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Occurrence and distribution of nematodes in Idaho crops

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Abstract. Surveys were conducted in Idaho, USA during the 2000-2006 cropping seasons to study the occurrence, population density, host association and distribution of plant-parasitic nematodes associated with major crops, grasses and weeds. Eighty-four species and 43 genera of plant-parasitic nematodes were recorded in soil samples from 29 crops in 20 counties in Idaho. Among them, 36 species are new records in this region. The highest number of species belonged to the genus *Pratylenchus*; *P. neglectus* was the predominant species among all species of the identified genera. Among the endoparasitic nematodes, the highest percentage of occurrence was *Pratylenchus* (29.7) followed by *Meloidogyne* (4.4) and *Heterodera* (3.4). Among the ectoparasitic nematodes, *Helicotylenchus* was predominant (8.3) followed by *Mesocriconema* (5.0) and *Tylenchorhynchus* (4.8).

Keywords. Distribution, *Helicotylenchus*, *Heterodera*, Idaho, *Meloidogyne*, *Mesocriconema*, population density, potato, *Pratylenchus*, survey, *Tylenchorhynchus*, USA.

INTRODUCTION

Previous reports have described the association of plant-parasitic nematode species associated with several crops in the Pacific Northwest (Golden *et al*., 1980; Ogbuji and Jensen, 1972; Santo *et al*., 1980; Hafez *et al*., 1992). Idaho, situated between approximately 42° and 49° N and 111° 3' and 117° 15' W in the United States, contains a vast area and varied topography that give it a number of distinct climatic zones. The mean annual temperature varies from about 36°F to 55°F. Precipitation varies, but in general it is greatest in the mountain region and least in the open plains. From traditional crops such as potatoes and grains to specialty crops such as fruits and mint, Idaho farmers utilize natural resources with state of the art technology to produce superior quality agricultural products. Idaho's agriculture is not only diverse but it is also a leader in several commodities nationally. In 2008 and 2009, Idaho ranked among the top five U.S. states in economic production value of barley, dairy, hops, lentils, peas, potatoes, peppermint, spearmint, and sugar beets (data from USDA National Agricultural Statistics Service).

Nematodes reduce yield and quality of a number of crops, causing economic losses. Diverse climatic conditions and cropping systems in Idaho are highly conducive for nematode multiplication. Information concerning the occurrence and distribution of nematodes in Idaho is important to assess their potential to cause economic damage to many crop plants. The objective of the present study was to identify nematodes associated with certain crops in Idaho, provide more extensive information on the distribution of genera and species of plant-parasitic nematodes, and document their presence and abundance to estimate the level of infestation by each species that may have a significant impact on agriculture in the region.

MATERIALS AND METHODS

The Nematode Diagnostic Laboratory of the University of Idaho is located in Parma, Idaho, USA. It receives pre-plant soil samples from growers and other sources during the Fall and Spring planting seasons. In the years 2000-2006, each of 1,628 soil samples received from 20 counties was thoroughly mixed and a sub-sample of 500 cm^3 was taken for nematode extraction (Cobb, 1918). Each sample was pre-soaked for 30 minutes and then passed through a 70-mesh sieve into a 2-litre bowl. The sieved soil and water in the bowl were then passed through a 400-mesh sieve. The

Table 1. Distribution of plant-parasitic nematode species found in soil associated with various crops in Idaho, USA.

Nematode	**Host****	**Geographical distribution*****
**Acrobeles* sp.	Seed	K
**Aglenchus* sp.	27	T
**Aorolaimus* sp.	18	O
**Aphelenchoides fragariae* (Ritzema Bos, 1891) Christie, 1932	16	P
Aphelenchoides sp.	9,12,14,21,26	K,P,Pa
**Aphelenchus avenae* Bastian, 1865	12,14,17,18,21,27,29,30	E,G,M,O,P,Pa
Aphelenchus sp.	5,6,26,29	C,O,P,Pa
**Atetylenchus abulbosus* (Thorne, 1949) Khan, 1973	29	Ba
**Boleodorus thylactus* Thorne, 1941	14	G
Boleodorus sp.	14,26	C
**Coslenchus costatus* (de Man, 1921) Siddiqi, 1978	14	G
Coslenchus sp.	6, 26, 27	B,O,Pa,T
**Criconema mutabile* (Taylor, 1936) Raski & Luc, 1985	27	NA
**Criconemella lobata* (syn. of *Mesocriconema rusticum* for Loof, 1965)	12,26, 27	B,C,G,Pa
Ditylenchus destructor Thorne, 1945	26,27	B,E,Pa
Ditylenchus dipsaci (Kühn, 1857) Filipjev, 1936	14,26	C
**Ditylenchus valveus* Thorne & Malek, 1968	26	
Ditylenchus sp.	2,6,9,14,18,21,26,27,29, 31, Unknown Hay	B,C,E,G,Mi,Pa,W
**Filenchus cylindricus* (Thorne & Malek, 1968) Niblack & Bernard, 1985		NA
Geocenamus tenuidens Thorne & Malek, 1969	8	Mi
Globodera pallida (Stone, 1973) Behrens, 1975	27	
Gracilacus sp.	6	T
Helicotylenchus bradys Thorne & Malek, 1968	30	Pa
Helicotylenchus crenacauda Sher, 1966	5,6,26	C,Pa
Helicotylenchus digonicus Perry in Perry, Darling & Thorne, 1959	4,5,6,10,11,12,14,15,17, 23,26,27,29,31	B,Bon,C,Ca,E,G,M,O,P,Pa,T
Helicotylenchus dihystera (Cobb, 1893) Sher, 1961	5,22,27	Pa
**Helicotylenchus erythrinae* (Zimmermann, 1904) Golden, 1956	19	NA
Helicotylenchus platyurus Perry, 1959	26	Pa
Helicotylenchus pseudorobustus (Steiner, 1914) Golden, 1956	2,5,7,12,13,18,26,31	C,G,O,Pa,W
Helicotylenchus sp.	26,31	C
Hemicycliophora californica Brzeski, 1974	12,27	Mi,P
**Hemicycliophora obtusa* Thorne, 1955	17,27	G,Pa
Hemicycliophora vidua Raski, 1958	26,27	C,Pa

Hemicycliophora spp.	9,26,27,29	Ca,Pa
Heterodera avenae Wollenweber, 1924	9,26,27,29	B,Bon,M,P
Heterodera humuli Filipjev, 1934	11	C
**Heterodera mani* Mathews, 1971	27	M
Heterodera schachtii Schmidt, 1871	4,17,26,29	Mi,Pa,T
Heterodera trifolii Goffart, 1932	9,17,22,26,27	B,Bon,Bonn,Pa, Lem
**Heterodera urticae* Cooper, 1955	22	NA
Heterodera sp.	6,22,26,27	G,Pa
**Hoplolaimus galeatus* (Cobb, 1913) Thorne, 1935	6,27,30	NA
Hoplolaimus sp.	12	Pa
**Longidorella saadi* (Siddiqi, 2006)	27	NA
Loofia thienemanni (Schneider, 1925) Siddiqi, 1980	4,12,13,22,26,27,29	C,G,P,Pa,W
Megadorus megadorus (Allen, 1941) J. B. Goodey, 1960	26	Mi,T
Meloidodera sp.	19	C
Meloidogyne chitwoodi Golden, O'Bannon, Santo & Finley, 1980	27	B,Bon,C,L
Meloidogyne spp.	5,6,9,12,14,15,17,18,22,23,26,27,29,31	B,C,E,G,Mi,O,P,Pa,T
Merlinius brevidens (Allen, 1955) Siddiqi, 1970	2,4,5,6,7,9,12,14,17,18,21,23,24,26,27,29,30,31	A,B,Bon,C,Ca,E,G,M,Mi,O,P,Pa,T,W
Merlinius grandis (Allen, 1955) Siddiqi, 1970	26	NA
Merlinius sp.	26	C,Pa
Mesocriconema curvatum (Raski, 1952) Loof & De Grisse, 1989	31	C
Mesocriconema ornatum (Raski, 1958) Loof & De Grisse, 1989	5,12,13,15,18,20,26,27,29,30	A,C,Ca,G,Mi,P,Pa,T
**Mesocriconema rusticum* (Micoletzky, 1915) Loof & De Grisse, 1989	12,17,26,27,29	C,G
**Mesocriconema xenoplax* (Raski, 1952) Loof & De Grisse 1989	22,26	C,P,Pa
Mesocriconema sp.	26, 29	Pa
**Nothocriconemoides lineolatus* Mass, Loof & De Grisse, 1971	26	
**Nothotylenchus* sp.	9,27	O,Pa
**Paratrichodorus allius* (Jensen, 1963) Siddiqi, 1974		NA
Paratrichodorus minor (Colbran, 1956) Siddiqi, 1974	6,12,18,22,26,27,28,29,30	C,G,M,Mi,P,Pa,T
Paratrichodorus porosus (Allen, 1957) Siddiqi, 1974	5,9,26,27	Mi,O,Pa
Paratrichodorus sp.	6,26,27,29	C,Mi,Pa
Paratylenchus bukowinensis Micoletzky, 1922	24	Pa
**Paratylenchus goldeni* Raski, 1975	27	G
**Paratylenchus lepidus* Raski, 1975	16	P
**Paratylenchus minor* Sharma, Sharma & Khan, 1987	26,29	
Paratylenchus projectus Jenkins, 1956	4,5,6,9,12,14,15,16,18,20,22,23,26,27,29,31	A,C,E,G,J,Mi,O,P,Pa,T,W
Paratylenchus tateae Wu & Townshend, 1973	12,17,26,27,29	B,C,P,Pa
Paratylenchus tenuicaudatus Wu, 1961	6,15	C,P

Paratylenchus sp.	6,10,12,13,14,17, 18,26,27,29,31	C,G,Mi,O,Pa,T,W
**Pratylenchus agilis* Thorne & Malek, 1968	27	
Pratylenchus brachyurus (Godfrey, 1929) Filipjev & Schuurmans Stekhoven, 1941		NA
Pratylenchus coffeae (Zimmermann, 1898) Filipjev & Schuurmans Stekhoven, 1941 (Goodey, 1951 also proposed this combination)	13,15,16	G,P,Pa
Pratylenchus crenatus Loof, 1960	12,14,26,29	Bon,Bonn,C,G,P
**Pratylenchus hexincisus* Taylor & Jenkins, 1957	18,26	
Pratylenchus neglectus (Rensch, 1924) Filipjev & Schuurmans Stekhoven, 1941	2,4,5,6,7,9,10,11,12,14,15,16,17,18,20,21,23,24,26,27,29,30,31	A,B,Bon,C,Ca,E,G,J,M,Mi,O,P,Pa,T,W
Pratylenchus penetrans (Cobb, 1917) Chitwood & Oteifa, 1952	12,14,15,16,20,26,27,30	A,Bon,Bonn,C,G,M,P,Pa
Pratylenchus scribneri Steiner, 1943	26,27,29,31	C,Mi,Pa,T,W
Pratylenchus thornei Sher & Allen, 1953	1,2,4,5,6,9,10,11,12,15,18,26,27,29,30,31	A,B,C,G,O,P,Pa,T,W
Pratylenchus vulnus Allen & Jensen, 1951	9,12,26	C,G,P,Pa
Pratylenchus sp.	9,13,14,22,26,27,30	C,G,P,Pa
Psilenchus sp.	12,14,27,30,31	C,G
**Quinisulcius acti* (Hopper, 1959) Siddiqi, 1971	18,26,27,31	C,O,P,Pa
**Quinisulcius acutoides* (Thorne & Malek, 1968) Siddiqi, 1971	8	Mi
**Quinisulcius acutus* (Allen, 1955) Siddiqi, 1971	5,6,9,10,12,18,26,27,29,31	C,G,J,O,P,Pa,T
**Quinisulcius capitatus* (Allen, 1955) Siddiqi, 1971	27	Pa
Quinisulcius sp.	9,29	P,Pa
**Subanguina balsamophila* (Thorne, 1926) Siddiqi, 2000	3	L
**Sulphuretylenchus elongatus* (Massey, 1958) Nickle, 1967	25	L
**Trichodorus elegans* Allen, 1957	19	NA
**Trilineellus obscurisulcatus* (Andrássy, 1959) Khan & Saeed, 1988		NA
Trophonema arenaria Raski, 1956 (= *Trophotylenchus arenarius* (Raski, 1956) Siddiqi 1999)	12	P
Trophurus minnesotensis (Caveness, 1958) Caveness, 1959	29	T
Tylenchorhynchus annulatus (Cassidy, 1930) Golden, 1971	17,26,27,29,31	C,O,P,W
**Tylenchorhynchus clarus* Allen, 1955	15,20,26,27	O,P,Pa,T
Tylenchorhynchus cylindricus Cobb, 1913	26,27	Mi,T
**Tylenchorhynchus idahoensis* Siddiqi, 2008	27	B,Pa
Tylenchorhynchus maximus Allen, 1955	12,17,26,27,29	C,Ca,E,G,P,Pa,T
**Tylenchorhynchus silvaticus* Ferris, 1963	27	NA
Tylenchorhynchus sp.	2,6,8,12,14,18,26,27,29	B,Bon,C,E,J,Mi,O,P,Pa,T
**Tylenchulus* sp.		NA
**Tylenchus exiguus* de Man, 1876		NA

Tylenchus spp.	5,6,10,12,14,17,26,27,30,31	B,C,G,O,P,Pa,T
Xiphinema americanum Cobb, 1913	12,22,26,27,30	C,G,P,Pa
Xiphinema californicum Lamberti & Bleve-Zacheo, 1979	27	J
Xiphinema rivesi Dalmasso, 1969	12,26,27	B,E,G
Xiphinema sp.	6,8,12,14,23,26,27,29,31	C,J,Mi,P,Pa,T

* New records in Idaho

** 1. *Allium cepa*, 2. *Allium* sp., 3. *Balsamhoriza* sp., 4. *Beta saccharifera*, 5. *Beta* sp., 6. *Beta vulgaris*, 7. *Brassica rapa*, 8. Brush, 9. *Hordeum vulgare*, 10. *Humulus lupulus*, 11. *Humulus* sp., 12. *Malus domestica*, 13. *Malus* sp., 14. *Medicago sativa*, 15. *Mentha piperita*, 16. *Mentha spicata*, 17. Pasture, 18. *Phaseolus* sp., 19. *Pinus monticula*, 20. *Pisum* sp., 21. *Poa pratensis*, 22. *Prunus persica*, 23. *Prunus* sp., 24. Row crop, 25. *Scolytus ventralis*, 26. Soil, 27. *Solanum tuberosum*, 28. *Trifolium* sp., 29. *Triticum aestivum*, 30. Unknown, 31. *Zea mays*

*** A-Ada, B-Bingham, Ba-Bannock, Bon-Bonneville, Bonn-Bonner, C-Canyon, Ca-Cassia, E-Elmore, G-Gem, J-Jerome, K-Kootenai, L-Latah, Lem-Lemhi, M-Madison, Mi-Minidoka, O-Owyhee, P-Power, Pa-Payette, T-Twin Falls, W-Washington, NA-Host and location not known

residue on the 400-mesh sieve was collected in a 200-ml beaker and allowed to settle at 3°C for 3 hours. The excess water on top of the beaker was siphoned off, leaving the residue containing nematodes on the bottom of the beaker. Nematodes were separated from the residue by the centrifugal flotation technique (Jenkins, 1964), collected on a 500-mesh screen and counted using a compound microscope at 100× magnification. Nematodes were identified to genus level, and species identification was performed at the USDA Nematology Laboratory in Beltsville, MD, USA.

RESULTS AND DISCUSSION

The lesion nematode *Pratylenchus* was the predominant genus (Tables 1 and 2). Of the ten species identified in Idaho samples submitted during 2000-2006, two were new records (*P. agilis* and *P. hexincisus*); others were *P. brachyurus*, *P. coffeae*, *P. crenatus*, *P. neglectus*, *P. penetrans*, *P. scribneri*, *P. thornei* and *P. vulnus* (Table 1). The earliest record of *Pratylenchus* spp. on potato in the USA was by Cobb (1917), who found *P. penetrans* causing pustules over the surface of potato tubers. In Washington, *P. penetrans* was reported to cause stunting of potatoes (Ingham *et al.*, 2005). In combination with *Verticillium dahliae*, *P. penetrans* caused earlier development of wilt symptoms (LaMondia *et al.*, 1999). The wilt severity is positively correlated to nematode populations (Davis and Everson, 1986). In Maine, *P. penetrans* and *P. crenatus* were encountered most frequently, with higher populations in the early season than in the late season (Huettel *et al.*, 1991). In Ohio, both *P. penetrans* and *P. scribneri* cause significant loss in potato yield (Wheeler and Riedel, 1994).

The populations of *P. neglectus* (Hafez *et al*., 1999) and *P. vulnus* (Lax *et al.*, 2004) from Idaho differ in their morphometrics and reproductive rates. Recently, it was found that *P. neglectus* and *P. thornei* cause significant yield reduction in lentils, dry beans (Riga *et al.*, 2008) and wheat (Smiley, 2009).

The next most predominant genus in Idaho was *Helicotylenchus* (Tables 1 and 2), whose economic importance has not been well studied on potatoes. This genus was represented by a new record (*H. erythrinae*) in addition to the already described six species (*H. bradys*, *H. crenacauda*, *H. digonicus*, *H. dihystera*, *H. platyurus* and *H. pseudorobustus*) and one unidentified species (*Helicotylenchus* sp.). The pin nematode *Paratylenchus* made up 8.2% of the total nematodes found in the Idaho soil samples (Table 2). Three species of *Paratylenchus* (*P. goldeni*, *P. lepidus* and *P. minor*) were reported for the first time in this study and *P. bukowinensis*, *P. projectus*, *P. tateae* and *P. tenuicaudatus* were the four species previously reported.

Tylenchorhynchus was another genus frequently occurring in Idaho (Tables 1 and 2). There were six species of this genus comprising two new reports (*T. clarus* and *T. silvaticus*) and four species (*T. annulatus*, *T. cylindricus*, *T. idahoensis* and *T. maximus*) that are already reported in Idaho. Siddiqi (2008) found large populations of *T. idahoensis* associated with potato in Idaho.

Discovery of root-knot nematode on potato in the USA dates back to 1889 when Neal reported *Meloidogyne arenaria* on a potato crop in Florida (Jatala *et al*., 1977). *Meloidogyne* made up 4.4% of the total nematode species found in Idaho samples submitted in 2000-2006 (Table 2). Although there are several species of root-knot nematodes, the most common on potato in Idaho is the Columbia root-knot nematode (*M. chitwoodi*). It was first described on potato from Quincy, Washington (Golden *et al.*, 1980) and

Table 2. The most abundant plant-parasitic nematode genera detected in soil samples collected and submitted by Idaho growers.

Nematode Genera	%
Pratylenchus	29.7
Helicotylenchus	8.3
Paratylenchus	8.2
Mesocriconema	5
Tylenchorhynchus	4.8
Meloidogyne	4.4
Heterodera	3.4
Hemicycliophora	3.0
Xiphinema	2.8
Paratrichodorus	2.6
Ditylenchus	2.3
Others	25.5

Table 3. Distribution of nematode species in Idaho counties.

Idaho County	Number of species
Payette	57
Canyon	45
Power	37
Gem	31
Owyhee	24
Twin Falls	24
Minidoka	19
Bingham	17
Elmore	14
Madison	11
Washington	10
Ada	7
Bonneville	7
Cassia	6
Jerome	6
Bonner	3
Latah	3
Bannock	1
Kootenai	1
Lemhi	1

later in Iron County, Utah (Griffin and Thomson, 1988). This is the predominant *Meloidogyne* species identified from the potato rhizosphere in Idaho and causes considerable loss in yield and quality to the potato industry (Hafez and Thornton, 1991). Females in the tubers cause enlargements or bumps in the outer layers of the tubers, rendering them useless for fresh packing or processing.

Heterodera is represented by two new records (*H. mani* and *H. urticae*) in this study; four species (*H. avenae, H. humuli, H. schachtii* and *H. trifolii*) were described earlier. Among these species, *H. schachtii* is the most serious nematode pest of the sugar beet industry in Idaho as well as other production regions. Yield loss can be substantial in heavily infested fields, and in warmer growing regions, damage can be exacerbated by secondary pathogens.

Stubby root nematode is represented by one new report (*Trichodorus elegans*) and three previously reported species (*Paratrichodorus porosus*, *P. minor* and *P. allius*). *Paratrichodorus allius* can transmit Tobacco Rattle Virus (TRV), which causes corky ringspot disease of potato, in which the deep cracks and shallow corky depressions on tuber surfaces render them unmarketable. Recently, corky ringspot of potato was reported from Michigan (Kirk *et al.*, 2008) and North Dakota (David *et al.*, 2010).

Xiphinema was represented by three species (*X. americanum, X. californicum* and *X. rivesi*). Lamberti and Golden (1986) described a somewhat uncommon species of *Xiphinema* from Idaho.

Pale cyst nematode, *Globodera pallida*, is a somewhat recent discovery on potato in the USA (Hafez *et al*., 2007). Morphological and molecular tests confirmed the identity of the pest (Skantar *et al.*, 2007). Discovery of *G. pallida* in Idaho was significant to potato producers and exporters since Idaho is the largest potato producer in the United States, growing about one-third of the country's potatoes (12.5 billion lbs), which earns farmers about US$700 million and contributes about US$2 billion to the state (Taylor *et al*., 2007) economy. After *G. pallida* was discovered in Idaho, Japan, Mexico, Korea and Canada immediately banned shipments of fresh potatoes from Idaho, hence additional surveillance programs have been initiated by the federal agencies throughout the USA to contain further spread of the pest to neighboring fields (USDA-APHIS 2010).

There were several other species of plant-parasitic nematodes found in this study, but their economic importance on potato is not established. These included one new report of *Mesocriconema xenoplax* and the already reported *M. curvatum*, *M. ornatum* and *M. rusticum. Hemicycliophora obtusa* is a new report in this region in addition to two known species (*H. californica* and *H. vidua*). *Loofia thienemanni* was also already known in this region.

Ditylenchus valveus is a new record for Idaho in addition to the two known species *Ditylenchus destructor* and *D. dipsaci.* The first record of *D. dipsaci* in Idaho dates back to 1943 when Blodgett reported it in the potato fields of Aberdeen. Species of *Ditylenchus* that are reported in other countries include *Ditylenchus solani* in India (Husain & Khan, 1976); *D. destructor* in 65 countries (CABI, 2009), *D. tenuidens* in USSR (Gritsenko, 1971) and *D. dipsaci* in Brazil (Lopes and Lordello, 1980). The original description of the species *Ditylenchus destructor* was by Thorne (1945) in Idaho on potato.

Other plant-parasitic species that are newly reported in Idaho from this study include *Aphelenchoides fragariae*, *Criconema mutabile*, *Nothocriconemoides lineolatus*, *Quinisulcius acti*, *Q. acutoides*, *Q. acutus*, *Q. capitatus*, *Subanguina balsamophila* and *Sulphuretylenchus elongatus*. The distribution of nematode species among Idaho counties from which samples were submitted is presented in Table 3. The highest number of nematode species (57) was found in Payette County followed by Canyon (45) and Power (37). The lowest number of nematode species was found in Bannock, Kootenai and Lemhi Counties (1 each).

Several non-plant-parasitic species were also found in the processed soil samples. These include *Acrobeles* spp., *Acrobeloides* sp., *Alaimus* spp., *Amphidelus* sp., *Aphelenchoides bicaudatus*, *Aporcelaimellus* sp., *Axodorylaimellus parvulus*, *Axonchium* sp., *Bathyodontus* sp., *Cheiloplacus* sp., *Chronogaster* sp., *Clarkus* sp., *Cylindrolaimus* sp., *Deladenus* sp., *Diphtherophora* sp., *Discolaimoides* sp., *Dorylaimus* sp., *Doryllium* sp., *Ecumenicus monohystera*, *Eucephalobus* sp., *Eudorylaimus* spp., *Heterotylenchus autumnalis*, *Miconchus* sp., *Monhystera* sp., *Mylonchulus* sp., *Panagrolaimus* sp., *Paraphelenchus* sp., *Paraxonchium* sp., *Plectus* sp., *Pseudacrobeles* sp., *Seinura* sp., *Tobrilus* sp., *Tripyla* sp., *Tylencholaimus* sp., *Tyleptus* sp., *Tylolaimophorus* sp., and *Wilsonema* sp.

Management of nematodes is important for successful agricultural production, and development of effective management methods requires accurate identification of the genera and species of nematodes involved. This research will be of use to scientists, growers, action agencies and extension agencies involved in nematode research and control and will serve as a useful guide in planning future research, identifying economically important nematode species, or determining which nematodes may be present in specific areas in Idaho and which ones may be involved in plant disease problems in this region.

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