahran, 2008). Green manures and other amendments also can be effective at controlling diseases and nematodes through the release of compounds into soil that are toxic to the nematodes (Widmer and Abawi, 2000), or by providing more habitable environment for antagonists of nematodes (Kerry, 2000). Certainly, effectiveness of cultural management practices is affected by farm specific conditions, such as soil type, temperature, moisture, and the availability of other pathogens. For example, the greatest economic damage occurs when the lesion nematode interacts with the wilt-causing fungus *Verticillium* spp., forming a disease complex known as early dying of potatoes (Rowe and Powelson, 2002).

This survey provides baseline data for the distribution of plant-parasitic nematodes associated with common vegetables in Vermont. The widespread presence of lesion nematodes in the state deserves the attention of researchers and extension agents. Estimates of economic thresholds and on-farm bioassays would help vegetable growers recognize potential or actual nematode problems and apply appropriate management strategies in their fields. Further research is also necessary to determine the interactions of common plant-parasitic nematodes with other soil pathogens.

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