Chapter 2
Plant Parasitic Nematodes of New York, New Jersey and Pennsylvania

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2.1 Introduction

New York, New Jersey and Pennsylvania have diverse geologies and geographies including forests, rivers, mountains, lakes and associated rural, suburban and urban communities. Their plant agriculture also varies widely with numerous fruit, vegetable and agronomic crops grown on coarse-textured to fine-textured and organic soils. The population density of more than 40 million people allows for vibrant ornamental and recreational plant industries. Plant parasitic nematodes are known to be associated with most, if not all of these ecosystems. Some of these nematode species are key limiting factors of major economic significance and have a sound associated research base. Relatively little, however, is known about the majority of the species of plant parasitic nematodes that exist in New York, New Jersey and Pennsylvania ecosystems. The first report of a plant parasitic nematode in the region was *Meloidogyne* sp. identified in New Jersey by Halstead in 1891 (Mai 1995).

The Science of Nematology in New York, New Jersey and Pennsylvania is diverse. The Widely Prevalent Nematodes of the United States (WPNL, NY-2011, NJ-2014, PA-2015) lists 77, 52 and 49 species as being present in Pennsylvania, New Jersey and New York, respectively. While the discovery of *Globodera*

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rostochiensis in New York in 1941 formed the basis of a strong nematology program at Cornell University (Mai and Lownsberry 1946), the January 23, 1956, organization of the Regional Research Project entitled, *Cultural and Chemical Control of Soil-Borne Pests* (NE-34) served as a major catalyst for nematology research and Extension in the region (Jenkins et al. 1963). The project was renewed and renamed on July 1, 1960, as the *Biology of Plant Parasitic and Soil Inhabiting Nematodes*. By 1963, there were six nematology courses taught among the three states; with nematodes being covered in seven other courses. In addition, 29 graduate students had been trained and *circa* 4000 h devoted to Extension programming. In 2017, this project, *Role of Plant parasitic Nematodes and Nematode Management in Biologically Based Agriculture* (NE-1640) is the oldest continuous Regional Research project in the U.S. Two of its many significant developments were the centrifugation-flotation technique for recovering nematodes from soil (Jenkins 1964) and pioneering nematode tissue culture research by Tiner (1961), both from Rutgers University. Pennsylvania State University provided early leadership for turfgrass nematology (Couch and Bloom 1959; Bloom 1961).

The objective of Plant Parasitic Nematodes of New York, New Jersey and Pennsylvania is to document the history, distribution, economic significance and management of the key species through summaries of published research. It is organized around sedentary endoparasites, migratory endoparasites and ectoparasites of root tissues and shoot system tissue parasites of major economic significance. Species presumed to be of less significance, but known to exist from various surveys, collections and the Widely Prevalent Nematodes of the United States database are included for these states. The topics of virus vector relationships, predisposition agents and nematode management are described in the appropriate parasitism sections.

2.2 Sedentary Endoparasites

2.2.1 Potato Cyst Nematode

The golden nematode, *Globodera rostochiensis* is a cyst-forming parasite of potato plants that originated in the center of diversity of potatoes in the Andes of South America (Mai 1977). The golden nematode has been widely distributed in many of the world's potato producing countries including much of Europe (Evans and Trudgill 1978), but this nematode and a closely related species, *Globodera pallida* are still of world-wide regulatory concern due to the severity of yield losses associated with infestations (Mai 1977). *Globodera rostochiensis* was first identified in the United States in New York State in July of 1941 when it was observed as the cause of severe stunting and yield loss in a Long Island Nassau County potato field (Cannon 1941). At that time, it had been present for years and was causing up to 70% yield loss in the affected area (Chitwood et al. 1942). Surveys of potato fields throughout Long Island demonstrated its spread, likely from that first infested field (Spears 1968). Quarantine measures were put into place by 1944 to restrict further spread. A new location, however, was discovered in Steuben County in upstate New York in 1967 (Mai 1977). Surveys of other potato producing states discovered small infestations in Delaware and New Jersey that were contained and permanently managed by taking the fields out of agricultural production.

A unique cooperative effort between the USDA/APHIS, USDA/ARS, New York State Department of Agriculture and Markets, Cornell University, New York State counties and towns and the New York State potato industry have successfully conducted a long-term program that combines regulatory and research efforts for survey and inspection, sanitation, and management. Management is designed to minimize the spread of cysts from infested fields and continually suppress nematode populations. For years, the golden nematode continued to be detected in additional locations in New York and it seemed as though regulators were chasing the pest. Sound sanitation and management systems developed by the research program, however, ultimately reduced nematode populations and limited spread. The long-term success of the program was demonstrated by cyst nematode population reduction to the point that potato fields were eventually deregulated. Beginning in 2010, some townships in New York were deregulated and released from the Golden Nematode Quarantine area (Kepich 2011). By 2015, it was reported that the Golden Nematode quarantine area had been reduced by 140,672 ha in nine counties to 2503 ha located in parts of eight New York counties (Kepich 2016).

While easily summarized, the Golden Nematode Regulatory Program in New York was a massive cooperative undertaking. Surveys are expensive and time-consuming. Quarantine and sanitation regulations were sometimes seen by growers as overly restrictive, and research progress required an integrated team approach and decades of effort (Mai and Spears 1954). The quarantine was initially put in place in 1944 and the first deregulation of potato fields still in production in quarantined areas did not happen until 2010. State and federal regulatory officials continue to conduct soil surveys and work toward deregulating additional areas which prove to be free of Golden Nematode infestations.

The Golden Nematode Program was deemed necessary as *G. rostochiensis* can be very damaging, and capable of causing total yield loss. The golden nematode can be easily spread to new locations as each cyst can contain hundreds of eggs which can survive desiccation and be easily moved in soil adhering to equipment, potato tubers, shoes or anything capable of moving soil. Each cyst can potentially transport a small population capable of starting a new infestation (Brodie 1993). Management of the nematode can be extremely difficult as a result of several unique features of its life cycle. Encysted juveniles within eggshells deposited in a new location may remain quiescent for years until stimulated to hatch by suitable environmental conditions and more importantly, recognition of host roots by the presence of an unknown chemical hatching stimulant, usually produced by potato plant roots (Fenwick and Widdowson 1959; Devine and Jones 2003). It may take years for nematode populations to reach damaging levels, even with continuous production of a suitable host. Few or no diagnostic symptoms are evident at low population densities. Even at low population densities, spread may occur as movement of a single cyst relocates many individuals and has the potential to start a new infestation in a new location (Brodie 1993).

Regulatory survey efforts concentrated on detecting new locations as early as possible (Spears 1968). Any field found to be infested and associated fields exposed to infestation were subject to quarantine regulations (Spears 1968). Population reduction procedures were initiated immediately. Control tactics and research efforts were not aimed at managing the pest to avoid yield losses as was done in many countries, but rather at eradication. Later, the long-term approach of continually reducing populations to maintain nematode population densities below detectable levels was used to reduce the probability of spread to fields in non-infested areas. One highly successful outcome of this intensive effort to reduce spread was that no potato grower in New York has experienced any level of yield loss due to the nematode since 1946 (Spears 1968; Brodie and Mai 1989).

2.2.1.1 Management Strategies

Management of the golden nematode initially focused on crop rotation away from host plants such as potato and tomato. Crop rotation alone did not allow an increase in nematode numbers, but was also relatively ineffective in reducing populations. Few juveniles hatched from cysts in the absence of a host and the hatch stimulation produced by host plant roots. Rotation required four or more years of cereals or other non-host crops to be effective (Mai and Lownsbery 1948; Mai and Harrison 1960). This was not practical for potato growers and the presence of solanaceous weeds during rotations could allow population increases and jeopardize control (Sullivan et al. 2007). Nematicides were included in the program in the 1940s. The soil fumigant dichloropropene-dichloropropane was quickly established as the most effective chemical product to reduce populations in fields where infestations were detected. Since fumigant nematicides are less effective near the soil surface where gases escape before nematode control can be achieved, fields were fumigated twice, 10 days apart, and the soil was turned between applications (Brodie and Mai 1989). Non-fumigant nematicides were investigated and incorporated as an additional tool in the management program in 1974 (Brodie 1980).

Breeding for plant resistance to the golden nematode in New York got its start when Ellenby (1954) identified a clone of *Solanum tuberosum* subsp. *andigena* that did not support reproduction and transferred that resistance into commercial *Solanum tuberosum* potatoes. This single dominant gene for resistance (H1 gene) was effective against the only pathotype present in New York at that time (Ro1). It was widely used in the Cornell potato breeding program to develop a range of varieties with resistance to *G. rostochiensis* Ro1. The first golden nematode resistant variety was released in 1966 as 'Peconic' (Peterson and Plaisted 1966). Since that time, over 20 varieties have been released in New York with the H1 gene for Golden Nematode resistance.

During the 1980s, concerns about environmental risks and contamination of groundwater with nematicides shifted the approach to management of the golden nematode away from chemical control to biological control, utilizing potato plant resistance and non-host crops. Plant resistance is very effective. Resistant plants stimulate nematode hatch, but do not allow feeding cell development, preventing reproduction of the nematode. A 4-year rotation cycle in soils with very low nematode populations (below 4 eggs/1 cm^3 of soil) consisting of two seasons of growing resistant potatoes followed by a non-host and then a susceptible potato crop, resulted in an overall population decline (Brodie 1996a; LaMondia and Brodie 1986). This strategy successfully reduced populations to the point where the nematode was eradicated from much of the quarantined acreage as stated above. The *G. rostochiensis* populations in the United States were believed to only consist of pathotype Ro1, which does not reproduce on potatoes with the H1 resistance gene, however, long-term exposure to that single source of resistance selected for an Ro2 pathotype, which was likely already present in certain locations (Belair and Simard 2009). The first indication of atypical reproduction on H1 potatoes in research plots was reported in 1996 (Brodie 1996b). Management of Ro2 pathotype was limited to the use of non-host crops until potato varieties with resistance to both Ro1 and Ro2 become available. A breeding line 'NY-140' has been demonstrated to carry resistance to both pathotypes (Kepich 2016). It is a promising source of resistance for future management of the golden nematode. In addition, it has been shown that populations of the golden nematode associated with Peconic, a potato variety resistant to the golden nematode, are very sensitive to soil disturbance through cultivation practices and desiccation.

2.2.2 Sugar Beet Cyst Nematode

The sugar beet cyst nematode, *Heterodera schachtii* (SBCN) has a broad host range. It consists of over 218 plant species, that are mostly members of the plant families Chenopodiaceae and Cruciferae (Steele 1965). This nematode is worldwide in distribution and is considered the major limiting factor in the production of sugar beets wherever they are grown. The SBCN was first reported in New York in 1961, causing damage to table beets grown for beet greens on a farm near Syracuse, New York (Mai 1961). The first observation of severe damage caused by the SBCN in a commercial field, however, was made in 1970 on table beets in a field near Lyon, New York (Mai et al. 1972). The occurrence and damage of the SBCN on several vegetable crops was well known and documented in numerous production areas in the United States and elsewhere (Lear et al. 1966; Olthof et al. 1974; Radewald et al. 1971). SBCN is also known to exist in Pennsylvania (WPNL 2015).

Results of an extensive survey conducted in 1970–1971 showed that the SBCN was distributed throughout the table beet- and cabbage-growing regions of Central and Western New York (Mai et al. 1972). The highest level of SBCN infestation level detected in a commercial field was 190 eggs and juveniles per 1.0 cm^3 soil. The practice of returning soil and debris (tare soil) to be spread on production fields from beet- and cabbage-processing plants undoubtedly contributed greatly to the wide spread distribution of this nematode. The tare soil returned to the farm usually included soil and debris from the grower(s) that made the previous delivery to the plant. Fortunately, this practice was voluntarily discontinued.

2.2.2.1 Crop Damage

Susceptible crops in addition to table beets and cabbage include cauliflower, broccoli, brussel sprouts, turnip, spinach, rutabagas and radish. In addition, the nematode feeds and reproduces on several weed hosts including shepherd's purse, dock, chickweed, hen nettle and wild radish. Above-ground symptoms of severe SBCN on table beets and cabbage are not diagnostic and appear initially as poor and uneven growth (Fig. 2.1a). Diagnostic symptoms of discoloration and reduced size can be observed on roots (Fig. 2.1b), in addition to white immature females on the root surface. The developing white females can be seen with the naked eye, especially on the red colored beet roots (Fig. 2.1c). Beet roots of severely infected plants are misshapen and small, whereas cabbage heads are loose, light in weight and smaller in diameter (Fig. 2.1d). The white females continue to develop on the root, become dirty white in appearance and turn brown, hard and lemon-shaped with up to 500 eggs within each cyst. The mature cysts fall into the soil when the roots die or decay, where the eggs within the cyst can survive for 7–8 years in the absence of a host. On its own, this nematode is able to move only a few centimeters per year, but

Fig. 2.1 (**a**) Poor and uneven growth of table beets in a commercial field with high infestation of *H. schachtii*; (**b**) Infected cabbage roots with *H. schachtii* (right) are discolored and smaller; (**c**) White immature females of *H. schachtii* on the surface of table beet roots; (**d**) Heavy infection of cabbage plants with *H. schachtii* result in the production of heads that are small, loose and light in weight (right)

distribution within and between production fields is accomplished through movement of contaminated soil and infected root tissues on farm equipment, animals, surface running water or in infected transplants.

Extensive damage to cabbage and table beet by the SBCN was demonstrated under greenhouse and field conditions in New York (Mai et al. 1972; Abawi and Mai 1977, 1980, 1983). The significant damage observed was negatively correlated with the initial soil population of the SBCN. The damage threshold density under field conditions to both total and marketable yields of table beet and cabbage was about 6–9 eggs/1 cm^3 soil. The latter affected both the quality and quantity of marketable yield of both crops. Significant damage to these and other vegetables have been reported from other regions in the United Stated and elsewhere (Lear et al. 1966; Radewald et al. 1971; Olthof et al. 1974).

2.2.2.2 Management Strategies

Cost-effective management of the SBCN dictates the employment of a multi-tactic strategy. Such a strategy might involve two or more of the following measures: sanitation practices, monitoring of soil population densities, crop rotation and use of chemical or biological control products. It is usually easier to prevent field contamination than to manage SBCN-infested field soils and those of other long-surviving pathogens. Thus, it is critical to use only certified transplants of host crops that are free of SBCN as well as other pathogens, if transplants are required for crop establishment. Also, farm equipment and tools used on infested or suspect soils should be washed thoroughly and dried before entering non-infested fields.

It is highly recommended that target planting sites are sampled and analyzed to establish a base line data and to follow-up with annual assessment to monitor the changes in the population density of SBCN. This information is needed as a decision tool for adjusting the length of the crop rotation with non-host crops or determining the appropriate control products to keep populations below the economic threshold density. In the absence of resistant commercial varieties of cabbage, table beets and other vegetables, crop rotation with non-hosts (corn, wheat, beans, cucurbits and many others) becomes of great importance in the management of SBCN. Results of an extensive crop rotation experiment on a commercial farm in New York demonstrated that populations of the SBCN increased with a non-host:host crop rotations of 1:2 and 1:1; whereas it decreased with those of 2:1–5:1 (Mai and Abawi 1980). The length of the rotation with non-host crops required to decrease the population of the SBCN below the damage threshold density is dependent on the level of soil infestation. In addition, the status of cover crops used should be determined and incorporated in the rotation scheme. Bio-fumigant crops incorporated as green manures might be helpful and their effects on the population of the SBCN, if any, should also be assessed. Furthermore, for any rotational scheme to be effective, weed hosts of the SBCN should be also controlled in order to prevent the survival of the nematode.

Numerous fumigant and non-fumigant nematicides were found to be effective in reducing the population and damage of the SBCN on cabbage and other hosts (Lear et al. 1966; Radewald et al. 1971; Keplinger et al. 1979; Abawi and Mai 1983). Preplant soil fumigants are more effective in light-textured soils as compared to their effectiveness in heavy-textured soils such as those prevailing in the cabbage and table beet producing areas of New York. Fenamiphos was found to be cost-effective and was registered for use on cabbage against this nematode in New York. Overall, it will be best to implement an integrated approach in the management of the SBCN and as a component of needed sustainable soil health management practices.

2.2.3 Other Cyst Nematodes

The soybean cyst nematode (*Heterodera glycines*) is a key limiting factor in U.S. soybean production. It was first detected in New Jersey more than two decades ago and more recently identified in Pennsylvania. The initial find of the soybean cyst nematode in New York was in Cayuga County in 2016 (Wang et al. 2017). The clover cyst nematode (*Heterodera trifolii*) is the only other species currently reported from the three states.

2.2.4 Root Knot Nematodes

Species of root knot nematodes are major pathogens of many crops in diverse plant families and are widely distributed throughout the United States and the world (Sasser and Carter 1985; Mitkowski and Abawi 2003a). Published reports on the root knot nematodes in New York and neighboring states date back to the late nineteenth century (Newhall 1942). However, only the northern root knot nematode (*Meloidogyne hapla*, NRKN) has been documented as being able to survive the characteristically low winter temperatures in New York (Mikowski et al. 2002; Mitkowski and Abawi 2003b) and likely in similar production areas, resulting in natural infections and damage to host crops the following growing season. Other warm temperature species of root knot nematodes (*M. incognita*, *M. javanica* and others) have been introduced on planting materials and observed causing damage during the growing season of introduction. Observations and standard recovery tests documented their failure to survive and cause damage to host crops in the following season. In addition to NRKN, *M. graminis* and *M. graminicola* are recorded in the WPNL (2015) for New York, *M. arenaria* and *M. incognita* (WPNL 2014) for New Jersey and *M. incognita* and *M. javanica* for Pennsylvania (WPNL 2011).

2.2.4.1 Damage and Losses

More than 550 crop and weed species are hosts to the NRKN. Significant variation has been shown to occur among and within field populations throughout New York, as determined by reproductive fitness and severity of galling on lettuce as well as by its nuclear and mitochondrial genomes (Mitkowski and Abawi 2003c). Over the years, this nematode has been observed infecting soybean, alfalfa, clovers, many vegetables and weed species (including dandelion, purslane, mallow and plantain) and others. Severe infections and damage by the NRKN have occurred frequently in recent years on various crops grown in New York including carrots, onions, lettuce, potatoes, and others grown on both organic and mineral soils (Abawi and Laird 1994; Viaene and Abawi 1996). Above-ground symptoms on host crops growing in heavily infested soils exhibit general stunting and uneven growth in a patchy field pattern (Widmer et al. 1999; Fig. 2.2a–c). Severely infected plants may also exhibit nutrient deficiency symptoms, delayed maturity, wilting and reduced marketable yield and quality. The latter symptoms are due largely to the reduced ability of severely infected root systems to absorb and transport water and nutrients. The diagnostic symptoms of root knot infection occur on roots in the form of galls that are large and distinct on lettuce (Fig. 2.2d, e) to smaller knots or root thickenings on onion roots (Fig. 2.2f).

Based on the characteristic galls produced on lettuce, an on-farm bioassay was developed for visually assessing soil infestation with this nematode and implemented as a decision management tool by producers and land managers in New York (Gugino et al. 2008). Other symptoms resulting from root knot nematode infection are extensive branching, stubby and forked roots (Fig. 2.2g). Most of the life cycle of this endoparasitic nematode is completed within the root tissues of its hosts. The life cycle of this nematode can be completed in as a few as 17 days, depending on the host and soil temperature. Spread of this nematode can be accomplished mainly through water, planting materials and infested soil adhering to farm equipment, humans and animals.

Under heavy soil infestation levels and favorable conditions, the northern root knot nematode is capable, and has caused, significant yield losses in quantity and quality of several crops grown in New York. For example, extensive losses impacting farm profitability have occurred on carrots, lettuce, onion and other crops, that necessitated the implementation of cost-effective management practices (Viaene and Abawi 1996; Gugino et al. 2006; Abawi et al. 2003). Carrots are among the most susceptible crops for extreme damage caused by NRKN. Symptoms of infection can be detected as early as 4 days after planting in infested soil (Slinger and Bird 1978). The damage threshold level of NRKN on commercial carrot varieties under field conditions was estimated to be <1 egg per 1.0 cm^3 soil (Gugino et al. 2006). Marketable yield losses as high as 45% were documented. Severely infected carrot roots are stubby, forked with numerous galls and not marketable. The damage threshold density of NRKN on lettuce was calculated to be one to two eggs per 1.0 cm^3 of soil (Viaene and Abawi 1996). Severely infected lettuce plants are small, loose and fail to produce marketable size heads. Similarly, heavily infected onion

Fig. 2.2 (**a**) Lettuce plants growing in organic soil heavily infested with *M. hapla*, exhibiting uneven and stunted growth; (**b**) Stunted growth of onion plants in a section of a commercial field with high infestation of *M. hapla*; (**c**) Extreme stunting and damage of *M. hapla* to carrot in a section of a commercial field left as a check for the standard application of Vydate against this nematode; (**d**) Distinct and rather large galls induced by *M. hapla* on lettuce roots; (**e**) Close-up of a rootlet with several galls and mature females with egg sacs stained red; (**f**) Root thickenings induced by *M. hapla* on onion roots; (**g**) Severely infected carrot roots with *M. hapla* exhibiting a stubby growth, forking and hairiness

plants produce smaller bulbs with thicker necks and are delayed in maturity. NRKN reduces the storability of onions and complicates harvest, increasing costs. Potatoes and other crops are affected similarly by reducing the marketable yield and quality. In addition, species of root knot nematodes are known to interact with other soil-borne pathogens such as *Fusarium* spp., resulting in increased disease severity and yield losses (Mai and Abawi 1987; Abawi and Chen 1998).

2.2.4.2 Management Strategies

A sustainable and cost-effective integrated pest management strategy (IPM) is the most effective approach for control of NRKN. Although only limited practical management options are available, there still exist numerous combinations of these practical tactics for the control of this nematode. In general, these are compatible with overall soil health management practices (Abawi and Widmer 2000). Unfortunately, none of the commercial varieties of major crops evaluated including carrot, onion, lettuce, potato and soybean, are resistant to the NRKN (Abawi and Ludwig 2003a, b; Gugino et al. 2006; Abawi et al. 2006). Fortunately, grain crops are not hosts of NRKN. Rotating out of host crops for two or more years with field or sweet corn, wheat or other grains will effectively manage this nematode, as long as, host weeds are also controlled.

Use of grain cover crops such as rye grain, annual ryegrass, barley, oats, tall fescue or sudangrass, in the rotation will contribute to the management of the NRKN. In addition, the incorporation of green manures of sudangrass cv. Trudan in moist and warm soils was found highly effective in reducing the population and damage of the NRKN (Viane and Abawi 1998). Suppression of the NRKN by sudangrass was attributed to its content of the cyanogenic glucoside dhurrin that upon biological decomposition in soil results in the production of hydrogen cyanide (HCN), a potent biocide, especially against nematode eggs (Widmer and Abawi 2000). Interestingly, cultivars and hybrids of sudangrass differed considerably in their suppressiveness against the NRKN. This was found to be closely correlated with the level of cyanogenic dhurrin in their cell walls (Widmer and Abawi 2002). Similarly, the incorporation of green manures of rapeseed, *Tagetes patula* (cvs. Jupiter, Polynema and Nema-Gone) and several accessions of white clover and flax were also found to be effective. Selected white clover and flax cultivars are also cyanogenic and have a similar suppressive mechanism through the production of HCN. However, the bio-fumigant effect of incorporated green manures of rapeseed and other cruciferous crops are due to the production of the nematicidal products, isothiocyanates (Halbrendt 1996).

In addition, the application of corn silage, brewery compost, chicken manures and other organic amendments have often been found to suppress the NRKN and plant parasitic nematodes in general. Thus, it is critical to carefully consider soil organic matter management, as it has major implications on the soil biology, crop productivity and sustainable soil health management (Abawi and Widmer 2000; Widmer et al. 2002).

Several fungi were found associated with eggs and juveniles of *M. hapla* including *Hirsutella rhossiliensis* and *Pochonia chlomydosporia*, which were found effective in reducing penetration and population of NRKN (Viaene and Abawi 1998a, b, 2000). Other nematophagous fungi and bacterial antagonists including *Pasteuria* and *Bacillus* spp., have been reported with activities against plant parasitic nematodes, but currently available commercial products are not widely used in New York.

Pre-plant soil fumigation with Telone-C or Vapam is available for nematode control in New York. Fumigation is effective when applied properly, but it is not widely used. Of non-fumigant nematicides, application of Vydate (Oxamyl) at planting as a spray incorporated or as an in-furrow treatment has been widely used, especially on carrots, onions and potatoes (Gugino et al. 2006, 2008). Seed treatment with Abamectin® was also found effective against NRKN in several trials on tomato, carrot and onions (Abawi et al. 2003; Abawi and Ludwig 2005). Overall, the adoption of multiple management tactics and the monitoring of the infestation levels of the NRKN are critical factors in the cost-effective management of this key pathogen and its damage to numerous crops in New York.

2.3 Migratory Endoparasites

2.3.1 Root Lesion Nematodes

Root lesion nematodes (*Pratylenchus* spp.) are widely distributed throughout the world and particularly in the northern temperate regions. A large number of species of lesion nematodes have been reported and are known to have a wide host range consisting of more than 400 plant species. The latter include fruits (apples, cherries, peaches, pears and other crops), grain crops (corn, wheat, rye, oat, barley and other crops), legumes (alfalfa, clover, vetch, soybean), vegetables (potato, bean, onion, cabbage, carrot, tomato and other crops) and many species of weed plants. The earliest reports on the occurrence of lesions nematodes in New York State were in 1956 (Mai and Parker 1956). It was reported that lesion nematodes caused losses on cherry, and their role in the replant problem on cherry and other fruits was also suggested (Mai and Parker 1956; Parker and Mai 1956a, b). The first report describing the relationships between *P. penetrans* on vegetables (Wando peas) and corn in New York was in 1960 and 1963 respectively (Dolliver et al. 1960, Miller et al. 1963). DiEdwardo (1961) documented the seasonal population variations of *P. penetrans* associated with strawberry, while Abu-Gharbieh et al. (1963) reported a relationship between root lesion nematodes and *Verticillium* and Heald (1963) documented root lesion parasitism of woody ornamentals. In addition, the collaborative Northeast Nematology Regional Research Project focused on the biology, ecology, culturing and management of lesion nematodes in the northeast region and beyond. The significant results of the latter were summarized in a bulletin authored by project participants (Mai et al. 1977). In addition, *P. neglectus* was detected in New York in 1997 (Timper and Brodie 1997).

2.3.1.1 Crop Damage and Losses

Today, lesion nematodes are widely distributed throughout the agricultural production regions in New York and neighboring states. In addition, population densities of lesion nematodes have increased significantly in recent years and the trend is continuing. Undoubtedly, the latter is due to the recent promotion and adoption of using grain and legume crops in long-term soil health management programs (Abawi and Widmer 2000). Numerous attempts over the years to characterize the populations of lesion nematodes on fruits, vegetables and other crops have shown that the primary species involved is *P. penetrans*, although with some morphological variability such as the shape and length of tail (Troccoli et al. 2003). Foliar symptoms on severely infected plants are of general poor and uneven growth, chlorosis and delay in maturity (Figs. 2.3a, b). Depending on the host, roots of severely infected plants exhibit poor development, discoloration and lack of adequate numbers of fibrous roots. Brown to black and narrow lesions may be visible on root surfaces at an early stage of infection of some hosts including soybeans and potatoes (Fig. 2.3c). Heavily infected young fruit trees often fail to produce good frame roots (Fig. 2.3d) and also generally lack functional feeder roots. In addition, shoot and root system growth of pear (Fig. 2.3e) and those of other fruits were shown to be drastically reduced under soil infestation with *P. penetrans* in greenhouse tests. The involvement of other soil-borne pathogens and saprotrophic organisms results in increased discoloration, rotting and death of roots. For positive diagnosis and damage assessment, it is critical to extract and confirm the identity of lesion nematodes in roots and associated soil. These nematodes survive as eggs and adults in roots of host crops or in soil. Distribution of lesion nematodes within and between production fields is mainly in infested soil on farm equipment, surface water or wind as well as in infected planting materials.

At high population densities, lesion nematodes are capable of causing significant losses in the quality and quantity of yield of both annual and perennials crops, especially in sandy soils. For example, maturity of onion was delayed and bulb weight was reduced by as low as 100 *P. penetrans*/100 cm^3 of soil. Most importantly, lesion nematodes, especially *P. penetrans*, are involved in classical disease complexes including the replant diseases of fruit trees (Fig. 2.3f), early dying of potato, and black root of strawberries (Mai and Abawi 1978; Abawi and Chen 1998; LaMondia 2004). Results from a survey of 27 strawberry farms in New York did not show a close correlation between populations of *P. penetrans* and poor root growth (Wing et al. 1995). This might be due to the different biology of black root rot in New York and the heavy and wet soil conditions of the farms sampled. However, lesion nematodes at even a very low number are capable of increasing infection and damage of other soil-borne pathogens and also non-pathogens on many crops.

Fig. 2.3 (**a**) Uneven growth of potato in a commercial field due to heavy infestation with *P. penetrans* (courtesy of W. F. Mai); (**b**) Delay in maturity of onions (green plants) due to high infestation with *P. penetrans*; (**c**) Close-up of the characteristically brown to black and narrow lesions of *P. penetrans* on soybean roots; (**d**) Infection of young trees with a high population of *P. penetrans* contribute to the production of poor frame roots (right); (**e**) Growth of pear seedlings in soil infested with different levels of *P. penetrans* (0; 5000; 10,000; and 20,000/13 cm clay pots under greenhouse conditions (Courtesy of W. F. Mai); (**f**) Uneven growth of 6-year old peach trees in a replant disease site in Western New York (Courtesy of W. F. Mai)

2.3.1.2 Management Strategies

Due to the wide and diverse hosts of lesion nematodes as well as the limited number of available resistant crop cultivars, it is a challenge to develop cost-effective management programs for these nematodes. The best approach requires implementation of multiple control measures on an as-needed basis. Thus, it is important to monitor the population densities of lesion nematodes on both annual and perennial crops, especially close to planting times.

There has been a considerable focus on the use of narrow or broad spectrum preplant fumigants for controlling lesion nematodes, especially on fruit crops (Arneson and Mai 1976; Mai and Abawi 1981; Mai et al. 1994). Reduction of lesion nematode populations was greater and significantly higher crop yields were achieved by broad-spectrum fumigants such as Vorlex (methyl isothiocyanate), as compared to the benefits resulting from using narrow spectrum nematicides such as Telone (1,3-dichloropropene). The benefits of soil fumigants were further enhanced by adjusting soil fertility, controlling weeds or establishing a ground cover with poor hosts for lesion nematodes such as perennial ryegrass and tall fescue. Also, the use of several non-fumigant nematicides including Fenamiphos, Carbofuran and Vydate, have been shown to be effective in reducing the populations of lesion nematodes on several crops including fruits and vegetables. In addition, the foliar application of Vydate was demonstrated to be effective in reducing the numbers of the lesion nematodes in roots and in soil around roots of fruit trees (Abawi and Mai 1975). The use of Vydate against the lesion nematode on onion, potatoes and other vegetables is also common in New York. Depending on the target crop and the production system, other management options that might be of interest are the addition of various organic amendments, incorporation of green manures of bio-fumigant crops, summer fallow and flooding, solarization, use of tolerant rootstocks of apples and other fruits, use of poor hosts (selected cultivars of ryegrass, oat, marigold, sesbania, alfalfa, and others) or resistant cultivars (marigold cv. Sparky and a wild oat cv. Saia) in a rotation, where available. Unfortunately, all commercial crop cultivars grown in New York, including those of onions, potatoes, beans, clovers and wheat tested under artificial inoculation in the greenhouse in New York, were found to be susceptible, although there were differences in their efficiencies as hosts to the population of *P. penetrans* used.

2.4 Ectoparasites

2.4.1 Dagger Nematodes

Dagger nematodes (*Xiphinema* spp.) are commonly found in temperate production areas of the world, around roots of perennial and annual crops as well as many weeds. In New York, Pennsylvania and other neighboring states, the species of dagger nematodes most reported belong to the *X. americanum*-group complex and *X. rivesi* (Forer and Stouffer 1982; Jaffee et al. 1987a, b; Molinari et al. 2004). In addition, populations of *Xiphinema* spp. from New York orchards expressed morphological morphological variations (Georgi 1988). In New York State, these nematodes were found primarily associated with roots of fruit trees (apple, pear, cherry and peach), small fruits (blueberry, raspberry and strawberry) and grapes. All life stages (eggs, juveniles and adults) can survive in soil and are spread by infested soil on farm equipment, water and planting materials. It has been suggested that only one generation per year is completed in northern temperate regions and that nematode population density is greatly impacted by soil temperature, moisture and texture. These large, ectoparasitic nematodes feed in the region just behind the root tips and can reach the vascular tissues with their long stylets. At extremely high populations, dagger nematodes are capable of causing numerous lesions, necrosis and destruction of feeder roots that at times result in the poor development of young plants. However, the main impact of dagger nematodes is their efficient ability to transmit several viruses. *Xiphinema* spp. are vectors of nepoviruses. These include tomato and tobacco ring spot viruses, *peach yellow bud mosaic virus* and other highly destructive virus pathogens of many crops. In New York, dagger nematodes were demonstrated to vector viruses that damage grapes, highbush blueberry and several fruit trees (Uyemoto et al. 1977; Fuchs et al. 2009).

Tomato ringspot virus (ToRSV) and *Tobacco ringspot virus* (TRSV) are efficiently transmitted from one host to another by *X. americanum*. Both viruses are located in different areas within the esophageal lumen (Brown et al. 1994, 1995; Wang et al. 2002). ToRSV has been identified in fruit trees in the region and infects a large number of small fruit, vegetable, ornamental and tree crops including blueberry and grape in New York as well as weeds. A large number of broadleaf orchard weed hosts of *X. americanum* serve as reservoirs of ringspot viruses. ToRSV can be seed transmitted in dandelion and acquired from infected plants by dagger nematode feeding (Mountain et al. 1983).

2.4.1.1 Management Strategies

Management of dagger nematodes and the nematode virus complex is best conducted with an integrated approach (Fuchs 2016). Virus-free certified planting stock is imperative. Tolerant or resistant cultivars or rootstocks should be used, if possible. Weed management in orchards is important as a means of reducing the presence and spread of virus reservoirs, and finally, reducing dagger nematode numbers is also critical, especially as disease incidence is not necessarily correlated with nematode numbers; individual nematodes may transmit virus. Limiting movement of soils between orchards or vineyards can also limit the distribution of viruliferous dagger nematodes. Management of dagger nematodes has historically relied on fumigant nematicides applied prior to orchard establishment and nonfumigant nematicides applied after planting (Halbrendt and Jing 1994; Bello et al. 2004; Halbrendt 2012).

More effective and practical nonchemical controls may include physical and biological tactics. While peach stem pitting has been known for a long time, its incidence increased when the cultural practices in orchards changed from mechanical cultivation of the entire orchard floor to eliminate weeds to establishing sod between rows and maintenance of weed-free strips within rows using herbicides to reduce compaction and soil erosion (Powell et al. 1982). Mechanical cultivation can reduce numbers of perennial weed hosts of nepo viruses such as dandelion, and also directly reduce population densities of dagger nematodes.

Biofumigation, as a form of allelopathy, has been demonstrated as an effective means of reducing the size of dagger nematode populations (Halbrendt and Jing 1994; Halbrendt 1996, 2012; Bello et al. 2004). Experiments in replanted orchard soils in Pennsylvania demonstrated that incorporation of a rapeseed rotation crop that released allelopathic nematicidal chemicals reduced dagger nematode numbers (Halbrendt 1996). Two rotations within a single year, an autumn planting of a winter rapeseed variety that was incorporated in the spring followed by a spring planting after 1 or 2 weeks that was incorporated in late summer, were as effective as a nematicide application (Halbrendt and Jing 1994; Jing 1994).

John Halbrendt's nematology research program at the Bigglerville Research Station of Pennsylvania State University was devoted to understanding the biology and control of dagger nematodes and virus diseases of peach trees and grape vines. Brown et al. (1994) demonstrated four *Xiphinema* spp. including three populations of the *X. americanum*-group and *X. rivesi,* as vectors of four North American nepoviruses. These included two strains of ToRSV, TRSV and *Cherry rasp leaf virus*. *Xiphinema rivesi*, however, was a more efficient vector than the other three species. Halbrendt's virus disease control research focused on prevention (removing virus reservoirs, testing for *Xiphinema*, evaluating site history and planting only certified virus-free vines or trees) and containment (removing symptomatic vines or trees and reducing the population density with chemical or biological procedures such as appropriate site preparation techniques). A significant amount of this research was pioneering work in respect to the potential roles of cover crops. In addition, it is important to note that fumigant- and non-fumigant-type nematicides are highly effective in reducing the numbers of dagger nematodes.

2.4.2 Stubby Root Nematodes

The nematode family Trichodoridae includes more than 95 species classified in five genera. The species currently recognized in the three states are all classified in the genera *Trichodorus, Paratrichodorus* and *Nanidorus.* The Widely Prevalent Nematode List (2014) includes *N. minor*, *P. nanus*, *P. pachydermus*, *P. porosus*, *T. aequalis* and *T. obscurus* for Pennsylvania, *P. nanus* and *P. pachydermus* for New Jersey and *N. minor* for New York. Species of the Trichodoridae vector short rod-shaped, single-stranded viruses (tobraviruses) that are severe pathogens of plants including potato which is widely grown in New York, Pennsylvania and New Jersey where the trichodoroid virus vectors are known to exist.

In the early 1960s, stubby root nematodes were a key limiting factor in onion production in organic soils in New York. Hoff and Mai (1962) documented the pathogenicity of *N. minor* on *Allium cepa*, and in 1967–1968, Bird and Mai published a series of articles on the embryogenesis, morphology, allometry and ecology of *N. minor* (Bird and Mai 1967a, b, 1968; Bird et al. 1968). They also published a numerical taxonomy of the family Trichodoridae and described a pointed tail stubby-root nematode, *Trichodorus acutus* (Bird 1967), from a population detected in the Cornell University Botanical Greenhouse. *Trichodorus acutus* has since been reported in nature in a number of localities worldwide.

2.4.3 Other Ectoparasites

The first report of ectoparasitic nematodes in New Jersey was made by Hutchinson et al. (1961). Bird and Jenkins (1964) identified 19 species of plant parasitic nematodes associated with *Vaccinium macrocaarpon* in cranberry bogs in New Jersey. They included *Atylenchus decalineatus, Mesocriconemas xenoplax, M. curvatum, Criconemoides* sp.*, Ditylenchus* sp.*, Helicotylenchus* sp.*, Hemicycliophora similis, H. gracilis, Hemicycliophora* sp.*, Hoplolaimus galeatus, Paratylenchus projectus, Rotylenchus uniformis, Scutellonema brachyurus, Tetylenchus joctus, Tylenchorhynchus dubius* and *T. maximus*. *Atylenchus decalineatus* was recovered from 80% of the 49 cranberry bogs included in the survey. *Atylenchus decalineaus* and *M. hapla* were the only two species that did not increase in population density in the associated parasitism studies and *M. curvatum, M. xenoplax,* and *H. similis* were pathogenic under greenhouse conditions. Jaffee et al. (1987a, b) reported on *M. curvatum* and *M. ornatum* associated with peach orchards in Pennsylvania.

Although the majority of the plant parasitic nematodes currently known to exist in New York, New Jersey and Pennsylvania are ectoparasites, relatively little is known about their specific biology and host parasite relationships in these states. Based on the Widely Prevalent Nematode List (2011, 2014, 2015) 77%, 65% and 51% of the species known to exit in New Jersey, Pennsylvania and New York, respectively, are ectoparasites. Species that are likely to be key pathogens in one or more of the three states, but not studied in detail include *Belonolaimus longicaudatus, Dolichodorus heterocephalus, D. marylandicus, Longidorus brevannulatus* and *L. elongatus*.

2.5 Shoot System Parasites

Seven species of shoot system tissue-feeding nematodes have been reported from New York, New Jersey or Pennsylvania. These include the stem and bulb nematode (*Ditylenchus dipsaci*), foliar nematodes (*Aphelenchoides ritzemabosi*, *A. fragariae, A. parietinus* and *A. besseyi*), seed gall nematodes (*Anguina* spp.) and potato rot nematode (*Ditylenchus destructor*). All of these can be highly destructive pathogens under the right conditions at specific locations. The stem and bulb nematode is a key pathogen and has been documented and researched extensively in New York. None of the other species have been documented or thoroughly researched in regards to their specific populations and relationships in the three states covered in this chapter.

2.5.1 Stem and Bulb Nematode

The stem and bulb (bloat) nematode, *Ditylenchus dipsaci,* is a destructive plant parasitic nematode of many crops, including onion, garlic and leek. It is widely distributed in temperate production regions of the world and has been known and studied extensively in Europe since 1877. In addition, this nematode occurs in many biological races with different host ranges and crop damage potential (Esquibet et al. 2003; Subbotin et al. 2005; Qiao et al. 2013). In addition to infecting garlics, onions, leeks, and chives, the garlic and onion race of *D. dipsaci* is reported to attack celery, certain varieties of peas and lettuce, hairy nightshade, Canada thistle, flower bulbs and several other plant species (Hooper and Southey 1978). The first report of the stem nematode in the United States was in 1929, when it was found damaging onions on a farm in Canastota, Madison County, New York, and again in 1939 on farms in Pine Island and Florida in Orange County, New York (Newhall et al. 1939; Newhall and Chitwood 1940). Severe infection and damage by the stem nematode to garlic was observed on a commercial farm in western New York in June 2010 (Abawi et al. 2011). The damage to garlic by the stem nematodes was reported from several other Northeastern states and Ontario, Canada and confirmed in 2011–2014 by the Nematode Diagnostic Service laboratory at Cornell University (Mountain 1957; Colett 2010; Johnson and Fuller 2012; Abawi pers. comm.).

Until the early 1960s, the stem nematode was widely distributed and caused economic losses to onions grown on organic soil throughout production regions in New York. The latter resulted in extensive research efforts to study the biology and management of this nematode (Lewis and Mai 1958, 1960; Mai et al. 1964; Smith and Mai 1964). Direct-seeding of onions was promoted and rapidly adopted by growers in the mid 1960s. This was done to avoid stem nematode damage as well as bacterial and fungal diseases that were associated with the use bulb sets at planting material. Since the use of true seeds of onions, damage by the stem nematode was rarely observed under commercial field conditions. A survey conducted shortly after the 2010 destructive outbreak of the stem nematode on garlic, clearly demonstrated that this nematode is widely distributed on garlic grown throughout New York (Abawi et al. 2011). It was recovered from garlic samples collected from 17 counties, with population densities as high as 3609/1 g of garlic tissue. The WPNL records *D. dipsaci* in Pennsylvania under the common name of alfalfa stem nematode (WPNL 2011), but not prevalent in New Jersey (WPNL 2015). A report by Pethybridge *et al.* (2016) confirmed the identity of the isolates recovered from infected garlic as *D. dipsaci* with extreme genetic uniformity. Only one isolate included in their study exhibited differences to those of *D. dipsaci* and only 97% similarity to *D. destructor*, thus it was labelled as *Ditylenchus* sp. The genetic uniformity of the characterized populations of the stem nematode suggested that a major introduction source was likely the cause of the latest infestation in garlic.

Vegetative propagation of garlic is continuing and seed exchanges and purchases among producers are of common occurrence. Unfortunately, early and light infestations of garlic bulbs by the stem nematode are symptomless. However, garlic plants severely infected by the stem nematode exhibit stunting, yellowing, collapse of leaves and premature dying. Infected bulbs initially show light discoloration, but later the entire bulb or individual cloves become dark brown, soft, sunken and light in weight. At later stages, infected bulbs may show cracks at the basal plate and various symptoms of decay resulting from the activities of other saprotrophic soil-borne organisms (Fig. 2.4a). Stem nematode infected onions and other hosts also show distinct swellings, twisting, and deformation of leaves, stems, bulbs and other foliar tissues. Severely infected seedlings and older plants may die before harvest (Fig. 2.4b).

2.5.1.1 Crop Damage and Losses

Infection and damage by the stem nematode significantly impacted onion production and profitability until the early 1960s. Currently, the stem nematode is a major constraint in garlic production. Yield losses as high as 100% have been observed in a few plantings. Symptomatic garlic bulbs are not marketable for fresh consumption

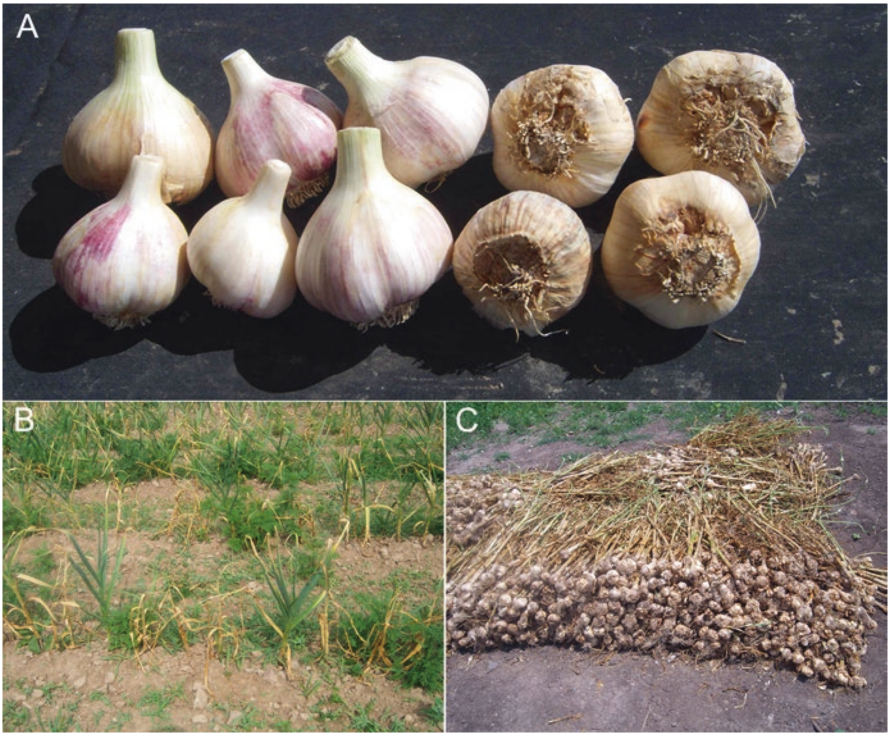

Fig. 2.4 (**a**) Mature garlic bulbs infected with *D. dipsaci* showing cracks and dry rotting of basal plates; (**b**) Pre-mature death of young garlic plants heavily infected with *D. dipsaci*; (**c**) Heavily infected garlic bulbs with *D. dipsaci* are not marketable and sorted out at harvest

(Fig. 2.4c) and those of infected lots, even at a low incidence, should not be sold for use as seeds. A good yield of garlic is about 8967 kg per hectare or higher and the price of garlic, although variable, is about $22 per kg or higher. Thus, even at a low percent of a yield loss, the impact of the stem nematode infection can be significant, especially to small-area garlic producers. About 30% of 400 garlic bulb samples obtained from garlic plantings throughout New York from June 2010 to early 2012, tested positive for the stem nematode. Interestingly, only about 10% of the garlic bulb samples analyzed in 2014 were found to be infected with the stem nematode. The latter might have been the results of the extensive outreach activities on the biology and management options of the stem nematode conducted in collaboration with personnel of Cornell Cooperative Extension, the Garlic Seed Foundation and garlic growers in New York and other states.

2.5.1.2 Management Strategies

Effective management of the stem nematode requires strict sanitation practices and the enforcement of quarantine regulations, in order to prevent the introduction of the nematode into production fields as well as the implementation of multiple control options. The latter includes the strict use of nematode-free seeds, hot water treatment of planting material, avoiding infested fields or treatment of soil with an appropriate product, practicing a proper crop rotation and the use of bio-fumigant cover crops (Lewis and Mai 1958; Dropkin 1989; Abawi and Moktan 2013). The wide host range of the stem nematode and its several biological races, however, makes its effective control difficult.

Infected planting materials are the major source of new infestation by the stem nematodes, thus only clean and stem nematode-free tested materials should be planted. Hot water treatment protocols of planting materials of garlic, onion and other crops, are available in the literature (Johnson and Lear 1965). However, hot water treatment should be considered only when clean planting materials are not available or when saving a valuable germplasm. Water temperatures reported to be effective against the stem nematode ranged from 38–49 °C, depending on the length of the soak period. Also, the efficacy of the hot water treatment was reported to improve with the addition of sodium hypochlorite, avermectin, formaldehyde, fungicides or other chemicals. Water temperature above 50 °C was reported to injure tissues of treated plant materials. The most common reported protocol for hot water treatment was a 20-min dip at 49 °C. In addition, clean planting materials should be planted only in stem nematode-free soil. It is critical to sample and analyze the soil of target planting sites for the presence of the stem nematode. Populations of the stem nematode as low as 10 per 500 cm^3 soil cause damage in many crops. Registered pre-plant soil fumigants (Telone®-C and Vapam® in NY) applied properly will control the stem nematode. Results of using non-fumigant nematicides (Vydate®, previously available for control of plant parasitic nematodes on onions, potatoes, carrots and other host crops in New York) have not been as affective as pre-plant fumigants against the stem nematode. Furthermore, practicing a long crop rotation

(3–4 years) out of susceptible hosts for the particular race(s) of the stem nematode is a highly effective management practice. For the onion and garlic race, rotating a site away from all *Allium* spp. (garlic, onion, leek, chives), celery, parsley, Shasta pea, salsify and other known hosts as well as controlling weed hosts (hairy nightshade and Canadian thistle) can be an important control tactic. Planting and incorporating green manures of known bio-fumigant crops (mustard, rapeseed, oilseed radish, sorghum-sudangrass hybrids and others) will also contribute to the management of the stem and other plant parasitic nematodes. However, the use of multiple and compatible management options is the best strategy to follow for the most effective and lasting control of the stem nematode.

2.5.2 Foliar Nematodes

Aphelenchoides ritzemabosi, *A. fragariae*, *A. parietinus* and *A. besseyi* have been reported from Pennsylvania; whereas, only *A. ritzemabosi*, *A. fragariae* and *A. parietinus* have been detected in New York and just *A. parietinus* in New Jersey. The early taxonomic history of these species includes a significant number of synonyms and confusion. The most common is *A. ritzemabosi*, the chrysanthemum foliar nematode. *A. fragariae* is the strawberry bud pathogen known as the spring crimp nematode. *Aphelenchoides besseyi* is the summer crimp nematode which also causes white tip of rice.

The chrysanthemum and spring crimp nematodes parasitize many herbaceous and woody plants. They feed on leaf mesophyll, resulting in necrotic tissue (blotches between veins) and non-functional apical meristems. The nematodes can move from plant to plant in thin films of moisture, splashing or rain/irrigation water or in infected plant material. *Aphelenchoides ritzemabosi* survives desiccation, but not extreme low temperatures. Use of nematode-free propagation materials and general sanitation procedures are the most appropriate management practices for these nematodes.

2.5.3 Potato Rot and Seed Gall Nematodes

Both the potato rot nematode (*Ditylenchus destructor*) and the wheat seed gall (*Anguina tritici*) are included in the 2014 WPN List for New York, but not for New Jersey or Pennsylvania. All three states have commercial potato industries, with New York's being the largest. While *D. destructor* is a regulatory species in some potato producing states, it has a relatively large host range including edible crops. *Ditylenchus destructor* causes severe necrosis of potato tuber tissue making infested tubers unmarketable. There are, however, no recorded detections of the potato rot nematode in New York potato production in recent years. Potato producing states with periodic detections of potato rot nematodes have highly developed and successful quarantine and certification programs that allow for continued export and certification of potatoes. Since potatoes are grown from tuber seed pieces, it is imperative for the seed to be pathogen-free. The overall U.S. potato seed certification programs allows farmers to obtain and plant high quality certified seed that is true to variety and pathogen free. Except for *Anguina tritici,* which has been eradicated from the USA, there are eleven recognized species of *Anguina*, each with its own biology and host range. It is highly likely that one or more of these species exist in New York, Pennsylvania or New Jersey.

2.6 Conclusions

New York, New Jersey and Pennsylvania have vibrant agricultural and human-living environment systems. These are inhabited by a diversity of plant parasitic nematodes. Throughout the years, strong research, academic instruction and extension-outreach programs in nematology evolved at Cornell University, Rutgers University and Pennsylvania State University. These institutions provided the information necessary to limit the detrimental impacts of these soil-borne organisms and contributed in significant ways to the evolution of the concept of both integrated pest management and sustainable agriculture. There were times, however, when nematology resources have been very limited at these three institutions. Ecosystems are dynamic and always changing. It is imperative that the Land Grant Institutions of New York, New Jersey and Pennsylvania provide highly significant future contributions towards the understanding of nematode biology, ecology and management in regards to the enhancement of overall human quality of life.

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