

## Plant-parasitic Nematode Communities and Their Associations with Soil Factors in Organically Farmed Fields in Minnesota

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**Abstract:** A survey was conducted to determine the assemblage and abundance of plant-parasitic nematodes and their associations with soil factors in organically farmed fields in Minnesota. A total of 31 soil samples were collected from southeast (SE), 26 samples from southwest (SW), 28 from west-central (WC), and 23 from northwest (NW) Minnesota. The assemblage and abundance of plant-parasitic nematodes varied among the four regions. The soybean cyst nematode, *Heterodera glycines*, the most destructive pathogen of soybean, was detected in 45.2, 88.5, 10.7, and 0% of organically farmed fields with relative prominence (RP) values of 10.3, 26.5, 0.6, and 0 in the SE, SW, WC, and NW regions, respectively. Across the four regions, other common genera of plant-parasitic nematodes were *Helicotylenchus* (42.6, RP value, same below), *Pratylenchus* (26.9), *Tylenchorhynchus* and related genera (9.4), *Xiphinema* (5.6), and *Paratylenchus* (5.3). *Aphelenchoides*, *Meloidogyne*, *Hoplolaimus*, *Mesocriconema*, and *Trichodorus* were also detected at low frequencies and/or low population densities. The similarity index of plant-parasitic nematodes between two regions ranged from 0.44 to 0.71 and the similarity increased with decreasing distance between regions. The densities of most plant-parasitic nematodes did not correlate with measured soil factors (organic matter, pH, texture). However, the densities of *Pratylenchus* correlated negatively with % sand, and *Xiphinema* was correlated negatively with soil pH.

**Key words:** *Aphelenchoides*, *Helicotylenchus*, *Heterodera glycines*, *Hoplolaimus*, *Meloidogyne*, *Mesocriconema*, nematode community, organic-farming, *Paratylenchus*, *Pratylenchus*, soybean cyst nematode, *Trichodorus*, *Tylenchorhynchus*, *Xiphinema*.

Organic production has been increasing steadily in recent years and will continue to grow in Minnesota. In 2010, the Minnesota Department of Agriculture has estimated the number of organic farms in Minnesota at 653 and in 2008 it was eleventh in the nation in organic production (Moynihan, 2010). Organic-cropping systems may have high pest pressures because there are fewer management options as compared with conventional production systems. Plant-parasitic nematodes are one of the important groups of pests on many organic crops. For example soybean cyst nematode (SCN), *Heterodera glycines*, causes greater crop loss than any other soybean (*Glycines max*) disease (Monson and Schmitt, 2004; Wrather and Koenning, 2006). In spite of the widespread availability of resistant cultivars of conventional soybean, management of *H. glycines* has proven to be difficult, and the distribution and severity of *H. glycines* continues to increase in the North Central region. *Heterodera glycines* was first detected in Minnesota in 1979 (MacDonald et al., 1980), and now occurs in most (approximately 65%) conventional soybean fields in southern and central Minnesota, and recently has been detected in a few counties in the Red River Valley in northwest Minnesota (Chen, 2011). Another group of nematodes, lesion nematodes (*Pratylenchus* spp.), are widely distributed in the United States, have wide host ranges (Mai et al., 1977; Taylor et al., 1958; Taylor and

Schleder, 1959), and are also important in conventional fields in Minnesota. Lesion nematodes are migratory endoparasites and involved in disease complexes such as early dying of potatoes (*Solanum tuberosum*) (Powelson and Rowe, 1993; Rowe and Powelson, 2002), exceeding the disease threshold from one nematode alone.

While management of plant-parasitic nematodes in conventional fields especially for the soybean cyst nematodes using resistant cultivars is widely practiced, little attention has been paid to nematode problems in the organically farmed fields, as most of the resistant soybean cultivars also carry a genetically modified gene for herbicide tolerance and these cultivars cannot be used in organic production systems. Management of insect, diseases, and nematodes in organic-farming systems may need to rely on the inherent equilibrium in nature (Delate, 2003). To achieve the natural low equilibrium level of pests and pathogens, farming practices must include diverse rotations, cover crops, organic matter maintenance/additions, and other practices to promote diverse microbial organisms for a healthy soil. Unlike conventional systems, continuous cropping or a simple corn (*Zea mays*)-soybean rotation that is commonly practiced in the Midwest in the USA in conventional fields is not allowed in the organic-farming system by the National Organic Program, the federal agency that governs the organic certification process (USDA, 2012). The multi-year crop rotation if appropriately designed may help manage plant-parasitic nematodes (Bhan et al., 2010). Organically farmed fields with application of organic fertilizer such as animal manure may enhance soil health and natural biocontrol of pests (Birkhofer et al., 2008). Transition from conventional to organic farming can increase populations of beneficial bacterivore nematodes while simultaneously reducing the population of the predominant plant-parasitic nematode, *Pratylenchus crenatus* (Briar et al., 2007).

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Little is known about the extent of the *H. glycines* and other plant-parasitic nematode problems in the organic-farming system in the Midwest of the USA. The objectives of this study were to assess diversity and abundance of plant-parasitic nematodes in the organically farmed fields in Minnesota, and their associated factors including soil characters, crops, and geographical locations. The main aim of the study was to provide baseline information for determining if management actions are needed in the organically farmed fields, and if the management needs should differ in different regions and fields. We hypothesize that the community of plant-parasitic nematodes in the organically farmed fields differ in different regions and fields within the state of Minnesota because there are significant variations of climates, soil conditions and crops across the state.

#### MATERIALS AND METHODS

**Sampling:** A survey was conducted in the fields on 58 certified organic farms during the crop-growing season in 2006 in southeast, southwest, west-central, and northwest regions in Minnesota (Table 1). Farms were arbitrarily selected from the "Directory of Minnesota Organic Farms 2006" and sampled with consent of the

farm owners. On each farm, one or two (from two fields with different cropping sequences) soil samples were collected, for a total of 108 samples (Fig. 1). Each soil sample was consisted of approximately 30 soil cores collected with a 2.5-cm-diameter soil probe to a depth of approximately 20 cm across an area of 0.5 to 2 hectares in a field. Most of the samples were collected during mid-season in August to September, and a few samples were collected at the end of season in October, 2006. After collection, soil samples were shipped within 1-2 days to the laboratory. The soils were stored in a cool room (~10 °C) and processed within 1-2 days after receiving. Crop sequences were recorded for most of the sampled fields.

**Sample processing:** The soil samples were thoroughly mixed. A subsample of 100 cm<sup>3</sup> soil was used to extract vermiform nematodes using the hand-decanting and sucrose centrifugal-flotation technique (Jenkins, 1964). Half of the nematodes in a sample were killed in water at 63 °C and fixed in 3.7% formaldehyde (Hooper, 1986), and the other half of a sample was placed in antibiotic solution (100 ppm streptomycin, 30 ppm chlortetracycline, and 20 ppm quinolinol). The samples were stored at 4 °C in a refrigerator. The nematodes in the antibiotic solution were generally alive and easier to identify and count, so they were used in

TABLE 1. Climate, soil characters, and current crops of the sampled organically farmed fields in the four regions in Minnesota.

	Southeast	Southwest	West Central	Northwest
	Mean (range)	Mean (range)	Mean (range)	Mean (range)
Annual mean temperature (°C) <sup>a</sup>	6.9 (3.5-10.4)	7.1 (0.9-13.2)	6.5 (3.3-8.9)	4.3 (0.8-7.2)
Annual precipitation (mm) <sup>a</sup>	807 (443-1,282)	685 (317-1,039)	615 (239-866)	559 (253-835)
Soil pH	6.8 (5.5-7.6)	6.9 (5.8-7.7)	7.3 (6.0-8.1)	7.9 (7.5-8.2)
Soil organic matter (%)	3.6 (1.9-6.8)	4.1 (3.1-5.2)	3.9 (1.2-6.3)	3.1 (2.0-4.5)
Soil % sand	39.7 (15-75)	40.0 (18-70)	41.7 (20-78)	58.8 (23-83)
Soil % silt	34.7 (9-61)	29.9 (17-49)	30.9 (12-45)	18.3 (6-34)
Soil % clay	25.6 (11-49)	30.2 (13-38)	27.5 (9-43)	22.9 (8-49)
	Number of fields with current crop of			
Alfalfa ( <i>Medicago sativa</i> )	4	2	5	1
Barley ( <i>Hordeum vulgare</i> )		2		1
Broccoli ( <i>Brassica oleracea</i> )	1			
Buckwheat ( <i>Fagopyrum esculentum</i> )	1			
Carrots ( <i>Daucus carota</i> )			1	
Cauliflower ( <i>Brassica oleracea</i> )			1	
Chickling vetch ( <i>Lathyrus sativus</i> )				1
Corn ( <i>Zea mays</i> )	4	5	3	
Fallow				2
Flax ( <i>Linum usitatissimum</i> )				3
Green pepper ( <i>Capsicum annuum</i> )			1	
Hairy vetch ( <i>Vicia villosa</i> )			1	
Oats ( <i>Avena sativa</i> )	3	2	2	2
Pasture	1		2	
Red clover ( <i>Trifolium pretense</i> )			1	
Rye ( <i>Secale cereale</i> )	2			
Soybean ( <i>Glycine max</i> )	13	13	5	11
String beans ( <i>Phaseolus vulgaris</i> )	1			
Sunflower ( <i>Helianthus annuus</i> )			1	
Tomato ( <i>Solanum lycopersicum</i> )	1		1	
Wheat ( <i>Triticum aestivum</i> )		3	4	2

<sup>a</sup> The data were obtained from the weather stations in Waseca for the southeast during 1915–2010, Lambertton for the Southwest during 1961–2009, Morris for West Central during 1886–2010, and Crookston for Northwest regions during 1890–2010.



TABLE 2. Frequency distribution of soil samples from Minnesota organically farmed fields among classes of *Heterodera glycines* egg numbers per 100 cm<sup>3</sup> of soil in 2006.

Egg density	Southeast		Southwest		West central		Northwest		All regions	
	No. of samples	% Frequency								
0	17	55	4	15	26	93	23	100	70	65
1-200	5	16	5	19	2	7	0	0	12	11
201-1,000	4	13	4	15	0	0	0	0	8	7
1,001-5,000	3	10	7	27	0	0	0	0	10	9
5,001-20,000	2	6	6	23	0	0	0	0	8	7

## RESULTS

*Soybean cyst nematode*: No cyst nematode females were observed on the clover roots in the bioassay, thus *H. glycines* was the only cyst nematode detected. *Heterodera glycines* eggs and/or J2 were detected in 45.2, 88.5, 10.7, and 0% fields in southeast, southwest, west-central, and northwest regions, respectively. The infestation of *H. glycines* in the soil samples was confirmed with greenhouse bioassay. The frequency distributions of soil samples among classes of egg population densities are summarized in Table 2. In the southeast, 29% of the fields had more than 200 eggs/100 cm<sup>3</sup> soil, which can cause yield loss to SCN-susceptible soybean cultivars. In the southwest, 65% of the fields had egg population densities exceeding 200 eggs/100 cm<sup>3</sup> soil. In some fields (6% in southeast and 23% in southwest) egg population densities were high (> 5,000 eggs/100 cm<sup>3</sup> soil), and could cause significant damage even to SCN-resistant soybean cultivars (Chen et al., 2001a). The egg population densities in the egg-positive fields across the regions with current soybean in 2006 ranged from 25 to 13,625 eggs/100 cm<sup>3</sup> soil with an average of 3,023 eggs/100 cm<sup>3</sup> soil. The population densities decreased with increasing years of non-host crops (Table 3).

*Composition and distribution of major plant-parasitic nematode genera*: A total of eleven genera of plant-parasitic nematodes were identified. The nematode genera and their prominence, which indicates the frequency of occurrence and population densities, differed among the four regions (Table 4). In the southeast, common genera included *Pratylenchus* (41.3, RP value, same below), *Helicotylenchus* (39.5), *Heterodera* (10.3), *Xiphinema* (4.8), and *Paratylenchus* (3.2); *Hoplolaimus*, *Mesocriconema*, and *Tylenchorhynchus* were observed in some samples with low population densities. In the southwest, common genera were *Helicotylenchus* (38.5), *Heterodera* (26.4), *Pratylenchus* (18.2), *Xiphinema* (12.0), and *Tylenchorhynchus* and related genera (4.5); *Hoplolaimus*, *Paratylenchus* and *Aphelenchoides* were detected with low prominence values. In the west central, *Helicotylenchus* (45.8), *Pratylenchus* (29.4), *Tylenchorhynchus* and related genera (10.6), *Paratylenchus* (6.4), and *Meloidogyne* (4.8 RP in 2 fields) were common; *Heterodera*, *Hoplolaimus*,

*Aphelenchoides*, and *Trichodorus* were the genera with low prominence values. In the northwest, the most common nematodes were *Tylenchorhynchus* and related genera (44.7), followed by *Helicotylenchus* (33.1), *Paratylenchus* (15.9), and *Pratylenchus* (4.6); *Hoplolaimus*, *Xiphinema*, and *Trichodorus* were infrequently observed. Across the four regions, the common genera of plant-parasitic nematodes based on relative prominence values were *Helicotylenchus* (42.6), *Pratylenchus* (26.9), *Tylenchorhynchus* and related genera (9.4), *Heterodera* (9.2), *Xiphinema* (5.6), and *Paratylenchus* (5.3).

Difference in the communities of plant-parasitic nematodes among the four regions increased with increasing distance between two regions (Table 5). The highest similarity was observed between the two adjacent southern regions (similarity index 0.71) with similar latitude (i.e., similar climatic conditions), and the lowest (similarity index 0.44) was between the southeast and northwest regions, which are farthest apart.

*Association of the nematode community with edaphic factors*: Correlation coefficients of population densities with soil pH, % organic matter, % sand, % silt, and % clay particles are summarized in Table 6. *Pratylenchus* was positively correlated with % silt (range 6-71%) and negatively correlated with % sand (range 15-78%). Within the range of pH 5.7-7.9, *Xiphinema* was more abundant in soil with a lower pH than in soil with a higher pH. No significant correlations of other plant-parasitic nematodes with the soil factors were observed.

## DISCUSSION

In the present survey, a number of plant-parasitic nematodes were detected in the organically farmed

TABLE 3. Population densities (eggs/100 cm<sup>3</sup> soil) of *Heterodera glycines* in fields with different number of years of non-host crops.

Years of non-host crops <sup>a</sup>	Number of fields	Average	Standard deviation	Minimum	Maximum
0	16	3,023	4,565	25	13,625
1	10	2,510	2,410	125	6,865
2	4	728	993	75	2,220

<sup>a</sup> 0 = current soybean in 2006; 1 = last soybean was in 2005; 2 = last soybean was in 2004.

TABLE 4. Distributions and prominence of major plant-parasitic nematodes in organic farms in Minnesota. <sup>a</sup>

Nematode genus	No. of positive samples	Absolute frequency (%)	Relative frequency (%)	Absolute density (#/100 cm <sup>3</sup> )	Relative density (%)	Prominence value	Relative prominence (%)
Southeast (n = 31)							
<i>Helicotylenchus</i>	24	77.4	27.3	128.0	36.1	112.6	39.47
<i>Heterodera</i>	13	41.9	14.8	45.2	12.8	29.3	10.26
<i>Hoplolaimus</i>	2	6.5	2.3	5.2	1.5	1.3	0.46
<i>Mesocriconema</i>	2	6.5	2.3	5.2	1.5	1.3	0.46
<i>Paratylenchus</i>	9	29.0	10.2	17.0	4.8	9.2	3.21
<i>Pratylenchus</i>	25	80.6	28.4	131.2	37.0	117.8	41.29
<i>Tylenchorhynchus</i> <sup>b</sup>	1	3.2	1.1	0.6	0.1	0.1	0.04
<i>Xiphinema</i>	12	38.7	13.6	22.0	6.2	13.7	4.80
Southwest (n = 26)							
<i>Aphelenchoides</i>	3	11.5	3.1	2.4	0.8	0.8	0.31
<i>Helicotylenchus</i>	21	80.8	21.6	110.6	36.9	99.4	38.46
<i>Heterodera</i>	22	84.6	22.7	74.4	24.8	68.4	26.47
<i>Hoplolaimus</i>	1	3.8	1.0	0.4	0.2	0.1	0.03
<i>Paratylenchus</i>	2	7.7	2.1	0.6	0.2	0.2	0.06
<i>Pratylenchus</i>	20	76.9	20.6	53.6	17.9	47.0	18.18
<i>Tylenchorhynchus</i> <sup>b</sup>	14	53.8	14.4	15.8	5.3	11.6	4.48
<i>Xiphinema</i>	14	53.8	14.4	42.2	14.1	31.0	11.97
West central (n = 28)							
<i>Aphelenchoides</i>	1	3.6	1.4	0.4	0.2	0.1	0.05
<i>Helicotylenchus</i>	20	71.4	27.0	81.0	37.3	68.4	45.78
<i>Heterodera</i>	3	10.7	4.1	2.6	1.2	0.9	0.57
<i>Hoplolaimus</i>	1	3.6	1.4	1.2	0.5	0.2	0.15
<i>Meloidogyne</i>	2	7.1	2.7	26.8	12.3	7.1	4.78
<i>Paratylenchus</i>	8	28.6	10.8	17.8	8.2	9.5	6.37
<i>Pratylenchus</i>	21	75.0	28.4	50.8	23.4	44.0	29.43
<i>Trichodorus</i>	1	3.6	1.4	1.4	0.7	0.3	0.18
<i>Tylenchorhynchus</i> <sup>b</sup>	8	28.6	10.8	29.6	13.6	15.8	10.59
<i>Xiphinema</i>	9	32.1	12.2	5.6	2.6	3.2	2.12
Northwest (n = 23)							
<i>Aphelenchoides</i>	1	4.3	2.3	1.8	0.6	0.4	0.21
<i>Helicotylenchus</i>	9	39.1	20.9	95.6	33.9	59.8	33.08
<i>Hoplolaimus</i>	1	4.3	2.3	4.8	1.7	1.0	0.55
<i>Paratylenchus</i>	5	21.7	11.6	61.8	21.9	28.8	15.93
<i>Pratylenchus</i>	4	17.4	9.3	20.0	7.1	8.3	4.62
<i>Trichodorus</i>	1	4.3	2.3	0.8	0.3	0.2	0.09
<i>Tylenchorhynchus</i> <sup>b</sup>	17	73.9	39.5	94.0	33.3	80.8	44.72
<i>Xiphinema</i>	5	21.7	11.6	3.2	1.1	1.5	0.82
All regions (n = 108)							
<i>Aphelenchoides</i>	5	4.6	1.7	1.0	0.4	0.2	0.11
<i>Helicotylenchus</i>	74	68.5	24.5	104.8	36.1	86.7	42.60
<i>Heterodera</i>	38	35.2	12.6	31.6	10.9	18.7	9.21
<i>Hoplolaimus</i>	5	4.6	1.7	3.0	1.0	0.6	0.32
<i>Meloidogyne</i>	2	1.9	0.7	7.0	2.4	1.0	0.47
<i>Mesocriconema</i>	2	1.9	0.7	1.4	0.5	0.2	0.09
<i>Paratylenchus</i>	24	22.2	7.9	22.8	7.9	10.7	5.28
<i>Pratylenchus</i>	70	64.8	23.2	68.0	23.4	54.7	26.89
<i>Trichodorus</i>	2	1.9	0.7	0.6	0.2	0.1	0.04
<i>Tylenchorhynchus</i> <sup>b</sup>	40	37.0	13.2	31.6	10.9	19.2	9.44
<i>Xiphinema</i>	40	37.0	13.2	18.6	6.4	11.3	5.56

<sup>a</sup> Absolute frequency = (number of samples containing a genus) × 100/(number of samples collected); relative frequency = (frequency of a genus) × 100/(sum of frequency of all genera); absolute density = average population density (nematodes/100 cm<sup>3</sup> soil); relative density = average number of individual genus × 100/average number of all nematode genera; prominence value = absolute density × square root (absolute frequency); relative prominence = prominence value of a genus × 100/sum of prominence values of all genera (Norton., 1978).

<sup>b</sup> Including related genera.

fields in Minnesota. The common genera of plant-parasitic nematodes observed in this study were similar to those reported in previous surveys in crop fields in Minnesota (Crow and MacDonald, 1978; MacDonald, 1979; Taylor et al., 1958; Taylor and Schleder, 1959).

*Heterodera glycines* was first detected in 1979 in Minnesota (MacDonald et al., 1980). This study revealed

that *H. glycines* frequently occurs in the organically farmed fields of certified organic farms in southern Minnesota, especially in southwest region where the percentage of organically farmed fields infested with the nematode is similar to that in conventional soybean fields (S. Chen, 2008, unpublished). While high population densities (>10,000 eggs/100 cm<sup>3</sup> soil) occurred

TABLE 5. Bray and Curtis similarity index of the plant-parasitic nematodes among the four regions in Minnesota.

	Southeast	Southwest	West central
Southwest	0.71		
West central	0.56	0.61	
Northwest	0.44	0.47	0.62

in some fields in southern Minnesota, a number of *H. glycines*-infested soybean fields (64% in southern and 39% in southwest) had egg population densities lower than 1,000 eggs/100 cm<sup>3</sup> soil. Previous studies demonstrated that one season of SCN-susceptible soybean can result in a high population density (Chen et al., 2001b) even with a low initial population density. Since no SCN-resistant cultivars were used, the low population densities of *H. glycines* in the soybean fields indicate the nematode was probably recently introduced, and the population has not yet widely established in the fields. Long rotation with non-host crops may have maintained the *H. glycines* population densities at a low level in some of the fields that were sampled. The infestation of *H. glycines* in west-central region has a relatively short history (about 15 years in west-central as compared 30 years in southern (Chen, 2011; MacDonald et al., 1980) and percentage of fields infested was also still low in conventional fields (S. Chen, 2008, unpublished). Although no samples from the northwest region were infested with *H. glycines*, the risk of *H. glycines* infestation in organically farmed fields is high because this nematode has been detected in conventional fields in a few counties within the region (Chen, 2011). Extensive soil movement in that region due to crop production practices, frequent flooding, and blowing soil particles will promote the spread of *H. glycines* in the future.

The soybean cyst nematode is a highly virulent pathogen and can cause severe yield loss to the soybean if it is not appropriately managed (Monson and Schmitt., 2004; Wrather and Koenning, 2006). For conventional fields, *H. glycines* management mainly relies on the use of SCN-resistant cultivars and rotation with non-host crops (Chen, 2011; MacGuidwin et al., 1995; Niblack, 2005; Niblack and Chen, 2004; Young, 1998). In

contrast, there is limited availability of SCN-resistant cultivars for the use in organically farmed fields in Minnesota because organic soybean food products generally require better quality of soybean seeds or specialty type of soybean (for instance Natto) than those produced by SCN-resistant soybean cultivars in conventional fields. Organic farms have more crops in the rotations as compared with most conventional fields because Minnesota organic farmers are required by organic certification rules to use a minimum of a three-crop rotation in order to lower the pressures of diseases and pests. Most of the crops in the rotation are non-hosts or poor hosts of *H. glycines*. Consequently, crop rotation is currently the most practical option for *H. glycines* management in organically farmed fields. However, an integrated approach may be needed for effective *H. glycines* management. Research is needed to determine the effectiveness of various cropping sequences, biological control, and cultural practices such as use of animal and green manures towards alleviating the damage from this nematode in organic production systems. Research efforts should also be directed to developing organic-grade quality of SCN-resistant soybean cultivars for organically farmed field use.

Other cyst nematodes including *H. trifolii*, *Punctodera punctata*, and *Cactodera* sp. were encountered at low frequencies in soil samples from Minnesota in previous surveys (Porter and Chen, 2005; Spears, 1956; Taylor et al., 1958), but they were not detected in this study. *Heterodera trifolii* was not detected by the bioassay in the sampled fields. However, there is a possibility that other cyst nematodes including *Cactodera* and *Punctodera* could be present at low frequencies and/or at low population densities, but could not be separated from *H. glycines* by briefly observing the J2.

About ten species of lesion nematodes have been identified from crop fields in Minnesota in previous surveys (Taylor et al., 1958; Taylor and Schleder, 1959). The nematodes have a wide range of hosts, are moderately to highly pathogenic to some crops such as potato, corn, and soybean (Mai et al., 1977). Therefore, even with the frequent rotation of crops in organic-farming systems, the nematodes may be able to establish their populations to damaging levels. Further

TABLE 6. Correlation coefficients between nematode populations and edaphic factors in the organically farmed fields in Minnesota.

Nematode	Number of samples	Soil characters				
		pH	% organic matter	%Sand	%Silt	%Clay
<i>Helicotylenchus</i>	74	-0.03	0.04	0.16	-0.20	-0.05
<i>Heterodera glycines</i> eggs	39	0.29	0.23	0.08	-0.24	0.17
<i>Heterodera glycines</i> J2	38	0.12	0.14	0.11	-0.30	0.16
<i>Paratylenchus</i>	24	0.20	-0.12	0.37	-0.35	-0.30
<i>Pratylenchus</i>	70	-0.01	0.16	-0.36 **	0.50 ***	-0.03
<i>Tylenchorhynchus</i>	40	0.12	-0.10	0.20	-0.20	-0.17
<i>Xiphinema</i>	40	-0.34 *	-0.10	-0.12	0.19	-0.05
Total plant-parasitic nematodes	103	-0.01	0.17	0.04	0.01	-0.09

\*, \*\*, \*\*\* denote significant levels at  $P < 0.05$ , 0.01, and 0.001, respectively.

studies, however, are needed to determine the yield loss of various crops to lesion nematodes in organic-farming system and develop effective management strategies.

Two species of dagger nematode, *Xiphinema americanum* and *X. chambersi*, were identified in Minnesota in previous studies (Crow and MacDonald, 1978; MacDonald, 1979; Taylor and Schleder, 1959; Wallace and MacDonald, 1979). *Xiphinema americanum* reported in early studies could be a species complex (Robbins, 1993), and the species identities of *Xiphinema* in Minnesota may need to be further studied. *Xiphinema* spp. are large nematodes, and they are highly pathogenic to a number of crops and fruit trees. The nematodes not only cause damage to plants directly by parasitizing the plants, but also by transmitting plant viruses to some crops. Associations of corn yield loss (Norton et al., 1978), reduction of growth of shelterbelt trees (Malek and Smolik, 1975), and decline of apple (*Malus domestica*) trees (Wallace and MacDonald, 1979) with *Xiphinema americanum* have been reported from Minnesota and the neighboring states. It is possible that in some organically farmed fields in this survey the high population densities (e.g., more than 100 nematodes/100 cm<sup>3</sup> soil) of *Xiphinema* may be able to cause significant yield loss to some crops.

Root-knot nematodes generally occur in warm regions and they are not common in the cold climate in Minnesota. In the previous statewide surveys conducted in 1950s, root-knot nematodes were encountered at a low frequency, but the species was not identified (Taylor et al., 1958; Taylor and Schleder, 1959). In later studies, northern root-knot nematode, *Meloidogyne hapla*, was observed in some fields (Crow and MacDonald, 1978), and this nematode can cause damage to some crops, such as carrot (*Daucus carota*) (Gugino et al., 2006), in the state. The root-knot nematode observed in this study, however, was not *M. hapla* based on preliminary morphological observation. Further studies are needed to identify the nematode to species and determine its economic importance.

*Helicotylenchus* spp., the spiral nematodes, are the most prevalent plant-parasitic nematodes in the organically farmed fields in Minnesota. The economic importance of the nematodes has not been well studied, although *H. pseudorobustus*, which is probably the most common species of the genus in the North Central USA, is considered a mild pathogen (Norton, 1977; Norton et al., 1978).

*Tylenchorhynchus* group of nematodes is taxonomically a complex of genera. Some genera included in this group found in this survey were probably *Merlinius*, *Trophorus*, and etc. These nematodes are generally considered a mild pathogen, but a high population density of *T. claytoni* caused significant yield loss of soybean in a microplot experiment (Ross et al., 1967). *Trophorus minnesotensis* was reported to associate with

sugar beet (*Beta vulgaris*) in Minnesota, but its economic importance has not been determined (Caveness, 1958)

Other nematodes including *Aphelenchoides*, *Hoplolaimus*, and *Trichodorus* were encountered at a low frequency. They may have low economic significance statewide, but can be important in a specific field. *Mesocriconema* was encountered at low frequency in the organically farmed fields in Minnesota. This nematode has low pathogenicity to soybean and corn (Barker et al., 1982), the common crops in Minnesota, although damage to fruit trees has been reported (Braun et al., 1975; Nyczepir, 1990). The nematode probably has little economic importance in Minnesota. *Paratylenchus* was encountered at a relatively high frequency, but the pathogenicity of the nematode to the crops included in this study has not been established, while study has demonstrated that this nematode also can damage fruit trees (Braun et al., 1975).

Significant correlations between soil parameters examined with the abundance of plant-parasitic nematodes were only detected between numbers of *Pratylenchus* and soil texture and numbers of *Xiphinema* and soil pH. Our study showed that *Pratylenchus* may be more abundant in the soil with less sand, and the result is similar to the previous study in Minnesota (Wallace et al., 1993). In our study, *Xiphinema* was more abundant in soil with a lower pH than in soil with a higher pH within the range of pH 5.7-7.9. In contrast, Norton and Hoffmann (1974) reported that *X. americanum* population density increased with increasing pH from 4.5 to 7.4 and decreased with further increase of pH, while *X. chambersi* decreased with increasing pH from 4.5 to 6.4. Further studies are needed to determine the soil pH effect on individual species of *Xiphinema*.

In this study the plant-parasitic nematode communities in organically farmed fields in four regions in Minnesota and their relationship with soil factors were assessed. Our results showed that a number of plant-parasitic nematodes occur in organically farmed fields, and the population densities of some nematodes such as soybean cyst, lesion, and dagger nematodes may be high enough to cause significant yield loss to certain crops. Although most genera of the plant-parasitic nematodes were detected in all four regions sampled, the similarity of the plant-parasitic nematode community decreased with increasing distance between regions. Further studies are needed to estimate yield loss caused by the important nematode species and develop management strategies in the rapidly increasing organic-farming hectareage in the state and region.

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