Chapter 13
Nematodes in Maryland and Delaware Crops

Ramesh R. Pokharel

13.1 Introduction

In Maryland, the green industry currently ranks second among agricultural commodities with a total of approximately $2 billion in gross receipts, occupying 8458 ha, including 1,765,158 m^2 of greenhouse space and employing more than 18,500 people with wages totaling $451 million. These businesses deal with several problems each year, including plant parasitic nematodes (PPN) that cause tremendous challenges because of difficulties of diagnosis and management.

The State of Maryland is divided into 24 counties and separated by Chesapeake Bay into two major production regions with variations in soil and microclimate. The Eastern Shore region, producing more agricultural crops, is shared with the Delaware Peninsula and has predominantly sandy soil, while the western region of the state has clay soil. Because of microclimatic differences throughout the state, a good variation of crops is grown including cereals, vegetables and fruit. In 2015, 15,378 ha of land were planted to corn producing 1,574,883 tons. Winter wheat yielded 4.3 tons per ha, with 431,823 ha harvested. Barley production has grown to 50,803 tons, averaging 4.64 tons per ha (MDA 2015). The State of Maryland also has significant acreage in fresh market vegetables including watermelon, snap bean and cucumber, with a value of $35.6 million in 2015, while the potato crop was worth $8.31 million. Sweet corn for fresh corn-on-the-cob is grown on over 1416 ha. A wide variety of fruits and vegetables are grown for direct sales to the public at farm stands, roadside markets, pick-your-own operations and farmers' markets throughout the state. Watermelon, cantaloupe, sweet corn, cabbage, green bean, potato, pepper, tomato, pumpkin, peach, apple and strawberry are the major crops

R. R. Pokharel (✉)
Maryland Department of Agriculture, Harry S Truman PKWY, Annapolis, MD, USA
e-mail: ramesh.pokharel@maryland.gov

S. A. Subbotin, J. J. Chitambar (eds.), *Plant Parasitic Nematodes in Sustainable Agriculture of North America*, Sustainability in Plant and Crop Protection,
https://doi.org/10.1007/978-3-319-99588-5_13

grown for the fresh market. This state is a major watermelon producing region with 1214 ha under cultivation.

Orchards cover 1610 ha in Maryland, with apples and peaches as the most productive crops. In 2015, about 728 ha of apple orchards and 724 ha of peach orchards were valued at nearly $12.2 million (USDA 2017). In addition, grape cultivation has been increasing with about 347 ha of vineyard and wineries in the state (MGGA 2014). A small number of cover crops grown in the state include rye, barley and other cereal grains. These are planted in the fall after summer crops are harvested.

Delaware is a small state of three counties and lies in the east of Maryland, in the Eastern Shore region near Delaware Bay and Atlantic Ocean. Agriculture is Delaware's largest single land use, with 41% of the state's land hectares in farming. The annual aggregate (direct, indirect, and induced) economic contribution of agriculture to Delaware's economy is estimated at nearly $8 billion (Cadwallader 2010). The annual value of agricultural production is over $1 billion. The value of agricultural products sold annually directly to consumers is over $3.5 million. Kent and Sussex are among top 2% of U.S. counties in value of vegetables sold. Delaware ranks number one nationally in value of agricultural products sold per farm at $425,387 and value of agricultural production produced per acre of land in farms at $2,123 (Cadwallader 2010). The state has about 2450 farms and more than 46,539 ha of farmland permanently preserved for agriculture. Soybean is the state's most important crop, followed by corn. Farmers also grow barley and wheat among grain crops, whereas potato and pea are the state's largest vegetable crop. Apple is Delaware's greatest fruit crop. Greenhouse and nursery products (flowers, ornamental shrubs, young plants) provide some income. About 2,500 farms spread across 206,491 ha of farmland benefit from some natural advantages such as presence of the state's natural soil, 'Greenwich'. This soil is classified as "Prime Farmland Soil," meaning it is one of the most productive soils for the state's agriculture and forestry (Do 2014).

13.2 Plant Parasitic Nematodes of Importance

13.2.1 Maryland

Several species of plant parasitic nematodes occur in Maryland soils, generally as mixed populations that are unevenly distributed throughout a field. Nematodes were estimated to cause 20% reduction in crop yields 60 years ago (Jenkins et al. 1957). It is hard to predict this figure at present because of a lack of recent data. Limited numbers of PPN-related publications exist for Maryland. Most regional publications have been based on surveys and nematode diagnostics. Research and diagnostic studies have been based on the traditional morphological taxonomic approach rather than molecular techniques. Available information indicates that most targeted, major areawide research on PPN was conducted in the 1950s. Jenkins et al. (1957) did extensive surveys of 1,210 farms and gardens with different crop plants. This was probably the only thorough published survey covering all counties in Maryland. These researchers collected variable numbers of samples in each county, with a minimum of 20 each in Kent and Hartford County and a maximum of 121 in Wicomico County. They found PPN in all samples examined and recorded 34 verified and possible PPN genera.

Plant parasitic nematodes of the genera *Xiphinema* (dagger nematodes) followed by *Pratylenchus* (root lesion nematodes), *Tylenchorhynchus* (stunt nematode) and *Ditylenchus* (stem and bulb nematode) were the most commonly recorded nematodes in Maryland (Jenkins et al. 1957). However, at present, soybean cyst (*Heterodera glycines*), root knot (*Meloidogyne* spp.), root lesion, stem and bulb and dagger nematodes are economically important in the state. Research projects have focused on crops and/or common and important associated nematode genera.

13.2.2 Delaware

Limited numbers of PPN-related publications for Delaware exist, similar to Maryland. Unlike Maryland, extensive nematode related work in the past creates a gap for the importance of plant parasitic nematodes in the state. Most regional publications only appeared recently and have been based on diagnostic and bioassay works. As in Maryland, research and diagnostic works have been based on the traditional taxonomic approach rather than modern molecular techniques. However, the important nematode genera within the state vary with crop and location and need further investigation. In Delaware, there is evidence of a shift in nematode populations, but more detailed investigations are needed. Similar to Maryland, at present, soybean cyst, root knot, and root lesion, stem and bulb and dagger nematodes appear to be economically important.

In this chapter, only known plant parasitic nematode genera are discussed for both states. Emphasis has been given to those genera/species which are more important or common or may be important for plant production. A nematode genus and/or species encountered more than once (sample, location or published paper) is considered common; populations causing significant damage or impact in plant production are considered important. Based on available records, nematode genera or species found in Maryland and Delaware are listed in Table 13.1. However, nematode genera and, or species, described below are based on published records in journals, extension publications, websites and personal communications for Maryland and Delaware. This paper does not include write-ups for all species or genera listed in 'Widely Prevalent Nematodes in the USA' (USDA 2014). Some references identified species that are listed as occurring in Maryland from specimens present in the USDA Nematological Laboratory collections.

Table 13.1 Some plant parasitic nematode species encountered in Maryland and Delaware

Species	Crop or plant	References
Anguina tritici	Wheat	Jenkins et al. (1957)
Aphelenchoides fragariae	Strawberry, butterfly bush	Jenkins et al. (1957), Esser (1966), and USDA (2014)
A. ritzemabosi	Chrysanthemum, strawberry	Jenkins et al. (1957) and USDA (2014)
A. besseyi	Chrysanthemum, strawberries	Jenkins et al. (1956), Esser (1966), and Cavigelli et al. (2005)
Belonolaimus longicaudatus	Soybean, turfgrass	Handoo et al. (2010)
Criconema mutuabile	Unknown	USDA (2014)
Ditylenchus dipsaci	Phlox, tulip, narcissus, hyacinth, onion, garlic	USDA (2014)
D. myceliophagus	Corn	Cavigelli et al. (2005)
Dolichodorus similis	Celery, sweet corn	Feldmesser and Golden (1972)
D. marylandicus	Perennial bluegrass	Lewis and Golden (1980)
H. dihystera	Alfalfa, asparagus, barley, clover, corn, oat, soybean, timothy, tobacco, tomato, vetch, wheat	Jenkins et al. (1957), Golden and Rebois (1978), and USDA (2014)
H. digonicus	Corn, turfgrass	Feldmesser and Golden (1972), Cavigelli et al. (2005), and USDA (2014)
H. erythrinae	Chrysanthemum, cucumber, lespedeza, muskmelon, pea, strawberry, watermelon	Jenkins et al. (1957) and USDA (2014)
H. microlobus	Unknown	USDA (2014)
H. multicinctus	Some plants	Bernard and Keyserling (1985)
H. pseudorobustus	Soybean, corn, turfgrass, tobacco	Feldmesser and Golden (1972), Golden and Rebois (1978), Cavigelli et al. (2005), Kaplan et al. (2008), and USDA (2014)
H. platyurus	Unknown	USDA (2014)
Hemicycliophora spp.	Barley, corn, grasses, raspberry	Jenkins et al. (1956, 1957)
Heterodera glycines	Soybean	Sindermann et al. (1993) and USDA (2014)
H. schachtii	Clover	Jenkins et al. (1957) and Golden and Rebois (1978)

(continued)

Table 13.1 (continued)

Species	Crop or plant	References
H. zeae	Corn, barley, oat, rice, sorghum, sugar cane, wheat, fall panicum, meadow foxtail, green sprangletop, witchgrass, broomcorn, fountain grass, reed canary grass, common reed, eastern gamagrass, teosinte	McGrown (1981), Ringer et al. (1987), and Sindermann et al. (1993)
Hoplolaimus galeatus	Carnation, clover, corn, grape, grass, lespedeza, oat, pea, pepper, ryegrass, soybean, sweet potato, timothy, turfgrassn tomato, tobacco, wheat	Jenkins et al. (1957), Feldmesser and Golden (1972), Golden and Rebois (1978), and USDA (2014)
H. columbus	Cotton, soybean, corn	Jenkins et al. (1957)
Longidorus spp.	Corn, soybean, tobacco	Jenkins et al. (1956, 1957)
Meloidogyne graminis	Turfgrass	Jenkins et al. (1956) and Feldmesser and Golden (1972)
M. hapla	Alfalfa, clover, tobacco, soybean, vetch	Sasser (1954), Jenkins et al. (1957), Golden and Rebois (1978), and USDA (2014)
M. javanica	Snapdragon plants	Jenkins et al. (1957) and Golden and Rebois (1978)
M. incognita	Corn, muskmelon, soybean, sweet potato, tobacco, tomato, vetch, wheat	Jenkins et al. (1957) and USDA (2014)
M. sasseri	American beach grass	Handoo et al. (1993)
Meloidogyne spp.	Snap bean, watermelon, cucumber, tomato, pepper, sorghum, sudangrass, lima bean, pea, cantaloupe, muskmelon, pumpkin, squash, potato, corn, as well as weeds such as, dandelion, mallow, purslane, pigweed, prickly sida, morning glory	Sasser (1954) and Golden and Rebois (1978)
Merlinius brevidens	Alfalfa, barley, corn, clover, grasses, oat, pea, timothy, wheat	Jenkins et al. (1957), Cavigelli et al. (2005), and USDA (2014)
Mesocriconema curvatum	Unknown	USDA (2014)
M. ornatum	Turfgrass	USDA (2014)
M. rusticum	Unknown	USDA (2014)
M. xenoplax	Unknown	USDA (2014)
M. simile	Peach	Jenkins et al. (1957), 4 and USDA (2014)
Nanidorus minor	Soybean	Golden and Rebois (1978)
Paratrichodorus pachydermus	Turfgrass	Jenkins et al. (1957)
Paratylenchus dianthus	Carnation, clover, corn, timothy, vetch, wheat	Jenkins et al. (1957)
P. hamatus	Clover	Jenkins et al. (1957)
P. nanus	Wheat	Jenkins et al. (1957)

(continued)

Table 13.1 (continued)

Species	Crop or plant	References
P. projectus	Alfalfa, bean, clover, corn, grass, lespedeza, soybean	Jenkins et al. (1957), Golden and Rebois (1978), Cavigelli et al. (2005), and USDA (2014)
Pratylenchus agilis	Soybean	Golden and Rebois (1978) and USDA (2014)
P. brachyurus	Alfalfa, asparagus, barley, clover, corn, grass, oat, rye, sorghum, soybean, timothy, tobacco, tomato, wheat	Jenkins et al. (1957) and Golden and Rebois (1978)
P. coffeae	Soybean	Golden and Rebois (1978) and Cavigelli et al. (2005)
P. crenatus	Soybean	Golden and Rebois (1978)
P. hexincisus	Soybean	Jenkins et al. (1957) and Golden and Rebois (1978)
P. neglectus	Corn	Cavigelli et al. (2005)
P. penetrans	Corn, soybean, bean, clover, tobacco, tomato	Jenkins et al. (1957), Golden and Rebois (1978), Cavigelli et al. (2005), and USDA (2014)
P. pinguicaudatus	Corn	Cavigelli et al. (2005)
P. pratensis	Alfalfa, barley, bean, clover, corn, grass, oat, pea, rye, sorghum, soybean, timothy, tobacco, tomato, vetch, wheat	Jenkins et al. (1957)
P. scribneri	Soybean	Golden and Rebois (1978) and USDA (2014)
P. subpenetrans	Boxwoods, broccoli, carnation, lespedeza, muskmelon, peach, potato, snapdragon, sweet potato, watermelon	Jenkins et al. (1957)
P. thornei	Corn	Cavigelli et al. (2005) and USDA (2014)
P. vulnus	Boxwood, ornamentals, fruits, nuts, vegetables	Jenkins et al. (1957), McGrown (1981), and USDA (2014)
P. zeae	Soybean	Jenkins et al. (1957), Golden and Rebois (1978), and USDA (2014)
Quinisulcius acutus	Soybean	Golden and Rebois (1978)
Rotylenchus buxophilus	Alfalfa, corn, grass, tobacco, wheat	Jenkins et al. (1957)
R. robustus	Alfalfa	Jenkins et al. (1957)
Scutellonema brachyurus	Unknown	USDA (2014)
Trichodorus primitivus	Mimosa	Jenkins et al. (1957) and USDA (2014)

(continued)

Table 13.1 (continued)

Species	Crop or plant	References
Tylenchorhynchus capitatus	Unknown	Jenkins et al. (1957)
T. clarus	Unknown	USDA (2014)
T. clatytoni	Alfalfa, barley, bean, clover, corn, grasses, oat, pepper, rye, soybean, strawberry, sweet potato, Timothy grass, tomato, tobacco, soybean, grasses, vetch, and wheat	Jenkins et al. (1956, 1957), Feldmesser and Golden (1972), Golden and Rebois (1978), and USDA (2014)
T. dubius	Barley and grasses, clover, grasses, oat, vetch, and wheat	Jenkins et al. (1957), Feldmesser and Golden (1972) and USDA (2014)
Geocenamus ornatus	Barley	Jenkins et al. (1957)
Xenocriconemella macrodora	Unknown	USDA (2014)
Xiphinema americanum	Tomato, turfgrass, soybean	Jenkins et al. (1957), Sindermann et al. (1993), Golden and Rebois (1978), Jenkins et al. (1956), Cavigelli et al. (2005), USDA (2014), and Evans et al. (2007)
X. chambersi	Unknown	USDA (2014)
X. rivesi	Apple, corn, potato, tobacco	Cavigelli et al. (2005) and USDA (2014)

13.3 Major Plant Parasitic Nematodes of Maryland and Delaware

13.3.1 Cyst Nematodes, Heterodera *spp.*

This important group of plant parasitic nematodes is becoming common in many areas within Maryland and Delaware. In Maryland, during the 1957 survey, Jenkins et al. (1957) identified the genus *Heterodera* in 7% of the total number of samples examined, mostly from northern and western counties. Five species of cyst nematodes were recorded from Maryland namely, *H. schachtii*, *H. trifolii*, *H. glycines* and *Cactodera* sp. At that time, *H. schachtii* group was the most commonly found species in Maryland. *Heterodera trifolii* was identified from clover in the state. This crop had frequently shown poor growth that initially was suspected to be caused by nematodes. *Heterodera trifolii* was also observed from fields with alfalfa, barley, bean, clover, corn, grasses, oat, pea, rye, soybean, Timothy grass, tomato, vetch and wheat in all Maryland counties, except the five southern counties (Anne Arundel, Prince George's, Charles, Calvert, and St. Mary's) and the Lower Eastern Shore counties (Wicomico, Somerset, and Worcester). Later, Golden and Rebois (1978) reported *H. schachtii* and *H. trifolii* in 15% of samples from soybean fields. In Maryland, the cyst nematodes have been regularly observed each year during Maryland Department of Agriculture soybean cyst nematode surveys (Maryland Department of Agriculture survey records) and are known to cause severe crop loss and poor soybean plant growth in Maryland. '*Heterodera cacti'* identified by Jenkins et al. (1957) from soybean field samples, should be considered as *Cactodera weissi* described later by Mulvey and Golden (1983). In Delaware, *H. glycines* is the only cyst nematode species reported.

13.3.2 Soybean Cyst Nematode (SCN), Heterodera glycines

Heterodera glycines damages soybean roots, reduces yield, and may cause reduction in plant height. Soybean cyst nematode is the most economically important nematode pest of soybean in the U.S., with yield losses estimated at $1.5 billion annually. From 2010 to 2014, surveys of soybean yield losses in 28 soybean-producing US states and Canada found that SCN was estimated to have caused more than twice as much yield loss to any other disease (Allen et al. 2017).

The SCN was first found in North America in North Carolina in 1954, and since then has spread to at least 31 soybean-producing states, and Canada. In Maryland, this nematode was first detected in Worcester County in 1980 (Sardanelli et al. 1982). The county was placed under quarantine by the Maryland Department of Agriculture. In 1990, more extensive surveys were conducted in various counties and eight were found positive for the soybean cyst nematode. Percentages of positive samples for each county are given in parenthesis: Caroline (31%), Dorchester (21%), Kent (3%), Queen Anne's (7%), Somerset (35%), Talbot (20%), Wicomico (51%) and Worcester (36%) (Sindermann et al. 1993). Further spread of this nematode to uninfected fields was suspected and races 1 and 3 of SCN were identified in a small number of fields in Maryland (Sindermann et al. 1993). During a CAPS (the Cooperative Agricultural Pest Survey program of the USDA APHIS PPQ), the Maryland Department of Agriculture detected SCN in two more counties: Charles and St Mary's Counties in 1993, and 1996. Surveys conducted in Maryland in 1993 and 1999 found that other than the ten counties mentioned above, other parts of the state were found free from SCN. However, in 2012, the Maryland Department of Agriculture detected SCN in two additional counties (Cecil and Harford) during a regular survey for the nematode.

In Delaware, the nematode was first discovered in the fall of 1979 when soybean cyst nematode was widespread in Sussex County (Mulrooney 2011). Although found in Kent County just a few years later, SCN was not discovered until 1991 in the adjacent Newcastle County, near Clayton. Soybean cyst nematode, which is not restricted by soil type, can be found anywhere soybeans have been grown for a long time. The symptoms of infection are not always obvious so it is difficult to determine incidence of the disease. It can go undetected for years until severe stunting or yield losses are experienced during harvest. Often growers can be unaware of the presence of SCN in fields and therefore need to understand how to detect and manage the nematode.

In Delaware, during 1993 and 1994, a major effort was made to survey soybean acreage for SCN and determines prevalent race composition of field populations present. During that time, about 60% and 30% samples belonged to race 3 and race 1 respectively. No similar surveys for SCN were conducted in Delaware from 1996 to 2009. In 2009, a second survey conducted in Delaware to determine the SCN race in fewer fields found a shift in composition. This time seven populations belonged to race 1, representing 47% of samples, five populations of race 5, representing 33% of the samples and three populations of race 2 accounted for 20% of the samples. Race 3 populations were not observed. This study also found evidence that soybean cv. 'PI88788' (a Round-up® ready cultivar) was no different from a susceptible one. In 2010, testing of a small set of samples indicated that a majority of the tested populations were race 1. This may have been due to the use of PI88788 which allowed reproduction of race 1 populations (Mulrooney and Gregory 2010). These two studies further confirmed that there was a shift in race composition of SCN in Delaware. In addition, Mulrooney and Gregory (2010) indicated that SCN was the most limiting biotic factor of soybean production in Delaware during that period. Mulrooney (2011) further suggested that growers may need to plant soybean cultivars derived from non-PI88788 resistance sources in order to successfully manage soybean cyst nematode in the future. Furthermore, in Delaware, soybean cyst nematode was observed only in 32% of 38 samples obtained in a Nematode Assay Service conducted by the University of Delaware Extension Service in 2015 (Kness and Kleczewski 2015). There is a current need for more extensive surveys to determine the shift in race composition and virulence of the nematode populations, since periodic checks of race and virulence of pathogen is important for the efficient management of the pathogen. No such information is presently available for Maryland.

13.3.2.1 Management

In Wicomico County, Maryland, soil amendment with poultry litter at V2 and V5 stages of soybean development in Manokin (resistant) and Essex (susceptible) soybean cultivars, at rates of 0, 5 or 10 t/ha found that 5 t/ha poultry litter was an effective means of improving productivity when soybean is grown in SCN-infested soil and the poultry litter had a greater impact on reducing cyst infestation in Essex than Manokin (Mervalin et al. 1997).

In Delaware, cropping without soybean is recommended in fields with a history of SCN. Due to limited sources of SCN resistance available for the area, avoiding continuous planting of soybeans and rotating with a crop such as corn, for at least one season between soybean plantings is recommended. Fields with higher numbers of nematodes should crop more years without soybean (Ernest and Johnson 2014). In the past, crop rotation and use of resistant varieties of soybean such as PI88788, were recommended for the control of this nematode. PI88788, the major source of resistance to SCN for the last 25 years, was very effective against the common races of SCN, and its resistance was easily incorporated into new varieties. In fact, there are few modern soybean varieties without SCN resistance (Mulrooney 2011).

13.3.3 Corn Cyst Nematode, Heterodera zeae

Heterodera zeae feeds on corn (*Zea mays*) causing stunted plant growth and reduced yield (Hashmi et al. 1993; Krusberg et al. 1997). In addition, this species is of phytosanitary concern.

In early 1981, corn cyst nematode (CSN) was discovered for the first time in the Western Hemisphere, in corn fields in Kent County, Maryland (Sardanelli et al. 1981). This species was found only in four counties, Cecil, Harford, Kent, and Queen Anne's Counties. Fields known to be infested with the corn cyst nematode were quarantined by the Maryland Department of Agriculture in 1986, and the quarantine was lifted in 1996. The nematode was later identified from Cumberland County, Virginia, over 274 km from the nearest known infested field in Maryland.

In 1987, the host range of CSN was investigated. This nematode infected all 22 corn cultivars tested, along with certain barley (*Hordeum vulgare*) cultivars, oat (*Avena sativa*), rice (*Oryza sativa*), sorghum (*Sorghum bicolor*), sugarcane (*Saccharum* interspecific hybrid) and wheat (*Triticum aestivum*). Fall panicum (*Panicum dichotomiflorum*), a weed species common to cultivated fields in Maryland, was also a host for *Heterodera zeae*. Other hosts included meadow foxtail (*Alopecurus pratensis*), *Calamagrostis eipgeios*, Job's tears (*Coix lachryma-jobi*), green sprangletop (*Leptochloa dubia*), witchgrass (*Panicum capillare*), broomcorn (*Panicum miliaceum*), fountain grass (*Pennisetum rueppeli*), reed canary grass (*Phalaris arundinacea*), common reed (*Phragmites australis*), eastern gamagrass (*Tripsacum dactyloides*), corn (*Zea mays*) and teosinte (*Zea mexicana*) (MacGrown 1981; Ringer et al. 1987).

The optimum temperature for development of a Maryland population of *H. zeae* was reported to be 36° C (Hutzell and Krusberg 1990). Reproduction of *H. zeae* increased with temperature increasing from 24 to 36 °C. (Hutzell and Krusberg 1990). They also showed that temperature affected nematode-induced suppression of plant growth. Females were produced in bioassays of cysts recovered from soil which had been stored for 38 months at 24 °C and for 32 months at 2 °C. No second stage juveniles were recovered from soil after 1 month in storage at −18 °C, but even after 7-month storage, second stage juveniles emerged from cysts and developed into females (Krusberg and Sardanelli 1989).

Dry weight and yield responses of corn plants to *H. zeae* were greater in coarse-textured soil than in fine-textured soil. Fertilizer amendments did not alleviate suppression of plant growth by *H. zeae.* The nematodes suppressed corn yields to a greater degree and more consistently in sandy soil than in silty soil and caused more plant damage in hot and dry than in cool and wet seasons (Krusberg et al. 1997). Because of a higher temperature requirement to complete a life cycle, *H. zeae* was considered economically unimportant in Maryland. The present situation of corn cyst nematode in Maryland including original positive counties, is unknown. No report on CSN exists for Delaware, even though some counties of Maryland adjoin corn cyst nematode-positive counties.

13.3.3.1 Management

In Maryland, from 1982 to 1984, several granular nematicides and one fumigant were applied in experimental field plots with populations of 50–300 cysts/250 cm^3 in Kent and Harford Counties. Fumigation greatly lowered nematode population densities in soil without any increase in corn yield, compared to unfumigated soil (Krusberg et al. 1997).

13.3.4 Root Knot Nematodes, **Meloidogyne** *spp.*

Root knot nematodes are endoparasitic nematodes that infect several plant species worldwide and cause approximately 5% of global crop loss (Sasser and Carter 1985). Root knot nematode juveniles infect plant roots causing the development of

Fig. 13.1 (**a**) Root knot nematode infection of carrot. (**b**) Dagger nematode

galls (Fig 13.1a) that interfere with proper intake and utilization of the plant's photosynthate and nutrients. Infection of young plants may be lethal, while infection of mature plants causes decreased yield and quality.

In Maryland, *Meloidogyne* spp. were reported from 12 counties (Sasser 1954). Very low percentages of 1%, 3%, 10% of 143 corn, 111 tobacco and 74 soybean samples, respectively, contained *Meloidogyne* spp. (Jenkins et al. 1956). However, a year later, Jenkins et al. (1957) described three species from their survey. They suggested that these nematodes might be important only in lighter soils of the Eastern Shore and Southern Maryland. *Meloidogyne* spp. were observed in 19% and 22% of soil and root samples of soybean (Golden and Rebois 1978) and in 2% of samples examined from soybean fields in eight counties of Maryland (Sindermann et al. 1993).

Over the past 20 years, significant numbers of root knot nematode populations have been found regularly in commercial plant and soil samples submitted to the University of Maryland Nematology Laboratory (Everts et al. 2006). In Delaware, root knot nematode was the most common plant parasitic nematode, occurring in 24% of 38 samples in a University of Delaware Extension Nematode Assay Service in 2015 (Kness and Kleczewski 2015). In Baltimore, Maryland, *Meloidogyne*, spp. were found in *S*wiss chard exhibiting heavy root galling, and were detected in less than 1% of experimental samples containing 500 plants examined at the Central Maryland Research and Education Center, University of Maryland (Kaplan et al. 2008).

The genus *Meloidogyne* has about 100 valid species (Elling 2013) worldwide, but only a few are reported from Maryland and Delaware. Two species, *M. incognita* (southern root knot nematode, SRKN) and *M. hapla* (northern root knot nematode, NRKN), are common in Maryland and Delaware (Sasser 1954). Jenkins et al. (1957) found a single incidence of an additional species *M. javanica*, from snapdragon plants (*Antirrhinum majus*) in a greenhouse in Baltimore County, Maryland. *Meloidogyne incognita* was found in three more counties (Jenkins et al. 1957). Feldmesser and Golden (1972) found *M. graminis* occasionally in eight *Zoysia japonica* and one *Poa pratensis* turf lawns in several locations of Maryland.

Meloidogyne incognita is the most common root knot nematode species in Maryland and Delaware (Everts et al. 2006). *Meloidogyne incognita* produces larger galls and causes more severe stunting, yellowing and wilting symptoms than *M. hapla* (Traunfeld 1998). This species causes severe damage on the Eastern Shore and in Southern Maryland, and is capable of overwintering in Maryland and Delaware soils (Traunfeld 1998). In Maryland, the species is commonly found associated with vegetable crops, corn, muskmelon (*Cucumis melo*), soybean (*Glycine max*), sweet potato (*Ipomoea batatas*), tobacco (*Nicotiana tabacum*), tomato (*Lycopersion esculentum*), vetch (*Vicia villosa*) and wheat (*Triticum aestivum*) (Jenkins et al. 1957). Similarly, *M. incognita acrita* was recognized in 5% of 42 soybean samples (Golden and Rebois 1978). These researchers also found an undescribed *Meloidogyne* sp. in 2% of 42 field samples. Potato (*Solanum tuberosum*), processing cucumber (*C. sativus*), sweet corn, green bean (*Phaseolus vulgaris*) and other vegetables are grown throughout the region and also have experienced significant losses due to this unknown species (Everts et al. 2006).

Meloidogyne hapla produces tiny galls on a wide variety of plants, compared to *M. incognita*. In 1957, it was associated with alfalfa, clover and vetch and categorized as a less common, but still important, species (Jenkins et al. 1957). High populations were associated with stunting and yield loss in tobacco in Charles and Calvert Counties in Maryland. Golden and Rebois (1978) recorded it in 14% of soil and 19% of 42 soybean root samples.

Meloidogyne sasseri was described and illustrated from American beachgrass (*Ammophila breviliffulata*) originally collected from Henlopen State Park and Fenwick Island near the Maryland state line in Delaware (Handoo et al. 1993).

The root knot nematodes cause yield and quality losses for most vegetable and field crops in Maryland when they exceed certain threshold levels and control measures are not applied. Growers need to determine nematode field population levels for efficient soil management practices. Summer or early fall sampling is more effective than mid-spring sampling. However, a degree days-based sampling has been suggested for Maryland (Kratochvil et al. 2004). The SRKN and root lesion nematodes prevalent in Maryland and Delaware cause severe damage in areas with sandy soils and in crops including tobacco, and vegetables such as sweet potatoes, tomatoes, potatoes, cucumber and green beans. Fields planted repeatedly with these crops have experienced significant losses due to RKN. Corn and wheat, common crops in the region, are reproductive hosts for RKN.

In Delaware, root knot nematode is found associated with soybean, snap bean (*Phaseolus vulgaris)*, watermelon (*Citrullus lunatus*), cucumber (*Cucumis sativus*), tomato, pepper (*Capsicum* spp.), sorghum and sudangrass (*Sorghum* spp.), lima bean (*Phaseolus lunatus*), pea (*Pisum sativum*), cantaloupe and muskmelon (*Cucumis melo*), pumpkin and squash (*Cucurbita* spp.), potato, corn as well as weeds, including dandelion (*Taraxacum* spp.), mallow (*Malva neglecta*), purslane (*Portulaca oleracea*), pigweed (*Amaranthus* spp.), prickly sida (*Sida spinosa*) and morning glory (*Ipomoea* spp.).

In Delaware, root knot nematode economic threshold levels are considered to have a two RGS rating (1–4 galls in each whole root) for carrots and three RGS rating (5–12 galls) for other vegetables (Ernest and Johnson 2014). Economic threshold levels of root knot nematode, when combined with other nematodes such as root lesion nematode in fall (1 + 2.2 nematodes per cm^3 soil) and in spring (4 + 1.6 nematodes per cm^3 soil) is lower than those for either root knot nematode or lesion nematode alone (Mulrooney 2012a, b).

13.3.4.1 Management

Currently, in both states, limited control measures for root knot nematode exist. Limited availability of effective broad spectrum nematicides such as methyl bromide, is a growing concern for crop producers, primarily vegetable producers. Also, due to a present limited availability of experts with an understanding of field biology of nematodes, a shift in nematode population dynamics and constant change in crop cultivars and crop rotation, the economic importance and damages caused by nematodes may increase in Maryland and Delaware.

Increased use of nematicides in many different crops by the growers has been observed in Delaware. Application of nematicides such as NIMITZ™ (fluensulfone), is highly effective in controlling plant-parasitic nematodes, especially root knot nematodes in tomato, other fruiting vegetables and cucurbits. Registration for crops such as carrots, strawberries and other crops is expected to follow. Some growers in the region have started using nematicide seed treatments (Avicta, Votivo) on field corn (Ernest and Johnson 2014). However, there are conflicting reports of increased yield due to seed treatments as no differences in nematode population between treated and nontreated controls have been observed later in the season. Thus, use of seed treatment in corn to reduce root knot nematode populations in succeeding vegetable crops, is still under debate (Ernest and Johnson 2014). However, such chemicals should be used when the nematode populations cross the economic threshold level.

Rotation is often a limited control strategy for root knot nematode because of its wide host range. Crops such as alfalfa or oats may be the safer crops to use in rotation in order to reduce root knot nematode populations. Increasing organic matter in fields with low organic matter and high root knot populations or other plant parasitic nematodes, can have a suppressing effect on root knot populations. Planting rape and other mustards may help suppress root knot populations by releasing isocythicynite, a toxic gas, by plowing green plant materials during flowering, before they go to seed in the spring prior to planting the next crop. Pokharel and Reighard (2015) reported increased efficacy by covering the plot after incorporating mustard green plant materials into the soil. The nematode may infect rape if the populations are high and soil temperatures are above 18.3 °C, at planting or in fall (Christy and Mulrooney 2011*).* Use of cover crops and poultry litter compost are effective methods to reduce nematode populations only if successively incorporated into rotational cropping sequences (Everts et al. 2006).

Soybean does not produce visible symptoms with low root knot nematode populations but yield loss can occur depending on growing conditions, especially low rainfall. High populations and adverse growing conditions causing plant stress, can cause stunting as severe as that produced by soybean cyst nematode. Root knot nematode resistance has been available for a long time but such varieties (group 4 soybeans) still are limited in use. Root knot nematode resistant soybeans would be an excellent rotation crop for vegetable growers who plant susceptible, free market or processing vegetables (Ernest and Johnson 2014).

Though several alternative techniques such as sanitation, soil management, organic amendments, fertilization, biological control and heat-based methods are recommended, their use alone has limited implications for yield loss management in comparison to nematicides. Combining control methods in a systemic analysis presents a challenge; sustainable management of root knot nematode is only possible with integration of several approaches, including maintenance of constant and rigorous research for each local nematode population and agro-climatic region.

13.3.5 Root Lesion Nematodes, **Pratylenchus** *spp.*

One of the most important nematode genera, *Pratylenchus*, has been found in almost all studies reported from Maryland and Delaware. *Pratylenchus* spp. were found in 40% of total number of samples collected from Maryland and in 60% of total numbers of samples collected from the four western counties of Frederick, Washington, Allegany, and Garrett. Seven species of *Pratylenchus* were reported from different crops (Jenkins et al. 1957). Lesion nematode was found in 78% of 362 samples of soybean fields in eight counties of Maryland (Sindermann et al. 1993) and in 29% tobacco samples analyzed at the Central Maryland Research and Education Center, University of Maryland (Kaplan et al. 2008). Jenkins et al. (1957) reported that *Pratylenchus* spp. and *Tylenchorhynchus* spp. are probably the most serious plant crop pests in Maryland based on their study of plant parasitic nematodes in 1,210 farms and gardens throughout the state.

Several species of *Pratylenchus* are described in Maryland, but not all are important. Species found in Maryland and Delaware are discussed below. Their importance varies with the targeted crop and location.

Pratylenchus pratensis was the most common species found in 9% of 1,210 survey samples by Jenkins et al. (1957). It was commonly found in the northern part of Maryland possibly because the nematode is better adapted to heavier clay-loam soil and somewhat cooler temperatures. The nematode was found during the latter part of July and August and was associated with alfalfa, barley, bean, clover, corn, grass, oat, pea, rye, sorghum, soybean, timothy, tobacco, tomato, vetch and wheat. Also, it was frequently detected in clover and grass roots in pasture fields (Jenkins et al. 1957).

Pratylenchus brachyurus was discovered in 4% of 1,210 soil samples collected from Northern and Western Maryland (Jenkins et al. 1957). This was the second most frequently detected species and was associated with alfalfa, asparagus, barley, clover, corn, grass, oat, rye, sorghum, soybean, timothy, tobacco, tomato and wheat. It was most often found in clover and grass roots in pastures.

Pratylenchus zeae was identified in about 4% of the samples from southern counties where light sandy soil is common. The largest population of this species was detected somewhat earlier than *P. pratensis* and *P. brachyurus*, which might be due to an earlier planting time. This species was associated with alfalfa, bean, corn, cucumber, grass, tobacco and tomato (Jenkins et al. 1957). Higher numbers of corn, followed by soybean samples, contained this species (Jenkins et al. 1956). Golden and Rebois (1978) found this species in 2% of 42 soybean fields in Maryland.

Pratylenchus penetrans was the fourth most commonly found species during the survey (Jenkins et al. 1957). It was found in about 2% of 1,210 samples distributed throughout the state with no soil type preference. This species was found in alfalfa, bean, clover, grasses, raspberry, soybean, strawberry, tobacco, tomato, vetch and wheat. It was most often observed in clover and grass roots in pasture (Jenkins et al. 1957). In Maryland, *P. penetrans* was found in 33% of 42 soybean fields (Golden and Rebois 1978). Sindermann et al. (1993) reported *P. penetrans*, a common species in Maryland and Delaware soybean fields capable of causing severe damage to potato and cucumber. Symptoms of root lesion nematode infections in potato range from poor crop growth and chlorotic foliage to root cell death, resulting from nematode feeding, and tubers with scabby or shrunken areas. Yield losses due to *P. penetrans* are highly variable and influenced by environmental conditions and the presence of the fungus *Verticillium dahlia* (Everts et al. 2006).

Pratylenchus hexincisus was found in less than 1% of 1,210 samples (Jenkins et al. 1957). No particular distribution pattern of this nematode was found. It was found associated with clover, corn, millet, rye, soybean and tomato. The largest population was observed during August, without any soil type preference. This species was found in 12% of 42 soybean fields in Maryland (Golden and Rebois 1978).

Pratylenchus vulnus was observed in boxwood samples collected from Montgomery County, Maryland (Jenkins et al. 1957).

Pratylenchus subpenetrans was found in pasture grasses in Prince George's County (Jenkins et al. 1957). They also reported the species to be associated with broccoli, carnation, lespedeza, muskmelon, peach, potato, snapdragon, sweet potato and watermelon. This nematode caused significant stunting of boxwood (Golden 1956).

Based on a statewide survey, Jenkins et al. (1957) described seven *Pratylenchus* species of which *P. pratensis* was the most common species detected. Golden and Rebois (1978) reported 7 species which, at that time included the new species, *P. agilis*, *P. coffeae*, *P. crenatus* and *P. scribneri,* from 42 soybean fields in Maryland with *P. agilis* being the most common. Similarly, seven species of *Pratylenchus* *(P. pinguicaudatus*, *P. neglectus*, *P. projectus*, *P. thornei*, *P. penetrans* and *P. zeae*.) were recorded from a no-till corn field in Beltsville, Maryland, where the last two species were previously reported and *P. thornei* was the major species detected (Cavigelli et al. 2005).

Pratylenchus was one of two important genera found in potatoes in Maryland, however, presently, root lesion nematode damage to the Maryland potato crop is low. This may be because processing potatoes are a relatively new crop in Maryland, and nematode populations have not yet reached economic levels (Edward et al. 2002). The lesion nematode in corn prefers high clay content. Yield loss trials conducted in the U.S. Corn Belt using NemaStrike™ Technology for 3-Year Average (2014–2016) in 264 trials in several states, including Maryland, demonstrated an average yield protection advantage of 0.18 ton, 0.08 ton in soybean, and varying results in wheat based on nematode pressure in each field (AgWeb 2017).

In Delaware, root lesion nematode was the most common plant parasitic nematode, occurring in 68% of 38 samples in a University of Delaware Extension Nematode Assay Service in 2015 (Kness and Kleczewski 2015). Two species of root lesion nematode, *P. thornei* and *P. neglectus*, may be present at damaging levels in wheat. In a low-precipitation environment, winter wheat losses can be up to 36% at a level of 10,000 *P. neglectus*/kg soil. Spring wheat losses are lower in high precipitation environments, but are still 14% at a level of 4,000 *P. neglectus*/kg soil (Smiley et al. 2004). Wheat and corn are important crops but no extensive survey of nematodes associated with these crops has been conducted even though both lesion nematode species are present in Maryland (and probably in Delaware as well). Losses caused by these two species, especially on wheat, are not known. In Delaware, the economic threshold levels for root lesion nematode in corn are 3.2 (juveniles, females or eggs) per cm^3 soil in fall and 2 (juveniles, females or eggs) per cm^3 soil in spring (Mulrooney 2012a, b), which may be comparable for Maryland growers.

13.3.5.1 Management

Growers use costly nematicides to control root knot and root lesion nematode on potatoes and cucumbers. In a typical year, as in 1998, only 25% of pickling cucumber acreage in Maryland and Delaware was fumigated for the nematode. Root lesion nematode has also caused severe damage on potato and cucumber, although yield losses due to the nematode are highly variable and influenced by environmental conditions (SARE 2005).

The use of sorghum-sudangrass in a regular rotation with susceptible vegetable and agronomic crops can be a suitable bio-control management practice for *M. incognita* and *Pratylenchus* spp. Late summer and early fall production of this high-biomass yielding crop should effectively manage residual nitrogen. Sorghum-sudangrass has the potential to be both a good cover crop for nutrient management and a good bio-control option for managing parasitic root nematodes (Kratochvil et al. 2004).

Soil amendment of cover crops, poultry litter (PL) and PL compost was tested in microplots to suppress root knot (*M. incognita*) and root lesion nematodes (*P. penetran)* in 1, 2, 3-year rotational sequences comprising potato (year 1), cucumber (year 2), followed by a moderately RKN-resistant or susceptible soybean cultivar, castor bean, grain sorghum, or sorghum-sudangrass; PL or PL compost were amended into some of the RKN-susceptible soybean and sorghum-sudangrass plots. In the 3rd year of the rotation, potato followed by soybean was planted in all 12 treatments. The RKN-resistant soybean, castor bean, sorghum-sudangrass, and fallow or tillage decreased populations of *M. incognita* compared with microplots where RKN-susceptible soybean had been grown. However, RKN populations quickly recovered. Root lesion nematode was reduced in the spring of year 1 following application of high rates of PL and PL compost the previous year. In the fall of year 1, sorghum-sudangrass alone or in combination with PL or PL compost, grain sorghum, or fallow or tillage reduced root lesion nematodes compared with either soybean cultivar. No treatment affected root lesion nematode the following year. The use of cover crops and PL compost is an effective method to reduce nematode populations only if successively incorporated into rotational cropping sequences (Everts et al. 2006).

13.3.6 *Stem and Bulb Nematode,* Ditylenchus dipsaci

Ditylenchus dipsaci, also commonly known as garlic bloat nematode, was observed in 57% of samples collected throughout Maryland, however, no large populations of this nematode were associated with plant injury (Jenkins et al. 1957). The genus was associated with alfalfa, asparagus, barley, bean, carnation, clover, corn, cucumber, grass, lespedeza, oat, pea, pepper, potato, rye, soybean, strawberry, sweet potato, timothy, tobacco, tomato, vetch and wheat. Golden and Rebois, (1978) found the genus in 4% of 42 soybean samples. Brust and Rane (2012) found garlic bloat nematode in several garlic samples submitted from growers with bloated, twisted, swollen leaves, distorted and cracked bulbs with dark rings. *Ditylenchus dipsaci* and *D. myceliophagus*, a mushroom parasitic species, are reported from Maryland.

Ditylenchus dipsaci is probably one of the important parasitic nematodes of several agriculture crops in the world. It is one of the destructive pests of several economically important crops such as alfalfa, garlic, onion, and tulips. However, damage found in many crops is often misidentified or not reported. This species causes twisted, stunted and abnormal plant growth, with symptoms in garlic and onion often starting early in the growing season. The species is often found in ornamentals including phlox, tulip, narcissus and hyacinth, but many other crops and weeds can also support it. Infected bulbs have distorted leaves and browned bulb scales. Infected phlox shows distorted growth, stunting and plant death. Large numbers of nematodes may be present in symptomatic plant tissues and can be seen through a microscope as a writhing white mass called "nematode cotton". In the past few years, this nematode has been found in garlic samples (Brust and Rane 2012) and many past incidences of decline observed in Maryland could be due to *D. dipsaci.*

13.3.7 *Dagger Nematodes,* Xiphinema *spp.*

Dagger nematodes belong to the economically important ectoparasitic nematode genus *Xiphinema* (Fig 13.1b) comprising certain species that transmit plant viruses. Jenkins et al. (1956) found *Xiphinema* sp. in 39%, 44% and 39% of 143 corn, 111 tobacco and 74 soybean samples, respectively, and reported the genus *Xiphinema* as one of the most commonly found groups in 41% of all soil samples collected in their extensive survey of 1,210 farms and gardens in Maryland. It has been reported that populations tend to be highest with outbreaks more likely in light, sandier soils, as opposed to heavier clay soils. Dorchester County experiences high levels of nematodes that may be due to favorable soil conditions. Population levels are prone to drastic fluctuations. Dagger nematode was found in 54% of 12 soybean fields in 8 Maryland counties (Sindermann et al. 1993).

Xiphinema americanum was the only species found in the extensive survey of 1,210 farms and gardens throughout Maryland, associated with stunting and poor growth of tomato plants in a field in Worcester County. This species was also found associated with turf lawns (*Zoysia japonica* and *Poa pratensis*), in several locations of Maryland (Feldmesser and Golden 1972). Later, Golden and Rebois (1978) found 26% of 42 soybean fields surveyed infected with *X. americanum*. This group is known to transmit different NEPO viruses and may be important for many crop growers in the region.

Xiphinema rivesi was found associated with apple (Lamberti and Bleve-Zacheo 1979; Wojtowlcz et al. 1982) and no-till corn in Beltsville, MD (Cavigelli et al. 2005).

Xiphinema spp. are a potentially serious pest of potatoes in Maryland, although at present no yield loss has been directly attributed to these nematodes. Potatoes are good hosts, causing increased populations. While yields don't seem to be affected, subsequent crops can be damaged. Dagger nematode was associated with tobacco in 44.17% of samples from Central Maryland Research and Education Center (Kaplan et al. 2008). In Delaware, dagger root nematode was observed only in 8% of samples (out of 38 samples) in a Nematode Assay Service in 2015 (Kness and Kleczewski 2015).

In Delaware and Maryland, dagger nematodes (*Xiphinema* spp.) were found at damaging levels in several samples that were to be planted to wine grapes (Mulrooney and Gregory, 1210). Minor species reported from Maryland include *X. chambersi* (Chamber's dagger nematode). While studies show that *Xiphinema* is commonly present in different crops in Maryland and Delaware, occurrence and densities vary with location and time. Thus, their role in crop production, including transmission of plant viruses in this area, is not known.

13.3.7.1 Management

In Sussex County, Delaware, more than 60 fields with severely stunted soybean plants with thickened, dark-green leaves have been observed to produce little to no yield over several years. These soybean plantings are infested with *Soybean severe stunt virus (SSSV*) which is transmitted by *X. americanum,* and symptomatic plants in the field are consistently associated with the dagger nematode. Greenhouse studies indicated that corn, wheat, marigold, castor and fallow treatments reduced dagger nematodes the most after 14 weeks compared growing with 'Essex' and 'HT 5203' soybean cultivars (Evans et al. 2007).

13.4 Other Plant Parasitic Nematodes of Lesser or Undetermined Importance in Maryland and Delaware

13.4.1 Foliar Nematodes, Aphelenchoides *spp.*

These above-ground plant-feeding nematodes cause damage to many landscape plants, affecting their esthetic value. As foliar feeders, these nematodes are known to infect ferns, peonies, begonias, anemones, *Baptisia*, *Hepatica*, *Heuchera*, hostas, *Hypericum*, *Ipomoea aculeatum*, iris, lilies, *Ligularia*, orchids, *Papaver*, *Orientale*, *Phlox*, *Polygonatum*, *Rogersia*, salvias and *Tricyrtus* (Kohl 2011). Privet and azalea are among the woody plants commonly infected with foliar nematodes. Foliar nematodes can easily spread from these woody hosts into herbaceous ones. This genus was recorded in 29% of 42 soybean fields surveyed (Golden and Rebois 1978) as well as in no-till corn samples in Beltsville, Maryland (Cavigelli et al. 2005). Three species have been reported in Maryland: *A. besseyi*, *A. ritzemabosi* and *A. fragariae*.

Aphelenchoides besseyi is mostly a pest of rice in developing countries causing white tip disease, however, in Maryland, it was found associated with chrysanthemum (Jenkins et al. 1957). Also known as 'summer dwarf nematode of strawberry', *A. besseyi* was found in wild strawberry in Maryland and considered widespread in commercial strawberries cultivated in Maryland and Delaware (Esser 1966).

Aphelenchoides ritzemabosi was observed in chrysanthemum from Montgomery County, Maryland (Jenkins et al. 1957). This species produces 'summer crimp' which appears in hot summer weather, intensifies with rain, and slows down by cool weather (Esser 1966).

Aphelenchoides fragariae was extracted from strawberry leaves in three locations on the Eastern Shore (Jenkins et al. 1957). This species, along with *A. besseyi*, was found in Maryland and Delaware in strawberry plants. It causes 'spring crimp' in strawberry (Esser 1966). The nematode can survive mild winters and hot summers in Maryland and may be a serious threat to strawberry production. In Delaware, the nematode was found associated with butterfly bush (*Buddleja* spp.) (Kunkel 2010). Information is limited on incidence, host-parasite relationships and importance of this nematode in strawberry as well as ornamental plants in Maryland and Delaware.

13.4.2 Spiral Nematodes

Spiral nematodes of the genus *Helicotylenchus* are frequently found in Maryland and Delaware. This nematode was observed in 57%, 46% and 47% of 143 corn, 111 tobacco and 74 soybean samples, respectively (Jenkins et al. 1956). The exact role of this external feeding nematode group in various crop plants is not known unless very high population levels exist. This nematode, recorded in 20% of the samples examined during a survey of 1210 farms in Maryland, was considered less common but still important (Jenkins et al. 1957). This genus is best suited to clay loam soils that are more common in the northern and western regions of the state. *Helicotylenchus* spp. were observed in 36% and 7% of 42 soybean soil and root samples (Golden and Rebois 1978). The following species of this genus are reported from Maryland in different crops.

Helicotylenchus erythrine was found associated with chrysanthemum, cucumber, lespedeza, muskmelon, pea strawberry and watermelon. Large populations of this species are associated with root injury and stunting of plants. This species is also regarded as one of the important parasites or pathogens of corn.

Helicotylenchus digonicus was occasionally found, in low numbers, to be associated with turf lawns (eight *Zoysia japonica* and one *Poa pratensis*) in several locations of Maryland (Feldmesser and Golden 1972) and in no-till corn in Beltsville, Maryland (Cavigelli et al. 2005).

Helicotylenchus dihystera was the most common species observed in Maryland. It was found associated with alfalfa, asparagus, barley, clover, corn, oat, soybean, timothy, tobacco, tomato, vetch, and wheat (Jenkins et al. 1957). *Helicotylenchus dihystera* was observed in 12% of 42 soil samples during the survey (Golden and Rebois 1978).

Helicotylenchus pseudorobustus was observed in 29% and 7% of soybean soil and root samples, respectively (Golden and Rebois 1978) and in low numbers in no-till corn in Beltsville, Maryland (Cavigelli et al. 2005). In soybean, this genus was found in 58% of 269 samples collected and tested from eight counties of Maryland (Sindermann et al. 1993). It was also observed associated with turf lawns (eight *Zoysia japonica* and one *Poa pratensis*) in several locations of Maryland (Feldmesser and Golden 1972). Similarly, it was also found in 91% samples of tobacco at the Central Maryland Research and Education Center (University of Maryland) (Kaplan et al. 2008).

Helicotylenchus multicinctus can infect a wide range of cultivated plants and is reported from Maryland (Bernard and Keyserling 1985).

In Delaware, spiral nematodes of the genus *Helicotylenchus* were the second most common plant parasitic genus occurring in 55% of 38 samples in a Nematode Assay Service in 2015 (Kness and Kleczewski 2015).

Other spiral nematode, genus *Rotylenchus* was found in 3% of samples from all over Maryland, in both low frequency and numbers. Preference for soil type was not determined (Jenkins et al. 1957). Only two species, *R. robustus* and *R. buxophilus*, are found in Maryland.

Rotylenchus robustus was detected in small numbers in soil around alfalfa roots in Frederick County (Jenkins et al. 1957).

Rotylenchus buxophilus was associated with alfalfa, corn, grass, oat, tobacco and wheat. Later, this genus was also recorded in 4.2% of 143 corn and 2.7% of 74 tobacco, but not in soybean samples in Maryland (Golden and Rebois 1978). A large population was found in boxwood samples affecting the plants in wider areas in Maryland (Sasser 1954). Sasser (1954) also found it to cause significant reduction of root growth in inoculated plants.

Spiral nematodes of the genus *Scutellonema* spp. infect several plant species, grass being more important than others. This nematode is recorded from Maryland in grass and apple samples (Horst 2008). No species is reported from these states.

13.4.3 Stunt Nematodes

This genus *Tylenchorhynchus* is the second most important, after *Pratylenchus* in Maryland. *Tylenchorhynchus* spp. were estimated to be the most serious pests of agricultural crops in Maryland in the 1950s and was recorded in 51%, 68% and 39% of corn, tobacco and soybean, respectively (Jenkins et al. 1956). Later, the genus was recorded in 60% soil and 7% of root samples in soybean, with two species identified in 42 soybean samples (Golden and Rebois 1978). The stunt nematode was observed in 83% of samples examined from the Central Maryland Research and Education Center (University of Maryland) (Kaplan et al. 2008). Five species are described from Maryland.

Tylenchorhynchus claytoni was the most common species found in 15% of samples from all counties, except, Kent, Queen Anne's, Talbot, and Baltimore. It was commonly found in Anne Arundel, Charles, Calvert, St. Mary's and Prince George's Counties. This species was associated with alfalfa, barley, bean, clover, corn, grasses, oat, pepper, rye, soybean, strawberry, sweet potato, timothy grass, tomato, vetch and wheat. It was also frequently associated with tobacco (Jenkins et al. 1957), soybean in 55% of 42 samples (Golden and Rebois 1978) and grasses including 8 *Zoysia japonica* and one *Poa pratensis*, in several Maryland locations (Feldmesser and Golden 1972).

Tylenchorhynchus dubius, the second most frequently encountered species, was observed in about 1% of 1210 soil samples, limited to northern and western counties (Howard, Montgomery, Frederick, Washington, Allegany, and Garrett) where soil is clay-loam. Dense nematode populations were associated with stunting and chlorosis of barley and the nematodes were also recovered from clover, grasses, oat, vetch and wheat (Jenkins et al. 1957). It was also occasionally associated with eight *Zoysia japonica* and one *Poa pratensis* turf lawn in several locations of Maryland (Feldmesser and Golden 1972).

Merlinius brevidens was identified in less than 1% of 1,210 samples. It was found in alfalfa, barley, clover, grasses, oat, pea, timothy, and wheat in clay loam soils of Carroll, Frederick, and Howard Counties (Jenkins et al. 1957). Other minor species, *Geocenamus ornatus* in a single sample from barley in Howard County (Jenkins et al. 1957), and *Quinisulcius acutus* in 2% of 42 soybean samples (Golden and Rebois 1978) have also been identified from Maryland.

13.4.4 Lance Nematodes, **Hoplolaimus** *spp.*

The lance nematode feeds on plant roots, externally (body remaining outside), internally (body completely within roots) or partially outside or inside (head region only within roots). In Maryland, this genus was observed in 18%, 15% and 23% of 143 corn, 111 tobacco and 74 soybean samples respectively (Jenkins et al. 1956) and in 43% of 199 soybean fields in 8 counties of Maryland (Sindermann et al. 1993). It was observed in 23.33% samples of tobacco at the Central Maryland Research and Education Center (University of Maryland) (Kaplan et al. 2008).

Jenkins et al. (1957) found lance nematodes in 16% of 1,210 samples collected in all counties, except Charles County. Despite occasional high populations in sandy soils, clay or clay-loam soil was the most frequent habitat. This nematode was associated with grass in the majority (about 3%) of total samples, and in tobacco and clover about seven times less. The nematode was also observed in grape roots in Montgomery County. In addition, it was associated with alfalfa, barley, carnation, clover, corn, grass, lespedeza, oat, pea, pepper, rye, soybean, sweet potato, timothy, tobacco, tomato and wheat; no difference in the preference of soil type was found. *Hoplolaimus* spp. were considered less common than other plant parasitic nematodes of the region. Three *Hoplolaimus* species important to agricultural pathogens are found in Maryland:

Hoplolaimus galeatus (= *H. coronatus*) was found in an extensive survey of 1,210 fields and garden (Jenkins et al. 1957), where the single species was present in 11% of samples examined. It was also found associated with alfalfa, barley, carnation, clover, corn, grape, grass, lespedeza, oat, pea, pepper, rye, soybean, sweet potato, timothy, tobacco, tomato and wheat. This species should be considered as a potentially important nematode pest in Maryland crops (Jenkins et al. 1957).

Hoplolaimus galeatus is important primarily in turf grasses and may be the major nematode pest of turf grass, after sting nematodes, in many warmer areas. It was reported associated with eight *Zoysia japonica* and one *Poa pratensis* in several locations of Maryland (Feldmesser and Golden 1972). Golden and Rebois (1978) found this species in 38% and 41% of 42 soybean soil and root samples. This species was also found in no-till corn with low in numbers in Beltsville, Maryland (Cavigelli et al. 2005). It also can be found in many crops, along with pine trees and grasses. The nematode, commonly found in lawns, is the major nematode pest of St. Augustine grass. Low numbers of this nematode can cause damage to turf grasses. It is common on the East Coast, from New England to Florida (Crow and Brammer 2015) including Maryland and Delaware.

In Delaware, lance nematode was the most common plant parasitic nematode, occurring in 29% of 38 samples in a Nematode Assay Service in 2015 (Kness and Kleczewski 2015). Because of limited study, it was hard to ascertain the current situation and potential threat of *Hoplolaimus* in different plants, especially landscape plants, in Maryland and Delaware.

13.4.5 Stubby Root Nematodes

Stubby root nematodes feed on plant roots and cause economic loss by direct feeding and indirectly by transmitting plant viruses. Populations of this nematode were identified in about 3% of 1210 samples, primarily from the lower Eastern Shore, where three species were reported (Jenkins et al. 1957). They found the nematode associated with bean, corn, grass, pepper, rye, soybean, strawberry, sweet potato, tobacco, tomato and wheat. Four species have been identified from Maryland. *Trichodorus* sp. was occasionally noted from eight *Zoysia japonica* and one *Poa pratensis* lawn, in several locations of Maryland (Feldmesser and Golden 1972).

Nanidorus minor (= *Paratrichodorus christiei*) was identified in 14% of 74 soybean soil samples (Golden and Rebois 1978).

Paratrichodorus obtusus was identified by Crow (2005) in large numbers. Later, Kaplan et al. (2008) also observed this nematode associated with tobacco during a field experiment at the Central Maryland Research and Education Center).

Paratrichodorus pachydermus was found in a single turf sample from Prince George's County, Maryland (Jenkins et al. 1957).

Trichodorus primitivus was found in soils from mimosa in Talbot County, Maryland (Jenkins et al. 1957). This nematode was found in 8%, 5% and 14% of 143 corn, 111 tobacco and 74 soybean samples, respectively (Jenkins et al. 1956). This genus was observed in 9% of 500 tobacco plant samples at the Central Maryland Research and Education Center (Upper Marlboro, MD (Kaplan et al. 2008) during a field research.

In Delaware, stubby root nematode was observed only in 16% of 38 samples in a Nematode Assay Service in 2015 (Kness and Kleczewski 2015).

13.4.6 Ring Nematodes, **Mesocriconema** *spp.*

In Maryland, these nematodes were reported from 4%, 2% and 3% of 143 of corn, 111 tobacco and 74 soybean soil samples, respectively (Jenkins et al. 1956). The genus, observed in about 3% of 1,210 soil samples, was found throughout the state associated with barley, bean, clover, corn, cucumber, grasses, pepper, rye, tobacco and soybean (Jenkins et al. 1957). Also ring nematodes were detected in 7% of 42 soil samples collected from soybean fields (Golden and Rebois 1978). Because of a lack of serious damage problems caused by ring nematodes in any crop plant, these nematodes were not considered an agricultural importance. However, it has been found that this group can play an important role in peach tree short life (PTSL) which is a severe problem in Georgia and the Carolinas (Nyczepir et al. 1985) but not in Maryland and Delaware, even though it has been reported from these states.

Mesocriconema ornatum was found in Maryland and was reported to be associated with turf lawns (eight *Zoysia japonica* and one *Poa pratensis*) several locations (Feldmesser and Golden 1972).

Mesocriconema simile was found associated with peach decline in some states including, Maryland (Horst 2008).

13.4.7 Sting Nematode, **Belonolaimus longicaudatus**

The sting nematode was found in irregular areas of severely chlorotic, stunted and dead soybean plants in Delaware, with a population density of 216 nematodes per 250 cm^3 of soil (Handoo et al. 2010). No other published information is available for this nematode in Maryland. Since *Belonolaimus longicaudatus* can be a serious problem in many lawns and golf grass, it may also be a problem in Maryland and Delaware turf lawns.

13.4.8 Sheath Nematodes, **Hemicyclophora** *spp.*

This genus is not common in Maryland and Delaware. This nematode was detected in only 5 of 1,210 corn soil samples collected from Maryland (Jenkins et al. 1957). The genus was also associated with barley, corn and grass, and a large population in raspberry was associated with chlorosis, reduced yield and general decline, thereby indicating a potential problem in raspberry production (Jenkins et al. 1957).

13.4.9 Needle Nematodes, **Longidorus** *spp.*

Longidorus spp. is an important group of plant parasitic nematodes, largely because they are known to transmit many plant viruses., However, the present incidence of this nematode in Maryland and Delaware is unknown. In earlier studies, it was present in low numbers in 6% and 7% of corn and soybean samples, respectively, but not in tobacco in Maryland (Jenkins et al. 1956). Some individual nematodes collected from stunted corn in three counties of Southeastern Iowa in 1971 and 1972, were similar to those collected from Delaware, but morphologically dissimilar to any recorded account, and the nematode was described as a new species, *Longidorus breviannulatus* (Norton and Hoffmann 1975).

13.4.10 *Ear Cockle Nematode,* **Anguina tritici**

Anguina tritici causes a disease in wheat and rye called, “ear-cockle” or “seed gall”. There is a brief account of the symptoms of “head nematode disease” (*Anguina tritici*) in wheat, which is important in underdeveloped countries, causing up to 70% losses (Leukel 1957), and as a phytosanitary pathogen in developed counties. This nematode was first found in the United States in 1909 in California, and subsequently in several states including Maryland, Virginia, and Georgia, primarily in wheat, but also in rye to a lesser extent (Leukel 1957). In Maryland, it was found in one sample with 20% infection from St. Mary’s County (Jenkins et al. 1957). However, modern mechanized agricultural seed grading practices that result in separation of clean seed from galls, along with crop rotation, have practically eliminated *A. tritici* from countries which have adopted these practices, and the nematode has not been found in the United States since 1975 (Randhawa 2017).

13.4.11 *Pin Nematodes,* **Paratylenchus** *spp.*

This nematode was found in 8%, 12% and 3% of corn, tobacco and soybean samples, respectively in Maryland, and was observed in 14% of 1,210 samples in various other crops without any preference of soil type (Jenkins et al. 1957). *Paratylenchus* sp. was found associated with strawberry in the wild (wooded areas) and this genus is also frequently found in commercial strawberry plantings (Crow and MacDonald 1976).

Paratylenchus dianthus was identified from 6 samples of 1,210 farms and gardens in Maryland from Carnation, clover, corn, timothy, vetch and wheat from Allegany, Washington, Prince George’s and Baltimore Counties (Jenkins et al. 1957) and currently is believed to be distributed throughout the state (Horst 2008).

Paratylenchus hamatus was found in Allegany and Carroll Counties, associated with clover showing stunted growth and low yield record (Jenkins et al. 1957).

Paratylenchus nanus was recorded in Garrett County from asymptomatic wheat (Jenkins et al. 1957).

Paratylenchus projectus was the most common species distributed throughout the state, associated with alfalfa, bean, clover, corn, grass, lespedeza and soybean (Jenkins et al. 1957). Furthermore, Jenkins et al. (1957) also recorded an unidentified species of this genus associated with alfalfa, barley, bean, carnation, clover, corn, grass, oat, pea, rye, strawberry, soybean, sweet potato, Timothy-grass, tobacco, tomato, vetch and wheat.

References

AgWeb. (2017). The lesion nematode, a major nematode species in corn in the U.S., prefers a higher clay content (Nematodes are everywhere, including in corn. https://www.agweb.com/article/nematodes-are-everywhere-including-in-corn-naa-sponsored-content/.

Allen, T.W., Bradley, C.A., Sisson, A. J., Byamukama, E., Chilvers, M. I., Coker, C. M., Collins, A. A., Damicone, J. P., Dorrance, A. E., Dufault, N. S., Esker, P. D., Faske, T. R., Giesler, L. J., Grybauskas, A. P., Hershman, D. E., Hollier, C. A., Isakeit, T., Jardine, D. J., Kelly, H. M., Kemerait, R. C., Kleczewski, N. M., Koenning, S. R., Kurle, J. E., Malvick, D. K., Markell, S. G., Mehl, H. L., Mueller, D. S., Mueller, J. D., Mulrooney, R. P., Nelson, B. D., Newman, M. A., Osborne, L., Overstreet, C., Padgett, G. B., Phipps, P. M., Price, P. P., Sikora, E. J., Smith, D. L., Spurlock, T. N., Tande, C. A., Tenuta, A. U., Wise, K. A., Wrather, J. A. (2017). Soybean yield loss estimates due to diseases in the United States and Ontario, Canada, from 2010 to 2014. *Plant Health Progress*. April 2017. 13 April 2018. St. Paul MN USA, ISSN 1535-1025.

Bernard, E. C., & Keyserling, M. L. (1985). Reproduction of root knot, lesion, spiral and soybean cyst on sunflower. *Plant Disease, 69*, 103–105.

Brust, G., & Rane, K. (2012). Garlic bloat nematode found in several garlic samples. University of Maryland Extension Bulletin.

Cadwallader, C. (2010). Delaware agriculture. https://www.nass.usda.gov/Statistics_by_State/Delaware/Publications/DE%20Ag%20Brochure_web.pdf.

Cavigelli, M. A., Lengick, L. L., Buyer, J. S., Fravel, D., Handoo, Z., McCarty, G., Millner, P., Sikora, L., Wright, S., Vinyad, B., Rabenhorst, R., et al. (2005). Landscape level variation in soil resources and microbial properties in a no-till corn field. *Applied Soil Ecology, 29*, 99–123.

Christy, M., & Mulrooney, R. P. (2011). *Managing root knot nematodes.* University of Delaware Cooperative Extension Online https://extension.udel.edu/weeklycropupdate/?p=2860.

Crow, W. T. (2005). Diagnosis of *Trichodorus obtusus* and *Paratrichodorus minor* on turf grasses in the Southeastern United States. Plant Management Network.

Crow, W. T., & Brammer, A. S. (2015). *Common name: Lance nematode scientific name: Hoplolaimus galeatus (Cobb*, *1913) Thorne*, *1935 (Nematoda: Tylenchida: Tylenchoidea: Hoplolaimidae)*. UF/IFAS.

Crow, R. V., & MacDonald, D. H. (1976). Phytoparasitic nematodes adjacent to established strawberry plantations 1, Paper No. 9661, Scientific Journal Series, Minnesota Agricultural Experiment Station. St. Paul: University of Minnesota.

Do. (2014). Delaware agriculture: A to Z. https://www.delawareonline.com/story/life/did-you-know/2014/11/12/delaware-agriculture-z/18899007/.

Edward, B., Dively, G., Dutky, E., Mulrooney, R., Sardanelli, S., Whalen, J. (2002). *Crop profile for potatoes in Maryland*. http://www.ipmcenters.org/cropprofiles/docs/mdpotato.pdf.

Elling, A. A. (2013). Major emerging problems with minor *Meloidogyne* species. *Phytopathology, 103*, 1092–1102.

Ernest, E., & Johnson, G. (2014). Managing root knot nematode. University of Delaware, Extension. Bulletin.

Esser, R. P. (1966). Nematode attacking plants above the soil surface. Nematology Circulation no 5. Florida Department of Agriculture.

Evans, T. A., Miller, L. C., Vasilas, B. L., Taylor, R. W., & Mulrooney, R. P. (2007). Management of *Xiphinema americanum* and soybean severe stunt in soybean using crop rotation. *Plant Disease, 91*, 216–219.

Everts, K. L., Sardanelli, S., Kratochvil, R. J., Armentrout, D. K., & Gallagher, L. E. (2006). Root knot and root lesion nematode suppression by cover crops, poultry litter, and poultry litter compost. *Plant Disease, 90*, 487–492.

Feldmesser, J., & Golden, A. M. (1972). Control of nematodes damaging home lawn grass in two counties of Maryland. *Plant Disease Report, 56*, 476–480.

Golden, A. M. (1956). Taxonomy of the spiral nematodes (*Rotylenchus* and *Helicotylenchus*) and the developmental stages and host parasite relationships of *R. buxophilus* n. sp, attacking boxwood. Maryland Agri. Experiment Station Bulletin A. 85. 28 P.

Golden, A. M., & Rebois, R. V. (1978). Nematodes on soybean in Maryland. *Plant Disease Report, 62*, 430–432.

Handoo, Z. A., Huettel, R. N., & Golden, A. M. (1993). Description and SEM observations of *Meloidogyne sasseri* n. sp. (Nematoda: Meloidogynidae), parasitizing beachgrasses. *Journal of Nematology, 25*(4), 628–641.

Handoo, Z. A., Skantar, A. M., & Mulrooney, R. P. (2010). First report of the sting nematode *Belonolaimus longicaudatus* on soybean in Delaware. *Plant disease: an international journal of applied plant pathology, 94*(1). https://doi.org/10.1094/PDIS-94-l-0133B.

Hashmi, S., Krusberg, L. R., Sardanelli, S., et al. (1993). Reproduction of *Heterodera zeae* and its suppression of corn plant growth as affected by temperature. *Journal of Nematology, 25*, 55–58.

Horst, R. K. (2008). Plant diseases and their pathogens. *Westcott's Plant Disease Hand Book 6th edition*.

Hutzell, P. A., & Krusberg, L. R. (1990). Temperature and the life cycle of *Heterodera zeae*. *Journal of Nematology, 29*, 414–417.

Jenkins, W. R., Taylor, D. P., & Rohde, R. A. (1956). A preliminary report of nematodes found on corn, tobacco, and soybean in Maryland. *Plant Disease Report, 40*, 37–38.

Jenkins, W. R., Taylor, D. P., Rohde, R. A., Coursen, B. W, et al. (1957). Nematodes associated with crop plants in Maryland. Bulletin/University of Maryland, Agricultural Experiment Station. A-89(1957). P25.

Kaplan, I., Sardanelli, S., & Denno, R. F. (2008). Field evidence for indirect interactions between foliar-feeding insect and root-feeding nematode communities on *Nicotiana tabacum* journal compilation. *Ecological Entomology, 34*, 262–270.

Kness, A., & Kleczewski, N. M. (2015). UD nematode assay service summary. In: N. Kleczewski & K. Everts (Eds.), *Applied research results on field crop and vegetable disease control P49*. University of Extension. https://desoybeans.org/hmi/wp-content/uploads/2017/02/KleczewskiAppliedResearchBooklet2015v2.pdf.

Kohl, L. M. (2011). Foliar nematodes: A summary of biology and control with a compilation of host range. *Plant Health Progress*. https://doi.org/10.1094/PHP-2011-1129-01-RV.

Kratochvil, R. J., Sardanelli, S., Everts, K., & Gallagher, E. (2004). Evaluation of crop rotation and other cultural practices for management of root knot and lesion nematodes. *Agronomy Journal, 96*, 1419–1428.

Krusberg, L., & Sardnelli, S. (1989). Survival of *Heterodera zeae* in soil in the field and in the laboratory 1. *Journal of Nematology, 21*(3), 347–355.

Krusberg, L. R., Sardanelli, S., Grybauskas, A. P., et al. (1997). Damage potential of *Heterodera zeae* to *Zea mays* as affected by edaphic factors. *Fundamentals of Applied Nematology, 20*, 593–599.

Kunkel, B. (2010). Foliar nematodes (*Aphelenchoides* sp.). https://www.forestryimages.org/browse/detail.cfm?imgnum=5429861.

Lamberti, F., & Bleve-Zacheo, T. (1979). Studies on *Xiphinema americanum sensu lato* with descriptions of 15 new species (Nematoda, Longidoridae). *Nematologia Mediterranea, 7*, 51–106.

Leukel, R. W. (1957). Nematode disease of wheat and rye. USDA Farmers Bulletin, 1607.

Lewis, S. A., & Golden, A. M. (1980). Description and SEM observations of *Dolichodorus marylandicus* sp. n. with a key to species of *Dolichodoru*s. Contribution No. 1800 of the South Carolina Agricultural Experiment Station.

MacGrown. (1981). *Heterodera zeae*, a cyst nematode of corn. Nematology Circulation no 77. University of Florida.

MDA. (2015). Annual report 2015. Maryland Department of Agriculture. http://mda.maryland.gov/Documents/15mda_ar.pdf.

Mervalin, A., Morant, J. L., Casola, C. B., Brooks, E., Philip, V., & Mitchell, G. (1997). Poultry litter enhances soybean productivity in field infested with soybean cyst nematode. *Journal of Sustainable Agriculture, 11*, 39–51.

MGGA. (2014). Maryland grape growers association. Annual report. http://www.marylandgrapes.org/ https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_State_Level/Maryland/.

Mulrooney, R. P. (2011). *Soybean cyst nematode*. University of Delaware, Extension bulletin PP 02. http://extension.udel.edu/factsheets/soybean-cyst-nematode/.

Mulrooney, R. P. (2012a). Nematode control recommendations for soybean 112012, nematode control recommendations for corn. University of Delaware Extension Bulletin.

Mulrooney, R. P. (2012b). Nematode control recommendation for corn. http://webcache.googleusercontent.com/search?q=cache:42Y5cXpPP3oJ:s3.amazonaws.com/udextension/ag/files/2012/05/Nematode-Control-Corn-11-2012.doc+andcd=1andhl=enandct=clnkandgl=us.

Mulrooney, R., & Gregory, N. (2010). Nematode Assay Service 2010 Report Cooperative Extension Service Department of Plant and Soil Science University of Delaware. In R. P. Mulrooney (Ed.), Plant pathology field trial results 2010 plant diagnostic clinic report nematode assay service report. Extension Plant Pathologist Nancy F. Gregory, Plant Diagnostician.

Mulvey, R. H., & Golden, A. M. (1983). An illustrated key to the cyst-forming genera and species of Heteroderidae in the Western Hemisphere with species morphometrics and distribution. *Journal of Nematology, 15*, 1–59.

Norton, D. C., & Hoffmann, J. K. (1975). *Longidorus breviannulatus* n. sp. (Nematoda: Longidoridae) associated with stunted corn in Iowa. *Journal of Nematology, 7*, 168–171.

Nyczepir, A. P., Bertrand, P. F., Miller, R. W., Motsinger, R. E., et al. (1985). Incidence of *Criconemella* spp . and peach orchards histories in short-life and non-short life sites in Georgia and South Carolina. *Plant Disease, 69*, 847–877.

Pokharel, R. R., & Reighard, G. L. (2015). Evaluation of biofumigation, soil solarization and rootstock on peach replant disease. https://doi.org/10.17660/ActaHortic.2015.1084.78.

Randhawa, R. (2017). *Anguina tritici* (Steinbach, 1799), Chitwood, 1935. Wheat seed gall nematode. California Pest Rating. California Department of Agriculture. http://blogs.cdfa.ca.gov/S/?p=3446.

Ringer, C. E., Sardanelli, S., & Krusberg, L. R. (1987). Investigations of the host range of the corn cyst nematode, *Heterodera zeae*, from Maryland. *Journal of Nematology, 19*, 97–106.

Sardanelli, S., Krusberg, L. R., & Golden, A. M. (1981). Corn cyst nematode, *Heterodera zeae*, in the United States. *Plant Disease, 65*, 622.

Sardanelli, S. L., Krusberg, L. R., Kantzes, J. G., & Hutzell, P. A. (1982). Soybean cyst nematode, fact sheet 340. College Park: Maryland Cooperative Extension Service.

SARE. (2005). Cultural practices for root knot and root lesion nematode suppression in vegetable crop rotations. Sustainable Agriculture and Research and Extension. http://www.sare.org/Learning-Center/Fact-Sheets/Cultural-Practices-for-Root knot-and-Root lesion-Nematode-Suppression-in-Vegetable-Crop-Rotations.

Sasser, J. N. (1954). Identification and host parasite relationship of certain root knot nematodes (*Meloidogyne*). *University of Maryland Agricultural Experiment Station Bulletin A, 77*:1–31.

Sasser, J. N., & Carter, C. C. (1985). Overview of the international *Meloidogyne* project 1975–1984. In J. N. Sasser & C. C. Carter (Eds.), *An advanced treatise on Meloidogyne* (pp. 19–24). Raleigh: North Carolina State University Graphics.

Sindermann, A., Williams, G., Sardanelli, S., & Krusberg, L. R. (1993). Survey for *Heterodera glycines* in Maryland. *Journal of Nematology, 25*, 887–889.

Smiley, R. W., Merrifield, K., Patterson, L. M., Whittaker, R. G., Gourlie, J. A., Easley, S. A., et al. (2004). Nematodes in dryland field crops in the Semiarid Pacific Northwest United States. *Journal of Nematology, 36*, 54–68.

Traunfeld, J. (1998). Root knot nematodes and vegetable crops. University of Maryland. Extension Bulletion HG 77 1999.

USDA. (2014). Widely prevalent nematodes in the United States. Data provided by Society of Nematology Widely Prevalent Plant Pathogenic Nematode Committee. https://www.prevalentnematodes.org/about.cfm.

USDA. (2017). U.S. Department of Agriculture's 2012 census of agriculture. https://www.agcensus.usda.gov/.

Wojtowlcz, M. R., Golden, A. M., Forer, L. B., & Stouffer, R. F. (1982). Morphological comparisons between *Xiphinema rivesi* Dalmasso and *X. americanum* Cobb populations from the Eastern United States' populations. *Journal of Nematology, 14*, 511–516.