Chapter 14
Plant Parasitic Nematodes in Georgia and Alabama

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14.1 Introduction

Growers in the State of Georgia incurred losses, including control costs of an estimated $800 million from diseases in 2015 (Little 2017). The value of the crops used in this estimate was approximately $5,385 million resulting in a 13.8% relative disease loss across all crops including field (row) crops, fruits and nuts, vegetables, turf, ornamentals and trees (Little 2017). One of the economically important pests that growers are concerned about are plant parasitic nematodes. Nematodes have long been known as soilborne parasites of cultivated crops but in recent years following the methyl bromide phase-out in the United States, there has been an increase in yield losses due to nematode pests. A wide range of plant parasitic nematodes are commonly found in association with crops in Georgia and Alabama (Table 14.1). The most economically damaging species include root knot (*Meloidogyne* spp.), reniform (*Rotylenchulus reniformis*), lance (*Hoplolaimus columbus*), stubby root (*Nanidorus minor*) and ring (*Mesocriconema ornatum* and *M. xenoplax*) nematodes. Other nematode species including root lesion (*Pratylenchus* spp.), sting (*Belonolaimus longicaudatus*) and soybean cyst (*Heterodera glycines*) nematodes are rarely found in fields and considered less economically important in both Georgia and Alabama. In addition to parasitic nematodes, crops are attacked by

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Table 14.1 Plant parasitic nematodes associated with different crops in Alabama and Georgia

Nematode	Host/rhizosphere soil	State[a]	References
Belonolaimus longicaudatus	Cotton, peanut, turfgrass	AL, GA	Motsinger et al. (1976a), Johnson (1970) and Norton et al. (1984)
Dolichodorus spp.	Blueberry	GA	Jagdale et al. (2013)
Helicotylenchus clarkei	Peach	AL	Sher (1966)
Helicotylenchus digonicus	Wide host range	AL	Sher (1966)
H. dihystera	Wide host range	AL, GA	Sher (1966), Johnson et al. (1975) and Motsinger et al. (1976a)
H. multicinctus	Tropical ornamentals	AL	Minton et al. (1963)
H. pseudorobostus	Wide host range	AL	Minton et al. (1963)
Helicotylenchus spp.	Switchgrass, blueberry	GA	Mekete et al. (2011) and Jagdale et al. (2013)
Heterodera glycines	Soybean	AL, GA	Motsinger et al. (1976b)
H. cyperi	Yellow nutsedge	GA	Hajihassani et al. (2018a)
Hoplolaimus columbus	Cotton, peanut	AL, GA	Motsinger et al. (1976a) and Norton et al. (1984)
H. galeatus	Wide host range	AL	Norton et al. (1984)
Longidorus sp.	Switchgrass	GA	Mekete et al. (2011)
Meloidogyne incognita	Wide host range including cotton, peanut, corn, soybean, vegetables, pine, blueberries	AL, GA	Motsinger et al. (1974), (1976a), Norton et al. 1984, Nyczepir et al. (1985), Davis and Timper (2000a), (2000b) and Jagdale et al. (2013)
M. arenaria			
M. javanica			
M. hapla			
M. partityla	Pecan	GA	Nyczepir et al. (2002)
M. graminicola	Yellow and purple nutsedge, wheat	GA	Minton and Tucker (1987)
Meloidodera floridensis	Woody plants	AL	Hooper (1958)
Mesocriconema curvatum	Wide host range	AL	Powers et al. (2014)
M. ornatum	Cotton, peanut, mixed forest, blueberries	AL GA	Minton and Bell (1969), Powers et al. (2014), and Jagdale et al. (2013)
M. onoense	Turfgrass	AL	Powers et al. (2014)
M. rusticium	Cotton, mixed forest	AL	Powers et al. (2014)
M. xenoplax	Ornamentals	AL	Powers et al. (2014)
	Peach	GA	Nyczepir et al. (1985)
Mesocriconema sp.	Corn	GA	Davis and Timper (2000b)
Mesoanguina plantaginis	Plantain	AL	Vargas and Sasser (1976)

(continued)

Table 14.1 (continued)

Nematode	Host/rhizosphere soil	State[a]	References
Nanidorus minor	Wide host range including cotton, peanut, corn, sweet corn, onion, broccoli, eggplant	AL, GA	Johnson et al. (1975), Norton et al. (1984), Davis and Timper (2000b), and Hajihassani et al. (2018b)
Paratrichodorus sp.	Switchgrass, blueberries	GA	Mekete et al. (2011)
Pratylenchus brachyurus	Corn, cotton, peanut,	AL, GA	Motsinger et al. (1976a) and Norton et al. (1984)
P. hexincisus	Wide host range	AL, GA	Norton et al. (1984) and Mekete et al. (2011)
P. penetrans	Wide host range	AL	Norton et al. (1984)
P. scribneri	Corn, cotton, peanut, soybean, switchgrass	AL, GA	Norton et al. (1984) and Mekete et al. (2011)
P. vulnus	Peach	AL, GA	Southern Cooperative Series Bulletin (1960) and Fliegel (1969)
P. zeae	Cotton, corn, peanut	AL, GA	Norton et al. (1984)
Pratylenchus sp.	Corn	GA	Davis and Timper (2000b)
Rotylenchulus reniformis	Cotton, soybean	AL, GA	Motsinger et al. (1976a) and Norton et al. (1984)
Trichodorus borneonsis	Soybean, cabbage palm	AL	Rebois and Cairns (1968)
T. primitivus	Corn, cotton, lespendeza, woody ornamentals	AL	Rebois and Cairns (1968)
Tylenchorhynchus claytoni	Field and ornamental crops	AL	Norton et al. (1984)
T. cylindricus	Field and ornamental crops	AL	Norton et al. (1984)
T. martini	Field crops, turfgrass	AL	Johnson (1970) and Norton et al. (1984)
T. nudus	Field, ornamental and native crops	AL	Norton et al. (1984)
Tylenchorhynchus sp.	Corn, blueberry	GA	Davis and Timper (2000a, 2000b) and Jagdale et al. (2013)
Xiphinema americanum	Cotton, peanut, switchgrass	AL	Norton et al. (1984) and Mekete et al. (2011)
X. krugi	Bahia grass, sorghum	AL	Frederick and Tarjan (1975)
Xiphinema sp.	Cotton, peanut, blueberry	GA	Motsinger et al. (1976a) and Jagdale et al. (2013)
X. pacificum	Peach	GA	Nyczepir and Lamberti (2001)

[a]Names of the states are represented by two letter abbreviations: *AL* Alabama, *GA* Georgia

soilborne fungal pathogens including *Fusarium*, *Phytophthora*, *Pythium* and *Rhizoctonia* producing disease complexes. Management of plant parasitic nematodes principally includes the use of chemical and biological nematicides and crop rotation with resistance or tolerant cultivars. Although several species of plant parasitic nematodes cause damage to several different crops, in this chapter major emphasis will be given on the detection, distribution and management of root knot, reniform, lance, stubby root and ring nematodes because of their economic importance in both states of Alabama and Georgia.

14.2 Economically Important Crops in Georgia and Alabama

In the State of Georgia, cotton (*Gossypium hirsutum*), peanut (*Arachis hypogaea*), vegetables (various species), pecan (*Carya illinoinensis*), corn (*Zea mays*), peach (*Prunus persica*) and blueberry (*Vaccinium* spp.) are the most widely and commercially cultivated crops that are considered major contributors to the state's economy (Table 14.2). In Alabama, cotton, hay, corn, peanut, soybean (*Glycine max*), wheat (*Triticum aestivum*) and cucumbers are the most economically important crops

Table 14.2 Major crops produced in Georgia (2017)

Crop	Planted hectares ($\times10^6$)	Harvested hectares ($\times10^6$)	Production in kilogram ($\times10^9$)	Sales in \$ ($\times10^6$)
Cotton	0.52	0.51	1.01	794.8
Peanut	0.34	0.33	1.64	780.5
Hay	–[a]	0.25	1.80	187.0
Corn	–	0.099	1.09	178.9
Sweet corn	0.010	0.010	0.204	98.4
Watermelon	0.008	0.008	0.355	74.2
Soybean	0.062	0.061	0.378	61.4
Tobacco	–	0.005	0.012	52.5
Cucumbers	0.004	0.004	0.084	43.8
Bell pepper	0.001	0.001	0.042	37.1
Cabbage	0.002	0.002	0.098	24.9
Squash	0.001	0.001	0.027	23.5
Snap bean	0.005	0.004	0.033	20.1
Wheat	0.064	0.028	0.089	13.9
Cantaloupe	0.001	0.001	0.018	8.9
Rye	0.08	0.0006	0.015	1.7
Pecan	–	–	0.03	–
Peach	–	–	0.01	–

NASS USDA (2018a)
[a]Data not available

Table 14.3 Major crops produced in Alabama (2017)

Crop	Planted hectares ($\times 10^6$)	Harvested hectares ($\times 10^6$)	Production in kilogram ($\times 10^9$)	Sales in $ ($\times 10^6$)
Cotton	0.176	0.174	0.17	265.9
Hay	–[a]	0.348	1.95	208.5
Corn	0.101	0.980	0.99	210.3
Peanut	0.079	0.078	0.32	155.7
Soybean	0.142	0.140	0.43	155.5
Wheat	0.061	0.040	0.21	35.4
Cucumbers	0.022	0.021	0.09	16.6
Oat	0.016	0.004	0.09	2.4
Pecan	–	–	0.01	–
Peach	–	–	0.02	–

NASS USDA (2018b)
[a]Data not available

(Table 14.3). Alabama's crop production valued at $1.01 billion in 2017, was up by 11% compared to 2016 values. In Georgia, the Southern Coastal Plain region supports the largest portion of both field and vegetable crops planted because it is dominated by warm and humid climates, and light sandy or sandy loam soils. Georgia was the first state in the U.S. to produce cotton commercially in 1734. Georgia often ranks second or third nationally in cotton production and hectares grown. Cotton has played a significant role in both the history and economy of the state. Georgia is the biggest peanut-producing state in the country, accounting for more than 45% of the nation's peanut production. The subtropical climate of Georgia is ideal for producing large yields of high-quality peanuts. The State of Georgia is also the nation's largest supplier of pecans, accounting for about a third of the United States pecan production. Pecan trees are commonly found throughout the state. Georgia is the nation's leading producer of fresh market vegetables including cucurbits, onions, leafy greens, bell peppers, tomatoes and sweet corn. Although vegetable crops were traditionally cultivated in Southern Georgia, their production has extended in recent years to areas where predominantly field crops such as corn, potato and others were grown. Georgia vegetables produced a farm gate value of well over $1.1 billion in 2016. In the State of Georgia peach production is a $42.1 million industry (2016 USDA Georgia Agricultural Facts), with production ranking third behind South Carolina and California, respectively. Blueberry production is mostly centered in Southeastern Georgia with a farm gate value in excess of $100 million that accounts for almost one-third of the total fruit and nut crop value for the state. The subtropical climate of Alabama is located in the coastal region with a temperate region in the north. The soils vary dramatically from fine sandy loams to clay loams and crop production occurs across the entire state utilizing the diversity of soil types, climates and growing seasons. Alabama's primary crops are forestry followed by the field crop production of cotton, soybean, corn, peanuts and forages. Alabama is the third largest producer of peanuts in the U.S. and ranks seventh in cotton production.

Soybeans and corn rank 23rd and 28th nationally. Alabama does grow vegetables, melon, potatoes, sweet potatoes, fruits, tree nuts and berries with rankings from 7th for sweet potatoes to 24th for sweet corn. There is a strong movement for the production of specialty high value crops in Alabama which has diversified production and enhanced grower economics. Overall, Alabama crop production was valued at $1.07 billion in 2016 over 8.8 million acres of farm land (2016 USDA Alabama Agriculture Facts).

14.3 Plant Parasitic Nematodes in Georgia and Alabama

14.3.1 Historical Perspective

The history of conducting applied nematology research in the State of Georgia dates back to 1935. In Alabama, the root knot nematode *M. incognita* was first observed as an economic pathogen in cotton in the late 1800s. Since then, considerable effort has been made to obtain information about the effect of nematodes on cultivated crops and strategies to manage these soilborne pests, mostly based on the use of chemical products and resistant cultivars. The primary purpose of all of these efforts has been to manage economically important nematode species to improve the production of crops and to maximize economic welfare of producers. Recent estimates of nematode damage on some major crops grown in Georgia have shown severe reductions in crop value that ranged from 2% to 10% (Table 14.4). Across the entire State of Alabama, it is estimated that 4% and 6% of the cotton crop was lost to the reniform and root knot nematodes respectively, which is estimated at an economic loss of nearly $21.8 million. Specifically, cotton yields over the last 5 years in a reniform nematode infested field with an average at planting of about 5,000 reniform/100 cm^3 of soil, have averaged 50% less compared to an identical field that had no detectable reniform nematodes (Lawrence et al. 2018). Thus, yield losses can be severe in reniform-infested fields. In both Georgia and Alabama, large amounts of traditional and newly introduced chemical nematicides are still being used to

Table 14.4 Estimated values of losses caused by plant parasitic nematodes on some major crops in Georgia

Crop	% Reduction in crop value	Damage in $ (×10^6)	Cost of control in $ (×10^6)	Total in $ (×10^6)
Cotton	10.0	71.3	60.8[a]	132.1
Peanut	2.75	18.8	5.8	24.6
Corn	6.5	16.4	1.3[b]	17.7
Soybean	3.35	4.3	–	4.3
Vegetables[a]	5.0	11.5	–	–

[a]Little (2017)

[b]Vegetable crops include watermelon, cantaloupe, cucumbers, bell peppers, snap beans, squash and cabbage

control the most damaging nematode species, particularly root knot nematodes. Research trends are currently directing efforts towards the use of crop resistance for effective control of nematodes. Additionally, rotation with non-host crops and biocontrol have shown potential for plant parasitic nematode management. However, scientific knowledge on the efficacy of biocontrol agents for plant parasitic nematodes lags behind that for other root diseases.

14.3.2 Root Knot Nematodes, Meloidogyne *spp.*

14.3.2.1 Detection and Distribution

Four major species (*M. incognita, M. javanica, M. arenaria* and *M. hapla*) have been reported on numerous crops in Georgia and Alabama (Table 14.1) (Motsinger et al. 1976a; Baird et al. 1996; Powers and Harris 1993; Norton et al. 1984). According to the Nematode Diagnostic Laboratory at University of Georgia that received 6431 soil samples during 2013 through 2017 from different growers located in 126 different counties that covered 4 geographical regions (Coastal Plain, Piedmont, Blue Ridge and Ridge and Valley) of Georgia, root knot nematodes were present in 85.7% of the counties (Fig. 14.1).

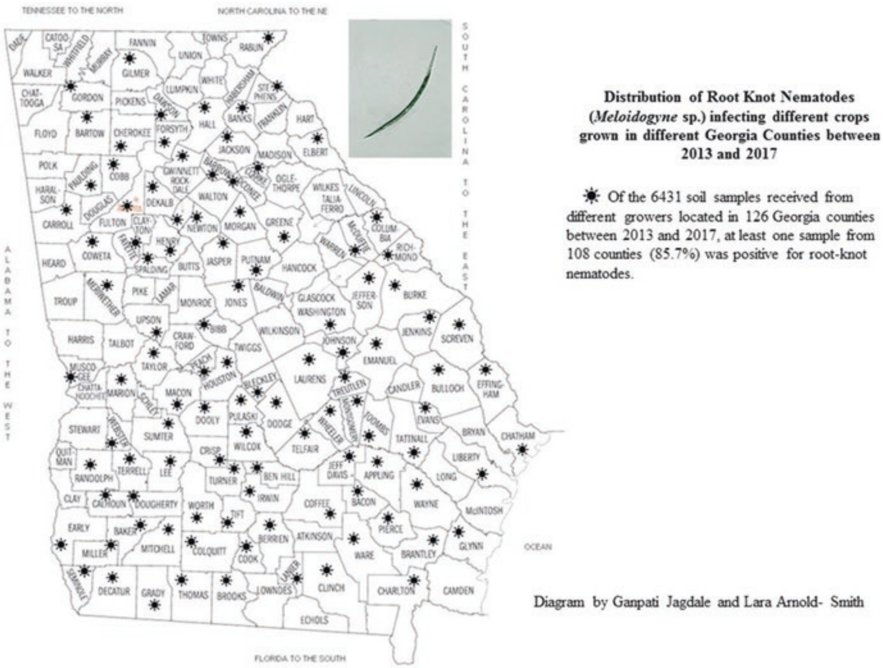

Fig. 14.1 The occurrence and distribution of root knot nematodes on different crops including turfgrasses grown in different Georgia counties

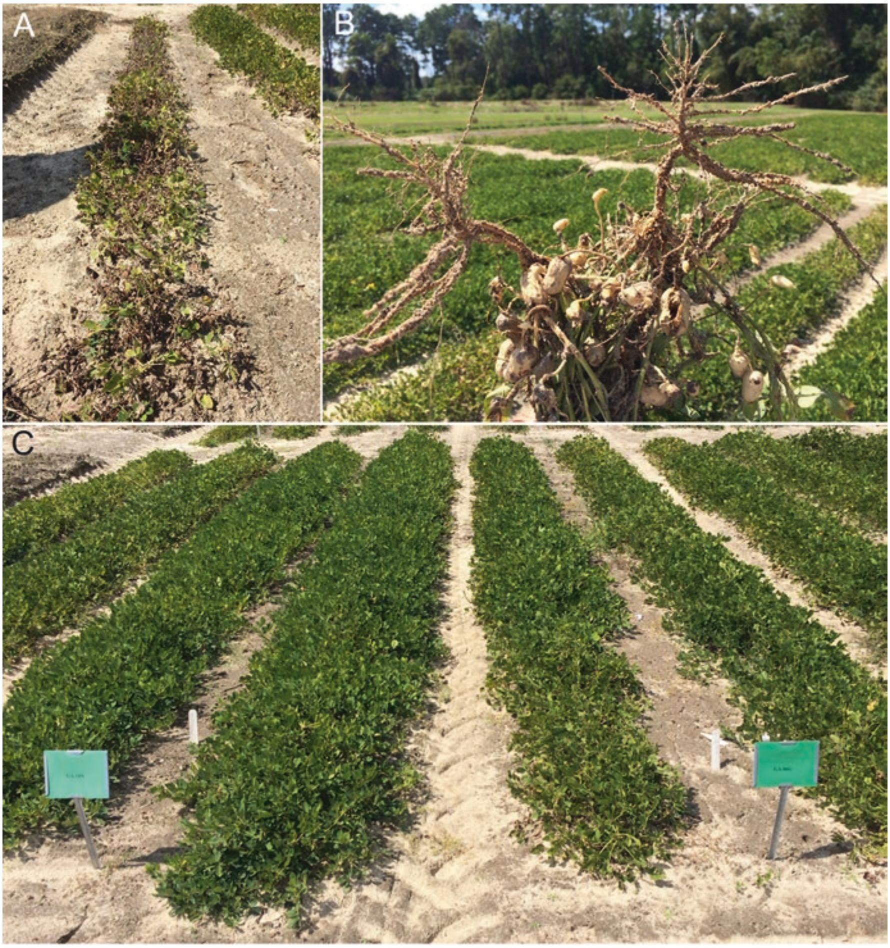

Fig. 14.2 Field symptoms of *Meloidogyne arenaria* damage in peanut, showing a row of completely yellowed and stunted plants (**a**), galls on roots and pegs (**b**) and growth responses of resistant 'GA-14N' (two rows on the left) and susceptible 'GA-06N' (two rows on the right) cultivars treated with a nematicide at the University of Georgia Blank Shank Farm in Tifton, Georgia (**c**). (Photos: Timothy Brenneman and Abolfazl Hajihassani)

Among these species, the southern root knot nematode, *M. incognita*, and the peanut root knot nematode, *M. arenaria*, are widely distributed in field, vegetable and fruit tree growing regions in Georgia. Root knot nematodes feed on roots of plants and produce distinguishing symptomatic galls on the primary and secondary roots that are distinctive and diagnostic in numerous crops including peanut, cotton, soybean, tomato and cucumber (Figs. 14.2, 14.3, and 14.4). In Alabama, *M. incognita* and *M. arenaria* are most often located in the sandy soils of the southern region of this state. A survey of Alabama cotton fields consisting of 969 samples collected in the fall

Fig. 14.3 Field symptoms caused by *Meloidogyne incognita* race 3 in cotton (**a**, **b**), soybean (**c**, **d**) and corn (**e**, **f**) in Alabama showing poor growth of plants and galled roots. (Photos: Kathy Lawrence)

of 1998–2000 found root knot nematodes in 7% of the fields with 57% and 27% of the fields with low or high nematode numbers (Gazaway and McLean 2003). In contrast, a survey of cotton fields in Georgia in 2006 found at least one species of root knot nematode in 69% of the fields planted to cotton. Medium to high populations of *M. incognita* were found in over half of the cotton-producing counties (Kemerait et al. unpubl.). *Meloidogyne* species have been found in 34 out of 102 fields of corn surveyed in 11 counties in Southern Georgia, with *M. incognita* as the most widespread species followed by *M. arenaria* (Davis and Timper 2000a, b). Field studies in

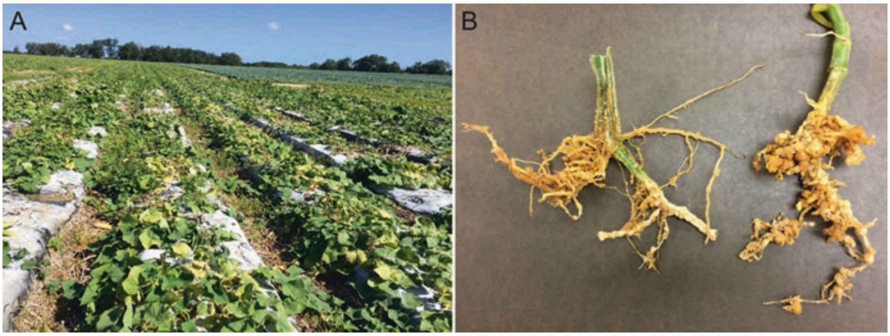

Fig. 14.4 Damage symptoms resulting from *Meloidogyne incognita* parasitism on cucumber grown on fumigated raised beds covered with plastic mulch in Georgia (**a**), heavily galled root systems of cucumber caused by *M. incognita* (**b**). (Photos: Abolfazl Hajihassani)

Georgia have revealed a suppression of about 8.5–35.7% in yield losses due to *M. incognita* parasitism on both susceptible and tolerant cultivars of cotton (Davis and May 2003). *Meloidogyne arenaria* can reduce peanut yields by up to 15% annually in the Southern U.S. Yield losses due to root knot nematodes can be particularly severe when two susceptible host crops are planted in sequence in the same year. This has been observed in many vegetable crops such as cucumber, tomato and squash when grown on raised beds covered with plastic much (Johnson et al. 1996). A preliminary survey of plant parasitic nematodes conducted in fourteen top vegetable-producing counties in Southern Georgia in 2018 showed that root knot nematodes were the dominant parasites. About 67% of surveyed fields grown to multiple vegetable crops including cucumber, tomato, watermelon, cantaloupe, eggplant, peppers, beans, squash, sweet corn and onions were infested by *Meloidogyne* spp. (Marquez and Hajihassani unpubl.).

The root knot nematodes typically become a serious problem in sandy soils, especially during summer and early fall when temperatures are warm and the season has adequate to excessive rainfall. In Alabama, a survey identifying species of root knot nematodes in field crops in 2016 and 2017 found *M. incognita* race 3 as the most prevalent species present. *Meloidogyne arenaria* was present in 3% of the samples (Groover and Lawrence 2018). Although root knot nematode alone is a serious root disease of numerous crops, disease severity and yield loss are often greater in the presence of fungal pathogens. For example, losses in peanut and cucumber due to Cylindrocladium black rot (*Cylindrocladium parasiticum*) and Pythium root rot (*Pythium aphanidermatum*) have been shown to increase substantially in the presence of root-knot nematodes in Georgia, respectively (Dong et al. 2009; Morris et al. 2016). Fusarium wilt is a serious disease complex caused by *F. oxysporum* f. sp. *vasinfectum* and *Meloidogyne* spp. can cause an annual loss of 1.3% or $3.7 million of cotton yield in both Alabama and Georgia (Bell et al. 2017; Lawrence et al. 2018).

14.3.2.2 Management of Root Knot Nematodes

14.3.2.2.1 Cultural Control

Crop Rotation The management of root knot nematodes in Georgia and Alabama has been characterized largely by crop rotation in which the host plants including cotton, soybean, peanut and corn are rotated with poor-hosts or non-host plants. In an ideal rotation, the previous crop suppresses populations of the target nematode and prevents damage to the subsequent crop. Because peanut is a non-host of *M. incognita* and cotton is a non-host of *M. arenaria* (Johnson et al. 1998), rotations with peanut and cotton are highly effective in the management of both nematode species. Davis and Timper (2000a, b) noted that commercial corn hybrids, which are commonly planted in rotation with cotton and peanut in Georgia, supported the reproduction of *M. incognita* (race 3) better than *M. arenaria* suggesting that corn is not a compatible rotation crop for cotton where *M. incognita* is a concern. In Alabama, rotations of cotton, soybean and corn in a *M. incognita* race 3 field found that the nematode populations continued to increase when the host crop was consistent over years. However, even rotations from cotton to a susceptible crop such as corn or soybean, only allowed the *M. incognita* population to increase by 13% and 25%, respectively, compared to continuous cotton (Groover et al. 2017). Since peanut is not a host for the southern root knot, reniform and lance nematodes, it can effectively control these nematode species when planted as rotational crop with susceptible crops in Georgia. Tobacco and many vegetable crops should not be included in rotations with cotton where management of southern and peanut root knot nematodes is the primary concern, even though *M. incognita* races 1 and 2 do not reproduce on cotton. Field and greenhouse research conducted in Georgia have shown that pearl millet hybrids (TifGrain 102) are resistance to various types of plant parasitic nematodes including *M. incognita* race 3, *M. arenaria* race 1, *B. longicaudatus* and *P. brachyurus*. These hybrids can be used in rotations with susceptible crops to reduce the nematode problems in subsequent crops such as peanut and cotton (Timper et al. 2002; Timper and Hanna 2005).

Cover Crops Although cover crops generally increase soil microbial activity, biological diversity and organic matter content, they can also help in suppressing the populations of plant parasitic nematodes and other soilborne pests of cultivated crops. This in turn may reduce the frequency of pesticide applications required to control plant parasitic nematodes. Generally, the use of cover crops for suppression of root knot nematodes should be done with caution because of the broad host range of *Meloidogyne* spp. and susceptibility of certain species/cultivars of cover crops that may increase root knot nematode populations in soil. Greenhouse and field studies in Georgia have revealed that certain summer and winter cover crops including rye (*Secale cereale*; cv. Wrens Abruzzi), pearl millet (*Pennisetum glaucum*; cv. TiftGrain 102), vetch (*Vicia sativa*; cv. Cahaba White), oat (*Avena sativa*), wheat (*Triticum aestivum*) and bahiagrass (*Paspalum notatum*), have a potential to be used as cover crops for the management of root knot nematodes (Johnson et al. 1998; Sumner et al. 1999; Timper et al. 2002, 2006). Timper et al. (2011) reported that incorporating rye residue into soil or scattering on the soil surface had no effect on populations of either *M. incognita* in cotton or *M. arenaria* in peanut. However, the use of high quantities of rye biomass resulted in reduction of *M. incognita* numbers in soil and root gall index in cotton (Timper 2017). As stated above, cover cropping may have suppressive effects on root knot nematodes, but it may support the reproduction of other species of nematodes. For example, oats, wheat and rye may be good hosts for *B. longicaudatus* and *H. columbus* but not for root knot nematodes (Davis et al. 2000). Incorporation of residues of legume cover crops into soil can help to prevent soil erosion, improve water retention in sandy soils and may produce toxic products that can be detrimental to nematodes. For example, preliminary field research in Georgia have shown that incorporation of sunn hemp (*Crotolaria juncea*) residue reduced the root knot nematode population to a depth of 25 cm in soil (Hajihassani et al. unpubl.). Integration of cover crops with other cultural management practices such as tillage or crop rotation with non-hosts may increase the beneficial effects of cover crops in controlling nematodes. Although some *Brassica* species have the potential as winter cover crops and green manure amendments for nematode management, many other species in the Brassicaceae family are known to be susceptible to root knot nematodes. For example, Monfort et al. (2007) reported that there was an increase in the *M. incognita* population density in the rhizosphere of *B. juncea*, *B. oleracea*, *Sinapis alba* or *B. napus* but when the crop residues of these crops incorporated in the soil, the population of nematodes was reduced. This suggests that the efficacy of biofumigation with *Brassica* crops for managing root knot nematodes clearly rely on the plant species used as cover crop and its adaptability to the environment.

14.3.2.2.2 Chemical Control

Precision agriculture has recently become a widely accepted practice in Alabama and Georgia; however, more research is required to fully implement this technique in grower fields. One important aspect of the technology is variable-rate applications of nematicides. In the field, plant parasitic nematodes generally have a patchy and clustered spatial distribution (Lawrence et al. 2008). The distribution varies with nematode species, soil texture and the crop grown. Variable-rate and site-specific application is the application of nematicides only to the areas where the nematode population has reached the economic threshold level and yield enhancement is expected. To implement a successful nematode management program, the nematodes present in the field and their location must be determined (Lawrence et al. 2007, 2008; Moore and Lawrence 2012; Davis et al. 2013). This is accomplished by collecting samples from a uniform systematic grid across the field or through the use of zone sampling (Ortiz et al. 2012). A representative number of soil samples is the key to success for any nematode management program as it becomes essential to decide suitable variable rates of application of nematicides.

The smaller the sample grid size (0.01–0.2 ha) the more detailed the nematode distribution map is generated that results into better placement of the nematicides. However, the more samples the higher the laboratory cost to process them. Zone sampling creates zones or areas of similarity from which samples are collected. Soil texture is one criterion for obtaining points from similar areas. Different nematode genera favor different soil textures so soil texture will influence the damage resulting from infection. Each sample point is geo-referenced using a global positioning system (GPS). This type of sampling is a popular sampling strategy that allows mapping the spatial information for a specific nematode pest. Once the nematode population numbers are located and mapped, nematode contour maps can be developed to graphically represent nematode numbers in a field. The map can be overlaid with yield maps to determine problem areas in the field. Poor crop yields in combination with high nematode numbers are good indications that areas may require nematicide applications. A nematicide prescription map and predetermined application rates are then loaded into the application equipment's computer. The specified amount of nematicides is applied to the selected areas as the equipment moves across the field.

14.3.2.2.3 Resistance

Use of nematode-resistant cultivars not only protects the crop in the field, but also reduces nematode infestations for the subsequent cash crop. *Meloidogyne*-resistant cotton cultivars suppress nematode reproduction compared to the susceptible cultivars but nematode tolerant cotton cultivars will support greater levels of nematode reproduction without affecting yields. Until recently, no commercial cotton cultivar with a high level of resistance to southern root knot nematode was available (Davis and May 2005) but resistant cultivars such as PhytoGen 487 WRF, Deltapine 1747NR B2RF and Stoneville 4946 GLB2 are now commercially available where *M. incognita* is a major problem (Georgia Cotton Commission 2018). Although these cultivars have shown a high level of resistance to the nematode, the infection risk associated with other pathogenic organisms may limit their effective use. For example, DP 1558NR B2RF was affected in some cotton fields in Georgia where the bacterial blight caused by *Xanthomonas citri* pv. *malvacearum* is present (R.C. Kemerait, Univ. Georgia, pers. com.). In peanut, very high levels of root knot nematode resistance have been characterized and introduced from wild species of *Arachis* spp. into newly established peanut cultivars. TifGP-2, Tifguard, Georgia-14N, TifNV-High O/L, NR 0812, and NR 0817 were released as resistant cultivars to *M. arenaria* (Anderson et al. 2006; Holbrook et al. 2008, 2012, 2017; Branch and Brenneman 2015). Field test evaluations in Southern Georgia have shown very high levels of resistance of these improved cultivars to *M. arenaria* in comparison to Georgia-06G, a widely grown and high-yielding susceptible cultivar (T. Brenneman, Univ. Georgia, pers. com.). In addition, Tifguard and its nematode-susceptible sister line, TifGP-2, have high resistance to Tomato Spotted Wilt Virus, making them very suitable for planting in the Southeastern U.S. (Holbrook et al. 2012). In vegetables, some nematode-resistant cultivars are currently available which will reduce production costs and increase marketable yields. Planting resistant cultivars of tomato (multiple cultivars), bell pepper (e.g. Charleston Belle and Carolina Wonder) and sweet potato (e.g. Covington and Evangeline) with resistance to *Meloidogyne* species, might be an effective option in managing root knot nematodes. However, the presence of *Mi* resistance-breaking species such as *M. haplanaria*, *M. hapla* and *M. enterolobii* in some vegetable-growing regions raises concerns about durability of resistance.

14.3.2.2.4 Biological Control

One of the potential biocontrol agents of root knot nematodes is *Pasteuria penetrans*. This endospore-forming, gram-positive bacterium is known as the primary biological agent that causes soil suppressiveness against root knot nematodes. *Pasteuria penetrans* is present in many Georgia peanut fields and can build up its population to levels which are suppressive to nematode populations (Timper 2009; Timper et al. 2016). Field studies in Georgia have shown that increasing *Pasteuria* populations in the soil significantly reduced root knot nematode reproduction (Timper 1999). Studies investigating *P. penetrans* in monoculture rotation systems and their influence in soil suppressiveness have yielded varying outcomes. Rotations including poor hosts for *Meloidogyne* spp. reduced the *P. penetrans* endospore densities compared to a monoculture of peanut (Timper et al. 2001). One of the obstacles of *P. penetrans*-based biological control is the downward movement of spores due to irrigation or rainfall that can result in endospore depletions in the top 15–20 cm of soil (Cetintas and Dickson 2005).

Another biological control option includes various strains of *Bacillus* spp. often targeting *M. incognita* (Kloepper et al. 1992). Gustafson developed BioYield®, a combination of *B. velezensis* strain IN937a and *B. subtilis* strain GB03, in a flowable formulation for management of soilborne pathogens and suppression of *M. incognita.* In Alabama, BioYield® reduced *M. incognita* populations and increased yields in tomato in greenhouse and field trials (Burkett-Cadena et al. 2008). VOTiVO, *Bacillus firmus* GB-126, is marketed by Bayer CropScience as a seed treatment for the control of plant parasitic nematodes on corn, cotton, sorghum and soybean. *Bacillus firmus* GB-126 tests indicated this product reduced egg production in *R. reniformis, Heterodera glycines* and *M. incognita* (Lawerence et al. unpubl.). Induced systemic resistance (ISR) was demonstrated with split-root experiments in the greenhouse and ISR was evident in *H. glycines* split-root assays on soybean but not in *M. incognita* assays on cotton (Schrimsher 2013). The newest biological seed treatment nematicide is Aveo (*B. amyloliquefaciens* strain PTA 4838) by Valent is available for plant parasitic nematode management on corn and soybean."

14.3.3 *Reniform Nematode,* Rotylenchulus reniformis

14.3.3.1 Detection and Distribution

Rotylenchulus reniformis is a major pathogen of cotton in the Southeastern U.S. (Koenning et al. 2004; Robinson 2007). Although first reported on cotton in Georgia in 1940 (Smith 1940) and in Alabama in 1958 (Minton and Hopper 1959), it was not recognized as a serious nematode pest on cotton until 1986, when it caused substantial yield losses in grower fields in South Alabama. The spread of the reniform nematode has been relatively slow across Georgia compared to other parasitic nematodes, in particular the southern root knot nematode. Between 2013 and 2017, the Nematode Diagnostic Laboratory at University of Georgia determined that 25.4% of the counties contained reniform nematodes (Fig. 14.5). A survey of Alabama cotton fields consisting of 969 samples collected in the fall of 1998–2000 found the reniform nematode to be present in 46% of the fields sampled with 44% and 33% of the fields having low and very high populations respectively. Although a damaging pathogen of several crops grown in the region, *R. reniformis* is a primary problem in

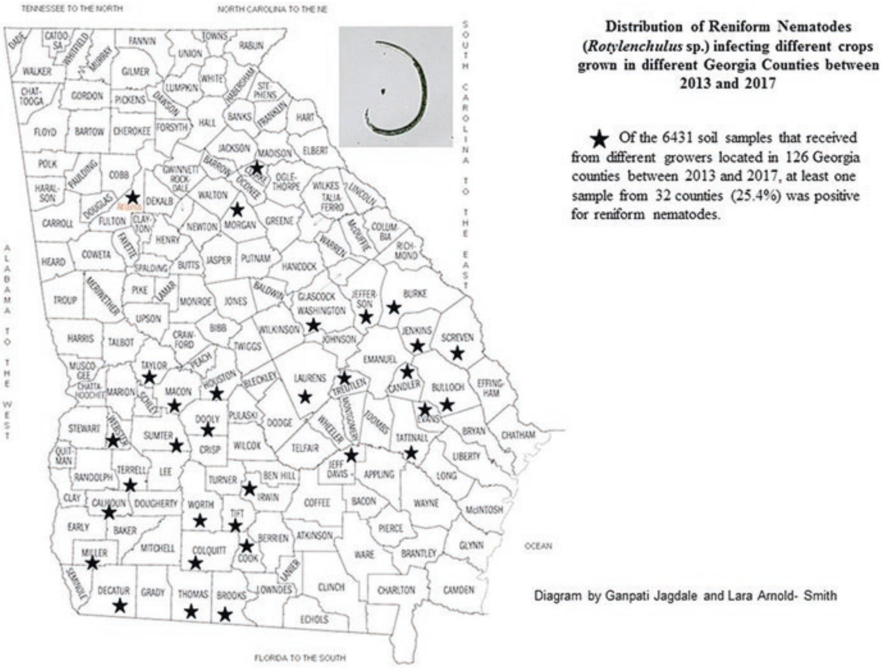

Fig. 14.5 The occurrence and distribution of reniform nematodes on different crops including turfgrasses grown in different Georgia counties

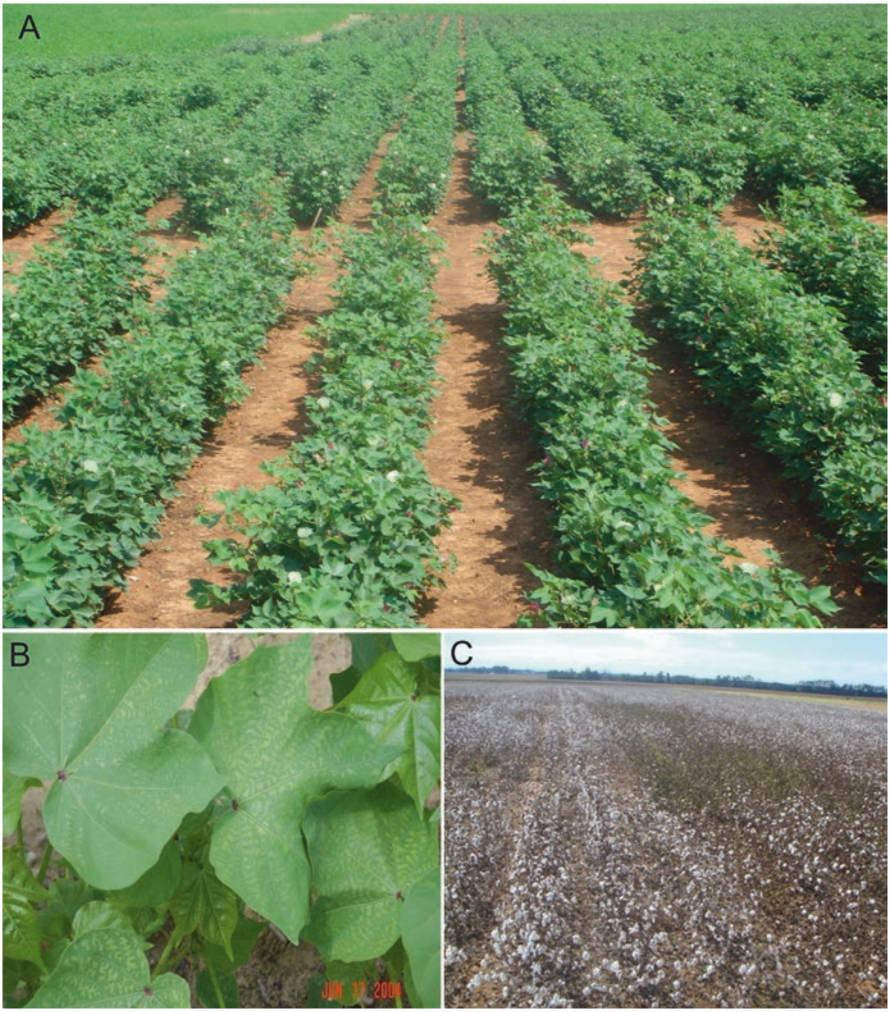

Fig. 14.6 Uneven growth of cotton plants in a reniform nematode infested field in Alabama (**a**), foliar symptoms of interveinal chlorosis associated with reniform nematode infested cotton (**b**), visual cotton yield reductions in areas of high *Rotylenchulus reniformis* numbers near harvest (**c**). (Photos: Kathy Lawrence)

cotton (Fig. 14.6) and is currently present in many of the main cotton-growing counties in Georgia, including nine of the ten counties with the highest cotton production. In a recent (2006) statewide survey of cotton fields, approximately 5% of the fields were infested with *R. reniformis* (Kemerait et al. unpubl.). The nematode can cause serious damages in more restricted areas of the state with heavier soils. A survey conducted in 1989 and 1990 in Alabama found 6.5% of the fields in North and Central Alabama to be infested with *R. reniformis* at populations above the economic threshold. Twelve years later in 2002, *R. reniformis* was found in 46% of the fields in the same regions and half of those fields had populations above the economic threshold (Gazaway and McLean 2003). In Alabama, *R. reniformis* has been shown to prefer finer textured soils and exists above economic thresholds in a wide variety of soil types. The natural migration of the reniform nematode was monitored in Alabama in a silty loam soil, under no-till cotton. The reniform nematode moved 200 cm horizontally and to a 91 cm vertical depth from the initial point of inoculation in one growing season (Moore et al. 2010a). Population density increased steadily in the irrigated trial during both years, exceeding the economic threshold of 1,000 nematodes/150 cm^3.

14.3.3.2 Management of Reniform Nematode

The methods currently used to manage *R. reniformis* in cotton can be economically beneficial if utilized with forethought. Rotation and nematicides are the principle means of *R. reniformis* management. As with many nematode infestations in cotton production systems, nematicide use is the major management tactics for *R. reniformis*. Cultivars resistant and or tolerant to *R. reniformis* have promise to alleviating yield loss, but these are not presently available in current cotton cultivars and the efficacy of tolerant cultivars has been questioned (Robinson et al. 1997; Koenning et al. 2000; Starr et al. 2007). A reniform nematode resistant cultivar named Phytogen will likely be marketed in the near future. Recently, some germplasm lines (LONREN-1, LONREN-2 and BARBREN-713) of upland cotton with high levels of resistance to *R. reniformis* have been developed (Bell et al. 2014, 2015). The BARBREN-713 line also is highly resistant to root knot nematodes. Field trials conducted in Alabama established that *R. reniformis* populations as 50% lower in these resistant lines compared with the susceptible cotton lines at 45 days after planting. However, the use of nematicides did increase yields of both the resistant and susceptible cotton lines (Schrimsher et al. 2014).

14.3.3.2.1 Cultural Control

Crop rotation is recommended as an important tactic for management of reniform nematode. Rotation crops useful for *R. reniformis* suppression include peanut, corn, reniform-resistant soybeans, bermudagrass, bahiagrass and sorghum. In Alabama, crop rotation to non-hosts such as corn or peanuts or highly resistant varieties of soybean, is an effective strategy for the management of *R. reniformis* (Gazaway et al. 2007). Corn, soybean and peanut all reduced initial *R. reniformis* populations compared to continuous cultivation of cotton (Moore et al. 2010b). Cotton yield following 1-year rotations of corn, soybean or peanut yielded 16%, 26% and 17% higher than continuous cotton. Two years of corn, peanuts or soybeans increased cotton yield higher than continuous cotton by 34%, 46% and 40%. All rotations resulted in a net profit over variable costs compared to continuous cotton both with and without a nematicide. The 3-year rotations of corn and soybeans followed by cotton produced the largest increase in net profit over variable costs, both with and without a nematicide. The use of the correct crop rotation for the suppression of the reniform nematode can have a positive impact on cotton yields, even without the use of a nematicide. Many native weed species are host of *R. reniformis* to some degree and can confound the positive effects of crop rotation if not properly controlled (Davis and Webster 2005; Jones et al. 2006; Lawrence et al. 2008; Wang et al. 2003). Davis et al. (2003) have shown that rotations of winter grain crops and soybean cultivars resistant to reniform nematode with cotton are effective for suppression of reniform nematode populations and increasing cotton yield. Although crop rotations with non-host crops are effective in reducing populations and damage incurred by *R. reniformis*, rotations with these crops are often economically prohibitive in many areas where cotton is grown in the United States (Davis et al. 2003; Lawrence and McLean 1999).

Cover crops have not been as beneficial for *R. reniformis* management as they have been for *Meloidogyne* spp. Crimson clover, subterranean clover and hairy vetch were shown to be hosts of *R. reniformis* in greenhouse tests, although field populations did not increase on these cover crops under the natural environmental conditions (Jones et al. 2006). These cover crops may increase initial *R. reniform* populations if the winter is mild and the covers are not terminated before soil temperatures rise. Varieties of radish, black mustard, white mustard, canola, lupin, ryegrass, wheat, oats and rye were poor hosts for *R. reniformis* and did not sustain reniform populations (Jones et al. 2006).

14.3.3.2.2 Chemical Control

An assortment of nematicides have been proven effective for the management of *R. reniformis*, including aldicarb (AgLogic 15G) (Lawrence et al. 2018; Lawrence and McLean 2000), fenamiphos (Nemacur) (Koenning et al. 2007; Lawrence et al. 1990) and terbufos (Counter) (Lawrence et al. 1990). Of the granular pesticides, aldicarb has been the most widely used in cotton production and its continual use has resulted in reports of enhanced degradation by soil microbes thus decreasing its overall efficacy (Lawrence et al. 2005). Fenamiphos is no longer labeled for use in the United States and terbufos was preliminary labeled for use in cotton production in Georgia. Seed applied pesticides such as abamectin, thiodicarb and fluopyram have become widely used in cotton production as a part of Avicta Complete Cotton, Aeris Seed Applied System and COPeO Prime, respectively, and have been reported to provide adequate management of *R. reniformis* (Lawrence and Lawrence 2007; Lawrence et al. 2018). Their protection of the root is limited (Faske and Starr 2007) as is their ability to provide adequate protection against high populations of *R. reniformis* (Moore et al. 2010a, b). The newest seed treatment nematicides on the market in 2018 are Monsanto's tioxazafen (NemaStrike™) and Cortiva's fluazaindolizine (Salibro™). In-furrow spray nematicides are the most recent additions to the nematicide arsenal. Fluopyram combined with imidacloprid (Velum Total) is the most frequently used nematicide in Alabama on cotton. The application of Velum Total resulted in an average 90% decrease in *R. reniformis* eggs/g of root over ten cotton cultivars and increased yield by an average of 23% or 903 kg/ha (Groover et al. 2017).

Oxamyl (Vydate® C-LV) is a foliar applied pesticide that also provides adequate management of *R. reniformis*, often in conjunction with previously mentioned pesticides (Baird et al. 2000; Lawrence and McLean 2000), but has been reported to be less effective in dry conditions (Koenning et al. 2007). Additional options for *R. reniformis* management are biologicals such as *Bacillus firmus* (Poncho®/VOTiVO®) and *Paecilomyces lilacinus* strain 251 (Nemout) as seed applied formulations (Castillo et al. 2013) that have been reported to have efficacy against the nematode. Furthermore, there are multiple nematophagous fungi with high levels of effectiveness in greenhouse studies (Wang et al. 2004; Castillo et al. 2009) that could prove useful in the future. Overall, the number of pesticides for the management of *R. reniform* is decreasing, resulting in increased challenges for producers.

14.3.4 Lance Nematode, Hoplolaimus *spp.*

14.3.4.1 Detection and Distribution

The lance nematode is a serious parasite of cotton, soybean and corn in parts of Georgia and Alabama (Davis and Noe 2000; Noe 1993). Among multiple species, *H. columbus, H. galeatus* and *H. magnistylus* are considered as the most pathogenic lance species. *Hoplolaimus galeatus* and *H. magnistylus* are the most frequently identified species in Alabama. In Georgia, *H. colombus* has been associated with cotton and soybean, on which tremendous damage and economic yield loss occurs in infested fields. From 2013 to 2017, Nematode Diagnostic Laboratory at University of Georgia found 51.6% of the counties contained lance nematodes (Fig. 14.7). Yield losses due to the nematode have been estimated to be as high as 18% and 48% on cotton and soybean, respectively (Noe 1993); however, losses of more than 50% can occur in sandy soils with high infestations (Fig. 14.8). The economic damage threshold was determined to be 50 nematodes/100 cm^3 of soil. Damaging levels of *H. columbus* has been found in 5% of cotton fields primarily in Georgia's Coastal Plain soils that have relatively high sand contents.

14.3.4.2 Management

Field studies conducted in Georgia (Davis et al. 2000) have shown that removal or destruction of root systems of cotton slightly suppressed populations of *H. columbus* but it had no effect on improvement of the yield of subsequent cotton crops. Control of *H. columbus* on cotton has been achieved primarily through nematicide application. Nematicides are expensive and environmental concerns make their usage problematic. Field research have shown that rotating tobacco with cotton may be effective in suppression of population densities of lance nematode. In soybean,

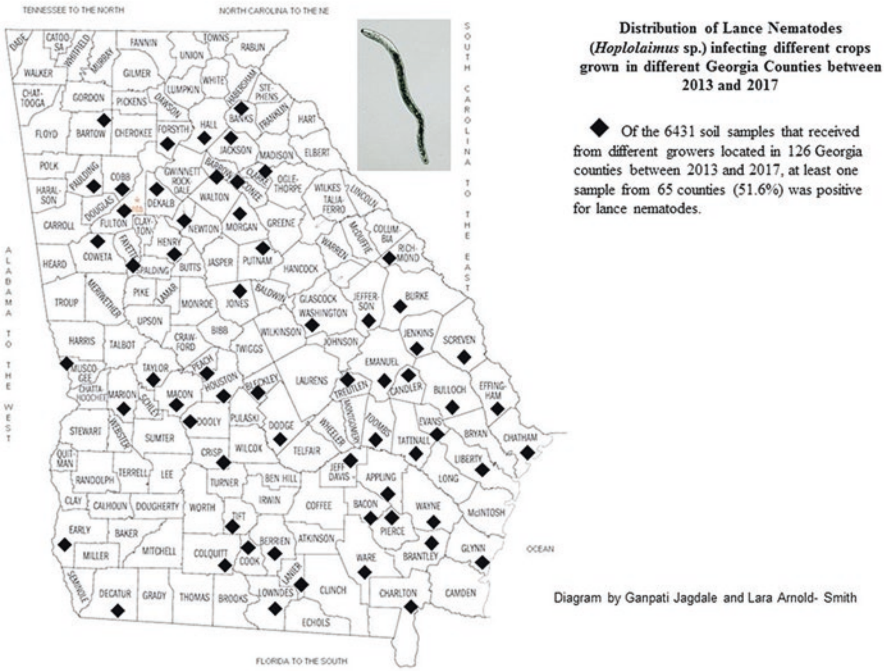

Fig. 14.7 The occurrence and distribution of lance nematodes on different crops including turfgrasses grown in different Georgia counties

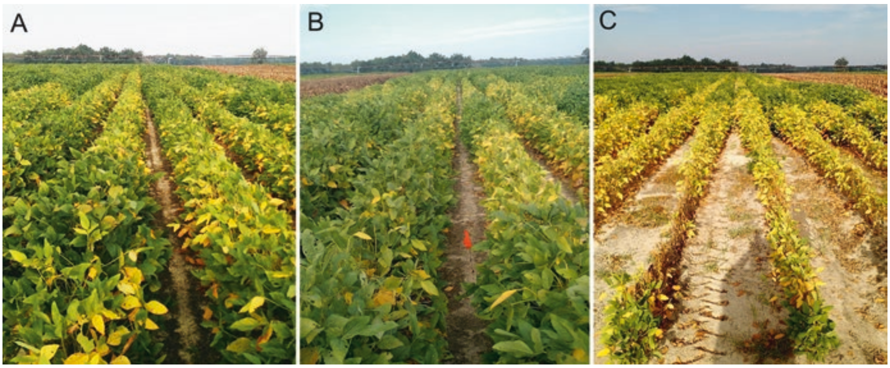

Fig. 14.8 Damage symptoms on soybean foliage in a field with low (**a**), moderate (**b**) and high (**c**) population levels of *Hoplolaimus columbus.* (Photos: John Mueller)

management of the lance nematode relies on the use of tolerant cultivars; however, variation in the response of soybean cultivars to *H. columbus* has been reported. Winter wheat and rye planted as cover crops had no impact on *H. columbus* populations (Davis et al. 2000).

14.3.5 *Stubby Root Nematode,* Paratrichodorus, Trichodorus *and* Nanidorus

14.3.5.1 Detection and Distribution

Stubby root nematodes are among the least studied nematode pests infesting cultivated crops in Georgia and Alabama. From 2013 to 2017, Nematode Diagnostic Laboratory at University of Georgia found 85.7% of the counties contained stubby-root nematodes (Fig. 14.9). Stubby root nematodes cause severe reduction in the growth and yield of multiple field and vegetable crops in the Southeastern U.S. These nematodes feed on the root tips of host crops, thus leading to a stunted, stubby appearance to the root system that can be incorrectly diagnosed as herbicide damage. The shoot of plants may appear stunted with chlorotic foliage (Fig. 14.10). Recent rise in corn acreage in the Southern U.S. has increased the presence of this nematode in the region. The nematode primarily occurred in the Coastal Plain soils of Georgia and Alabama although isolated fields infested with this nematode has been found in Northern Georgia. Severe root pruning to corn roots by the stubby root nematode is most often observed in cool wet springs in the Coastal Plain soils.

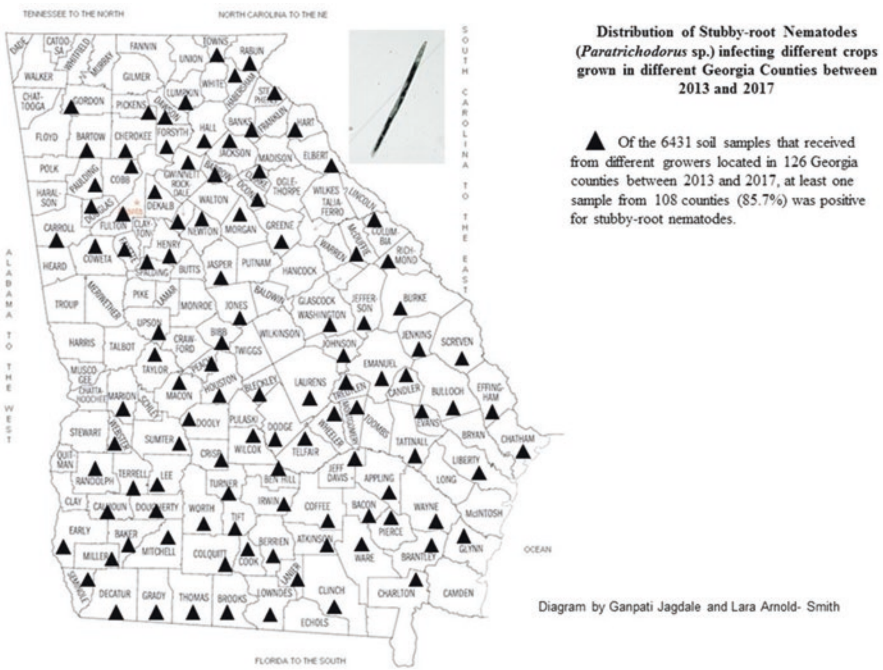

Fig. 14.9 The occurrence and distribution of stubby root nematodes on different crops including turfgrasses grown in different Georgia counties

Fig. 14.10 Field symptoms of *Nanidorus minor* in sweet corn (**a**, **b**), broccoli (**c**, **d**) and onion (**e**, **f**) showing large area of unevenly stunted plants and abbreviated root systems in Georgia. (Photos: Abolfazl Hajihassani)

In the Southern Georgia, *N. minor* is considered a major pest on multiple vegetable crops grown in sandy soils and is responsible for reduction in yield of sweet corn and sweet onion (Hajihassani et al. 2018b).

14.3.5.2 Management

The ability of stubby root nematodes to live deep in the coarse-textured soil profile and to reproduce fast in the presence of host plant roots make control of this nematode particularly challenging. It is known that continuous growing of highly susceptible crops such as corn and certain vegetable crops (e.g. onion, eggplant and sweet corn) can build up *N. minor* population to the economic damaging levels that may necessitate nematicide application on subsequent crops (Hajihassani et al. unpubl.). Tillage tends to reduce numbers of stubby root nematodes as well as rotation to peanut or soybean (Johnson et al. 1974). Cover crops such as pearl millet hybrids (cv. TifGrian 102), cowpea (cv. Mississippi Silver) or seasame (cv. Sesaco 16) tend to keep stubby root nematode populations below the damage threshold and may lessen grower's reliance on chemical control (Timper and Hanna 2005; McSorley and Dickson 1995). Resistant cultivars to the stubby root nematodes are not commercially available in current field and vegetable crops.

14.3.6 Ring Nematodes, **Mesocriconema** *spp.*

14.3.6.1 Detection and Distribution

Multiple species of ring nematodes (*Mesocriconema* spp.) occur in high population densities in the rhizosphere of crops including blueberry, peanut, soybean, corn, ornamentals, peach, turf grass and vegetables that are grown throughout Georgia. Between 2013 and 2017, the Nematode Diagnostic Laboratory at University of Georgia found ring nematodes in 85.7% of the counties (Fig. 14.11). However, *M. ornatum* and *M. xenoplax* are considered the most damaging species of ring nematode in Georgia. Of these two species, *M. ornatum* is predominantly associated with crops like blueberry, corn, cotton, peanut, soybean, vegetables and turfgrass whereas *M. xenoplax* is mainly associated with peaches, grapes, ornamentals and turfgrasses. Although both *M. ornatum* and *M xenoplax* cause serious damage to many crop species, a major emphasis in this chapter is placed on their impact on blueberries and peaches, respectively, because of their tremendous economic damage to these valuable crops in Georgia.

14.3.6.2 Ring Nematode, *Mesocriconema xenoplax*

In Georgia, peach, *Prunus persica* production is a $31.3 million industry (2012 USDA Georgia Agricultural Facts), but it is on the verge of decline due to the incidence of many diseases like Armillaria root rot and plant parasitic nematodes like ring nematodes, *M. xenoplax* (Savage and Cowart 1942; Miller 1994). Ring nematode is a primary cause of peach tree short life (PTSL) disease that causes premature deaths of peach trees (Nyczepir et al. 1983). Peach tree short life is a disease

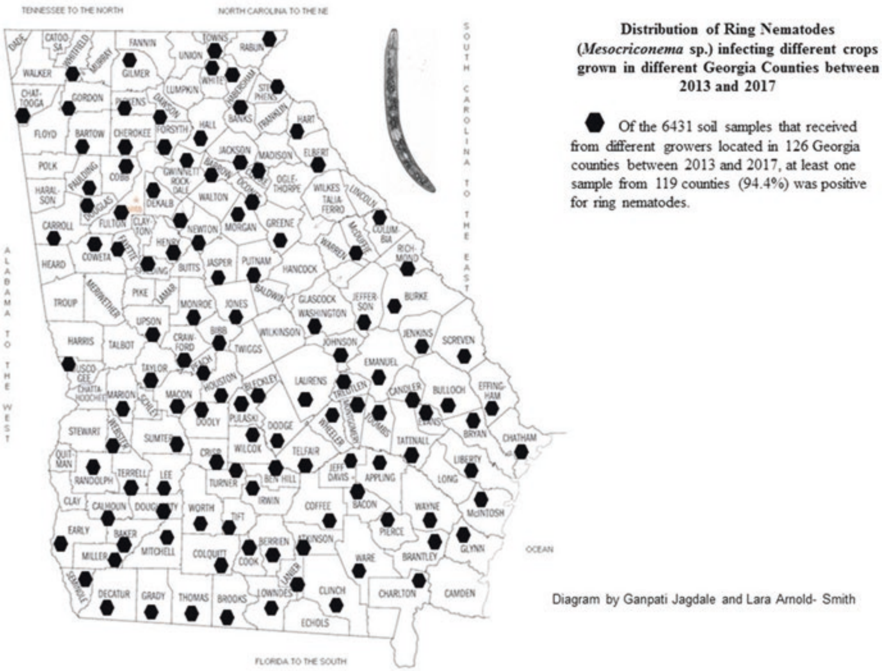

Fig. 14.11 The occurrence and distribution of ring nematodes on different crops including turfgrasses grown in different Georgia counties

complex in which ring nematode infested peach trees become susceptible to combination of factors including cold injuries and bacterial canker disease caused by *Pseudomonas syringae* pv. *syringae* or to each of these individual factors (Brittain and Miller 1978; Nyczepir et al. 1983). According to Nyczepir et al. (1983), *M. xenoplax* infested peach trees died of cold injury, but trees without nematode infestations were resistant to cold injuries. Furthermore, *M. xenoplax* infested trees were more susceptible to bacterial spot disease caused by *Xanthomonas arboricola* pv. *pruni* than uninfected trees (Shepard et al. 1999). The main symptoms of PTSL (Fig. 14.12) include wilting of young leaves, discoloration of cambial tissue and the collapse of new growth above the soil line and eventually death of trees (Nyczepir et al. 1985).

14.3.6.2.1 Management of *M. xenoplax*

The management of ring nematodes is essential for maintaining and optimizing yield of peach orchards. It has been demonstrated that pre-plant fumigation with 67% methyl bromide +33% chloropicrin mixture suppressed the population of *M. xenoplax* in the peach orchards (Nyczepir et al. 2012). Since importation and

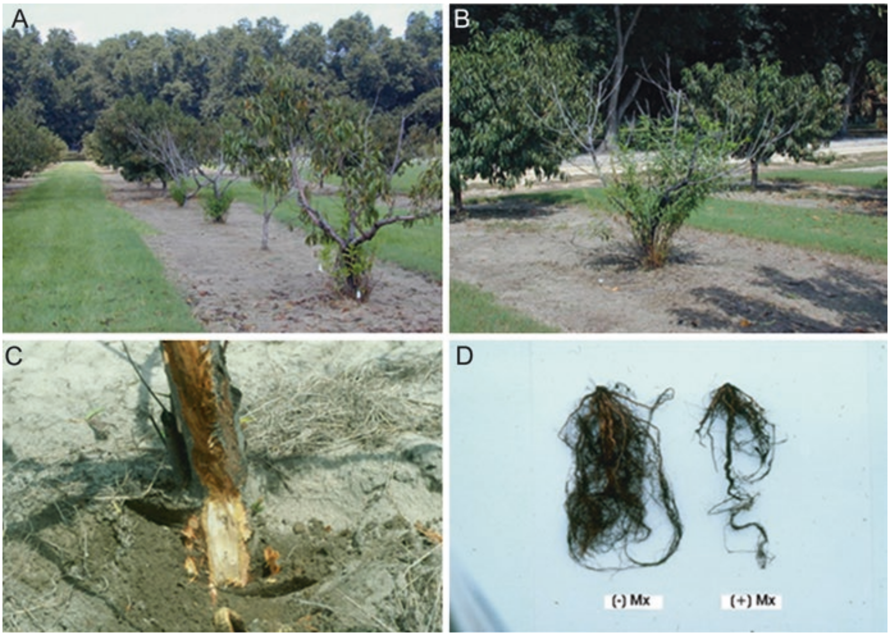

Fig. 14.12 Peach tree short life (PTSL) disease caused by ring nematode, *Mesocriconema xenoplax*. (Photos: Andrew Nyczepir)

manufacturing of methyl bromide was banned in the US and Western Europe after January 2005 (Clean Air Act 1990) there was interest in finding alternatives to chemical nematicides to manage ring nematodes infesting peach orchards. Currently the only pre-plant fumigant chemicals available are Telone II (1,3-Dichloropropene) and Vapam® (metam sodium), with Telone II being the one primarily being used and recommended to growers (Horton et al. 2013). Crop rotation with different cover crops has been recognized as one of the best management practices that reduces plant parasitic nematode populations and the associated crop damage (McSorley 2001). Growers in the Southeast generally remove the peach orchard when heavy tree loss from PTSL occurs and often replant these orchards with field crops or small grains instead of peaches. Studies conducted by Georgia scientists on the interaction between small grain crops and *M. xenoplax*, showed that wheat (cv. Stacy) and sorghum (cv. NK2660) plants were poor and nonhost of *M. xenoplax*, respectively (Nyczepir and Bertrand 1990; Nyczepir et al. 1996). They also demonstrated that planting wheat as a groundcover can suppress the populations of *M. xenoplax* and prolonging tree survival on PTSL sites (Nyczepir and Bertrand 2000). Sorghum as green manure was also as effective as methyl bromide in suppressing populations of *M. xenoplax*. According to Nyczepir (2005), rotation of land with wheat/fallow for 3 years prior to re-planting peach orchards can be effective as pre-plant methyl bromide fumigation in suppressing ring nematode populations and increasing tree survival on a PTSL sites. Based on the results of 3-year preplant wheat rotation research, a current recommendation of pre-planting of wheat as rotation crop to prolong tree survival on PTSL sites is available for peach growers in the Southeastern U.S. (Horton et al. 2010). Resistant rootstocks also play an important role in reducing the severity of PTSL. For example, studies conducted in both South Carolina and Georgia showed that peach trees on Guardian rootstock survive better than on Lovell and Nemaguard rootstock when planted in *M. xenoplax* infested fields (Okie et al. 2009). Solarization can influence the population density of *M. xenoplax* in the fields. The effects of solarization, biological control bacteria, *Pseudomonas* spp. and wheat as rotation crop as alternatives to chemical nematicides against *M. xenoplax* in Georgia were evaluated from 2004 to 2011 (Nyczepir et al. 2012). These researchers found that *M. xenoplax* populations were equally suppressed in solar-wheat-treated soil and methyl bromide fumigated plots. Recently, Noe et al. (2015a, b) reported that application of the nematicide fluensulfone (Nimitz) has potential to suppress of *M. xenoplax* population densities on both very susceptible (Nemaguard) and tolerant (Guardian) peach rootstocks to PTSL.

14.3.6.3 Ring nematode, *Mesocriconema ornatum*

Blueberry (*Vaccinium* spp.) is grown in more than 30 states representing over 29,137 ha in the United States (Anon. 2012). The blueberry industry in Georgia continues to grow rapidly, with substantial acreage increasing on a yearly basis. However, although good sites remain for rabbiteye (*V. virgatum*) and southern highbush (*V. corymbosum*) production, the cost of land and site preparation is substantial, especially for southern highbush cultivars that may require added organic matter. Due to the age of the industry in Georgia, many plantings are now reaching the greater than 25-year timeframe and as these plantings decline in productivity, growers often replant these older sites rather than purchase new land. In addition, as newer varieties with desirable traits enter the market, older varieties are often not competitive in yield or quality; therefore, older varieties are often replaced with newer varieties even prior to their natural decline. These replanted sites often exhibit poor plant growth, yellowing, stunting, higher mortality, premature decline (J.P. Noe, Univ. Georgia, pers. com.) and severely reduced yields, symptoms collectively known as Blueberry Replant Disease (BRD; Figs. 14.13a, b), which is considered an emerging threat to the blueberry industries in Georgia (J.P. Noe, Univ. Georgia, pers. com.). In 2008, a preliminary survey of several commercial blueberry fields in Georgia revealed very high ring nematode populations (ca. 1,000 *M. ornatum*/100 cm^3 soil) associated with the rhizosphere of blueberries exhibiting typical BRD symptoms (P.M. Brannen, Univ. Georgia, pers. com.). Major parasitic nematodes frequently associated with commercially grown blueberries in Georgia include ring (*M. ornatum*), dagger (*Xiphinema* spp.), stunt (*Tylenchorhynchs* spp.), spiral (*Helicotylenchus* spp.), lance, root knot and stubby root nematodes (Jagdale et al. 2013). Although the pathogenicity of most of these plant parasitic nematodes to blueberry is unknown, preliminary tests with fumigant nematicides, oxamyl and

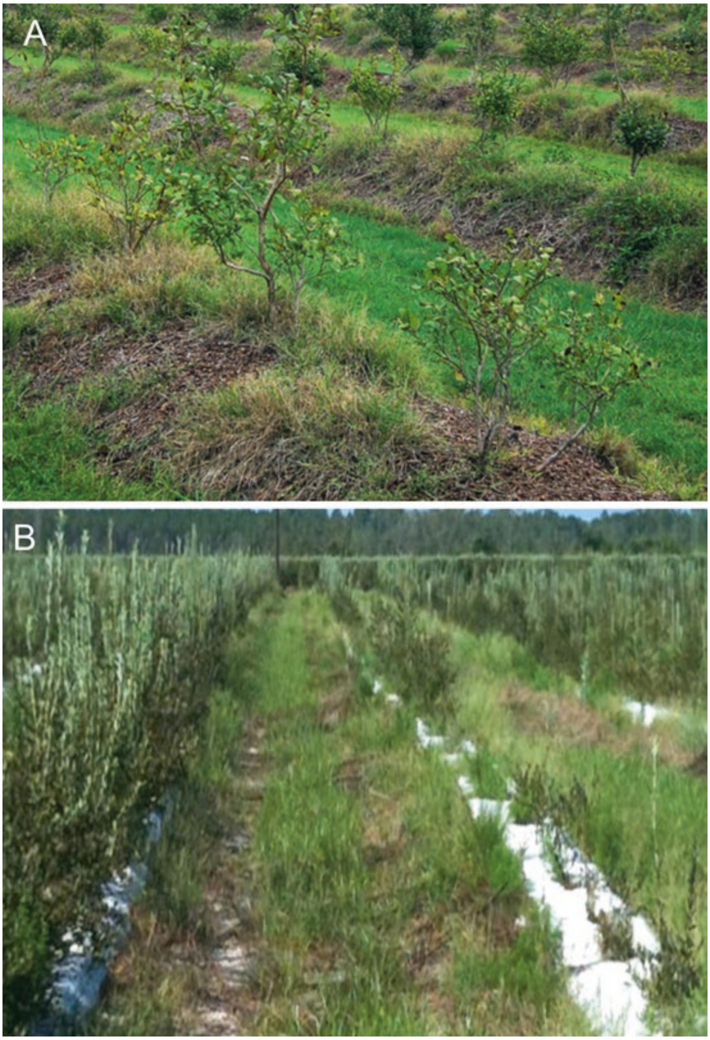

Fig. 14.13 Blueberry replant disease caused by ring nematode, *Mesocriconema ornatum* (**a**), blueberry plots infested with *M. ornatum* and treated with methyl bromide (left) and untreated control (right) (**b**). (Photos: Jim Noe and Phillip Brannen)

Telone II showed a strong correlation between increased plant growth, vigor and decreased nematode densities, suggesting detrimental impacts of nematodes (Noe et al. 2012) especially ring nematodes, *M. ornatum* (Jagdale et al. 2013). The widespread occurrence of ring nematodes in blueberry and their demonstrated pathogenicity, indicates that BRD could become a major limitation to continued production on existing farms. The economic impact of BRD could be devastating to growers when establishing new plantings, as the estimated cost of establishing and maintaining blueberry is $93,800/ha for the 4 years normally required before full production (Fonsah et al. 2007). If the farm is infested with ring nematodes, as 52% of the fields sampled in Georgia were (Jagdale et al. 2013), then the grower could lose the entire investment at about the time that the blueberries would normally be coming into production.

14.3.6.3.1 Management of *M. ornatum*

Pre-plant fumigants such as oxamyl and Telone II are available for use against *M. ornatum*, but these products are expensive, pose health risks to the applicator if handled improperly, kill beneficial soil microbiota, highly regulated (U.S. EPA 2009) and they only temporarily suppress nematode populations. Since surviving nematodes will continue feeding and multiplying on new plants, a post-plant nematicide is needed to minimize population densities that increase in blueberry over multiple years; currently, there are no post-plant nematicides registered for use on blueberry. In addition, no nematode-resistant cultivars have yet been identified in blueberry. Although the management of nematodes including *M. ornatum* on blueberry has relied heavily on pre-plant fumigation, there is interest in developing safe alternatives as acceptable post-plant methods of control. In addition, due to increased consumer demand for organic foods including fruits and vegetables, many blueberry growers are also inclined towards production of organic blueberries. Studies on pre-plant fumigation with methyl bromide and solarization of the soil under clear plastic showed that solarization and fumigation reduced population densities of *M. ornatum* by 64% and over 90%, respectively compared with nontreated plots (Noe et al. 2012). Noe et al. (2015b) studied the efficacies of pine bark amendment with and without pre-plant application of soil fumigant against *M. ornatum* under field conditions and showed that the addition of pine bark soil amendment with a robust protocol of pre-plant soil fumigation may provide a more sustainable level of management for blueberry replant disease. Five cultivars each of Rabbiteye (Brightwell, Ochlocknee, Powder Blue, Premiere, Vernon) and southern highbush (Emerald, Farthing, Rebel, Star, Legacy) blueberry types were evaluated for their resistance/tolerance to BRD in fields in Georgia. *Mesocriconema ornatum* population densities increased between May and October for all cultivars, but increases were greatest for highbush cultivars, suggesting that BRD is more severe on southern highbush (Noe et al. 2014).

14.4 Future Research and Challenges

The options available for plant parasitic nematode management include sanitation, resistant and tolerant cultivars, crop rotation, cover crops, conservation tillage, soil amendment, biocontrol and nematicides. In most cases, a stand-alone option for control of plant parasitic nematodes is not sufficient and a combination of management practices will be needed to keep nematode populations below the economic thresholds. With the potential loss or shortage of effective fumigant or non-fumigant nematicides in the future, the need for continued assessment of alternative approaches for environmentally friendly, yet sustainable and effective treatment options has increased. Resistance is the most aggressive, economical treatment to manage plant parasitic nematodes and provides the best opportunity to manage nematodes affecting agricultural crops. Sources of resistance to southern and peanut root knot and reniform nematodes have been identified in some field and vegetable crops. Identifying new sources of resistance are required to develop new cultivars with broad and durable resistance to injurious nematodes. In order to advance breeding for resistance, genetic diversity of nematode populations need to be studied further and new molecular markers for resistance genes needs to be developed in order to expedite the process of introgression of nematode-resistant genes into high-yielding cultivars. The development of cultivars with resistance or tolerance to parasitic nematodes will provide growers with a simple to use, consistently effective and inexpensive tool for nematode management.

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