Chapter 16
Plant Parasitic Nematodes of Economic Importance in Texas and Oklahoma

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16.1 Agricultural Crops of Economic Importance in Texas and Oklahoma

The region of Texas and Oklahoma produce a wide range of crops that are grown under a diversity of environments. There were over 66 million hectares involved with farm operations in these two states during 2016. Some of the most economically valuable field crops include cotton ($2.1 billion [value of production or sales] on 1,910,116 ha), hay ($1.37 billion on 3,136,313 ha), corn ($1.26 billion on 910,543 ha), wheat ($973 million on 2,974,439 ha), sorghum ($645 million on 1,157,401 ha), soybean ($127 million on 198,296 ha), peanuts ($120 million on 71,629 ha) and rice ($111 million on 52,609 ha) (Table 16.1). The highest valued vegetables grown in this region include potato ($107 million), cabbage ($31 million), onions ($20 million) and chili peppers ($14 million). Fruits grown in this region include melons ($69 million), grapefruit ($39 million), grapes ($18 million), oranges ($17 million) and peaches ($8 million). There is also a large industry for bedding plants (annuals, $136 million; perennials, $32 million), indoor flowering ($27 million) and foliage plants ($10 million).

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Table 16.1 Rank of select commodities in Oklahoma and Texas by value of production in 2015[a]

Commodity	Value ($) of Production × 1000		Percent of US[b]
	OK	TX	
Cotton	126,546	1,992,429	53.1
Hay	515,320	858,921	8.3
Corn, grain	141,952	1,116,990	2.6
Wheat	471,276	501,615	9.7
Sorghum, grain	73,307	571,616	31.2
Bedding plants, annual		136,112	21.8*
Soybean	102,300	25,116	0.4
Peanuts	6,518	112,992	10.3
Rice		111,154	4.6
Potatoes		106,922	2.7*
Pecans	20,770	73,860	18.3*
Melons	7,290	61,577	8.1*
Grapefruit		38,557	15.6*
Bedding plants, perennial		32,118	5.7*
Cabbage		30,855	6.8*
Flowering plants (indoor)		27,165	3.4*
Sunflower	1,295	21,052	3.9
Canola	20,845		4.6
Onions		19,680	2.1*
Sugarcane		18,768	1.9
Grapes		18,260	0.3*
Rye	17,646		23.4
Oranges		16,509	0.7*
Peppers, chili		14,335	0.2*
Beans		12,779	1.5
Oats	669	10,428	5.2
Squash		10,260	5.4*
Foliage plants (indoor)		10,213	1.9*
Cucumbers		9,122	5.4*
Peaches		8,460	1.3*
Sweet corn		7,138	2.5*
Spinach		5,523	2.1*
Tomatoes		4,860	0.4*

[a]USDA/NASS 2015 State Agriculture Overview for Texas and Oklahoma
[b]Commodities with a * had the % of US value calculated based on total production in the US in 2014

Water stress is a major limiting factor for crop production in the western part of Texas and Oklahoma. In Texas, annual rainfall in the southeastern part of the state, near Houston, averages approximately 129.5 cm, whereas, totals in the northcentral region, near Dallas, average approximately 91.4 cm (Fig. 16.1a). Rainfall amounts for western areas are far less, averaging 48.3 and 22.9 cm for Lubbock (High Plains area) and El Paso (Trans Pecos area) respectively. The eastern part of Oklahoma

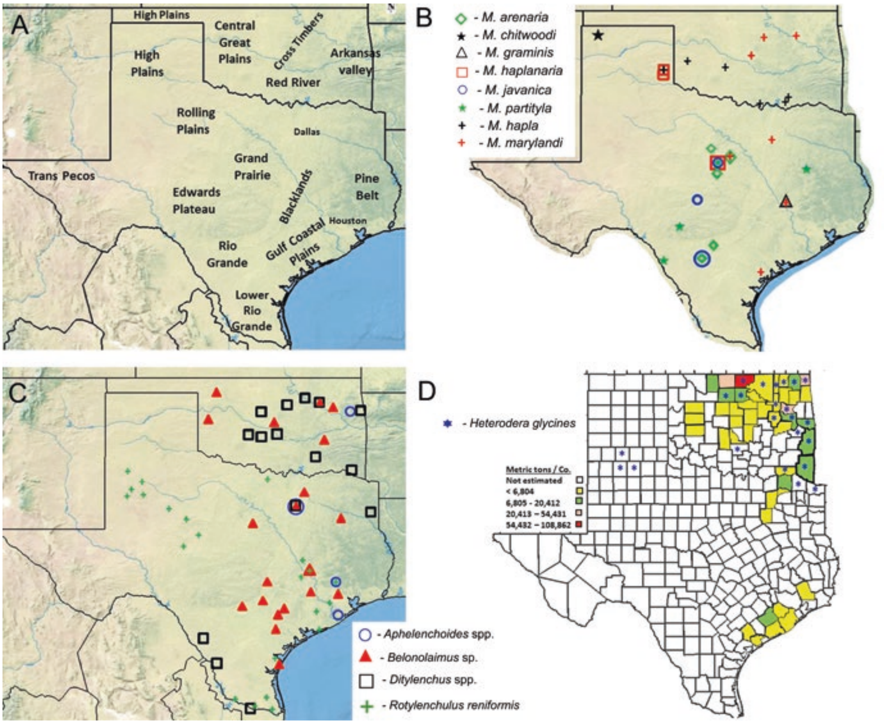

Fig. 16.1 (**a**) Map of geographic regions in Texas and Oklahoma; (**b**) Distribution of root knot nematodes; (**c**) Locations of counties found positive for the foliar nematode *Aphelenchoides* spp. sting nematode *Belonolaimus* sp., stem and bulb nematode, *Ditylenchus* spp. and reniform nematode *Rotylenchulus reniformis*; (**d**) Map of soybean production in 2016 as determined by the U.S. Department of Agriculture National Agricultural Statistics Service. Location of counties that have tested positive for *Heterodera glycines*

averages around 99–119 cm of rain (Arkansas Valley), decreasing to 76–97 cm in the Central Great Plains and down to 38–51 cm in the High Plains.

The most important plant parasitic nematodes associated with crop production in the States of Texas and Oklahoma are the root knot nematodes (*Meloidogyne* spp.). The species of importance can vary depending on the crop. *Meloidogyne incognita* is the root knot nematode species that attacks cotton (*Gossypium hirsutum*), whereas, *M. arenaria*, is the most important species affecting peanut (*Arachis hypogaea*) in Texas and *M. hapla* is the most important species on peanut in Oklahoma. While several root knot nematode species can be found on potato (*Solanum tuberosum*), *M. hapla* is most frequently found in Texas. There are other root knot nematode species that are also present in the region including *M. partityla* on pecan (*Carya illinoinensis*), *M. graminis* on grass species, *M. marylandi* on turf, *M. javanica* and *M. haplanaria* on peanut, *M. chitwoodi* on potato and various species of root knot nematode on soybean. Other nematode species that can be highly damaging, depending on crop and location, include citrus nematode (*Tylenchulus semipenetrans*) on citrus in the Lower Rio Grande Valley, reniform nematode

(*Rotylenchulus reniformis*) on cotton in Texas, soybean cyst nematode (*Heterodera glycines*) on soybean in Oklahoma, sting nematode (*Belonolaimus longicaudatus*) on several crops in both states, stem and bulb nematode (*Ditylenchus dipsaci*) primarily on alfalfa in Oklahoma and the foliar nematode (*Aphlenchoides besseyi*) on rice and ornamentals, bedding plants and indoor flowering plants. The distribution and importance of these nematodes in Texas and Oklahoma are discussed below.

16.2 Plant Parasitic Nematodes That Are Economically Important in Texas and Oklahoma

16.2.1 Root Knot Nematodes, Meloidogyne *spp.*

16.2.1.1 Cotton

The southern root knot nematode, *Meloidogyne incognita*, is found throughout Texas and Oklahoma. Cotton is the most valuable crop in this region, and the highest concentration of cotton is produced in the southern part of the High Plains of Texas (Fig. 16.1a). Approximately 40–50% of the cotton in this area is planted in coarse-textured soils and is infested with *M. incognita* (Starr et al. 1993; Wheeler et al. 2000). Root knot nematode is rarely found in soils with a clay component greater than 40% (Starr et al. 1993). In Oklahoma, *M. incognita* can be found throughout the south and southwestern regions where cotton is grown.

Damage to cotton caused by *M. incognita* in the southern part of the High Plains (in the absence of any management) was estimated at 26% average yield loss, based on 80 field trials conducted over 16 years (Orr and Robinson 1984). Root knot nematodes typically form galls on roots and, consequently, cause plants to have shorter root systems. Interactions with fungi such as *Thielaviopsis basicola,* which is also common in this region, (Walker et al. 1998; Wheeler et al. 2000) can also limit root growth (Ma et al. 2014). This reduction in root length has been associated with a corresponding reduction in water transported through roots (Dorhout et al. 1991). Cotton yields are often limited by insufficient amounts of water in soil. Roots that are inefficient or smaller due to root knot nematode infections will place further stress on plants. However, drier conditions may also inhibit hatching of *M. incognita* eggs and limit movement of second-stage juveniles in soil.

Cotton producers take definite steps to manage root knot nematode, however, management options must fit into their overall production systems. For example, wind erosion is a significant problem in the Southern High Plains and a cover crop of wheat or rye can be planted in the fall or winter to keep the soil from blowing away. Other cover crop species are not often utilized in the western part of Texas and Oklahoma because they can require too much water for establishment and growth. The winter months are relatively dry in the Southern High Plains. From 2007 to 2016, the average accumulation of rainfall from December through March was 7.6 cm in Terry County, TX, which is located centrally within the high root knot nematode-infested region. Recently, across the U. S., there has been a surge in the use of cover crops to improve soil health, and in some cases to assist in nematode management. However, the more arid parts of Texas and Oklahoma are limited to cover crops that require less moisture for plant establishment and growth, or the non-use of cover crops to conserve soil moisture for the cotton crop. Cover crops remove moisture from the soil profile, and consequently in drier years, greatly reduce cotton yield. Deficit irrigation is practiced in 30–40% of the Southern High Plains of Texas, which means that cotton can be irrigated, but there is insufficient irrigation water available to replace water lost through evapotranspiration. The remaining area is termed dryland (rainfed) where *M. incognita* may be present, though often in lower densities than in cotton cultivated on irrigated land. Many dryland hectares are abandoned each year due to lack of rain, therefore, nematode management on non-irrigated land must budget for frequent crop failure.

Crop rotation can be an excellent method of managing root knot nematodes and improving soils for subsequent cotton production. Peanut, as a non-host for *M. incognita*, will provide excellent root knot nematode control in the cotton crop that follows it. Currently in Oklahoma and Texas, less than 10% of the areas infested with *M. incognita* are in rotation with peanuts as water limitations prohibit the production of this crop.

Sorghum is another popular crop that is used in rotation with cotton in Texas and Oklahoma. This crop provides good residue when harvested for grain. The remaining plant residue after harvest does not degrade as quickly as a low-residue crop like cotton. The higher residue left on the soil reduces erosion and improves rainfall retention in soil. However, sorghum cultivars are generally adequate hosts for local populations of *M. incognita* (Orr and Morey 1978). There have been several studies that indicate sorghum is a poor host for *M. incognita* (Aminu-Taiwo et al. 2015; Fortnum and Currin 1988; Ibrahim et al. 1993). Most *M. incognita* host-range studies with sorghum cultivars have been conducted on races that are not found in this region. A survey of *M. incognita* was conducted across the Southern High Plains of Texas and all 50 populations tested were race 4 (Wheeler unpublished). A 3-year study was conducted in Dawson County, TX, on a 2-year cotton and 1-year sorghum rotation compared to continuous cotton. Cotton lint yields in the continuous cotton system averaged 669, 865 and 974 kg/ha at a low, medium and high irrigation rate, respectively (Keeling et al. 2010a, 2011a, 2012a). Cotton lint yields following sorghum in the same field and during the same years, averaged 672, 900 and 1108 kg of lint/ha at a low, medium and high irrigation rate, respectively. The yield improvement in the rotated cotton over continuous cotton was 1%, 4% and 12% for the low, medium and high irrigation rates, respectively (Keeling et al. 2010b, 2011b, 2012b). Root knot nematode density sampled in the fall over those 3 years, averaged 808/500 cm^3 soil in sorghum, 4,473/500 cm^3 soil in cotton following the sorghum crop and 3,649/500 cm^3 soil in continuous cotton (Wheeler unpublished). Generally, irrigated sorghum yields in this region are not considered as profitable as yields from irrigated cotton. Therefore, to maintain profitability, reducing cotton hectares to rotate with sorghum requires better yields from rotated cotton than from continuous cotton.

A better rotation for root knot nematode management is cotton followed by winter wheat, followed by summer fallow. This rotation maximizes retention of rainfall in the soil and greatly increases cotton yields while reducing root knot nematode densities. As irrigation pumping capacities have dropped in Texas and Oklahoma, it has become more popular to leave a portion of a field out of cotton so that irrigation water can be concentrated on only part of that field. The winter wheat/summer fallow fits well into this cropping system. The limited irrigation capacity can be utilized on part of the field during the cotton growing season to produce good cotton yields (typically on less than 18 cm irrigation), and there is limited irrigation available during the winter to grow the wheat crop. The high-residue wheat stubble left after the spring harvest of wheat, allows rain to be retained in the field and keeps the soil from blowing. A 3-year study was conducted on a cotton/wheat/fallow rotation compared to continuous cotton in Dawson County, TX. Using a root knot nematode susceptible cultivar, the yield of cotton following a wheat/fallow rotation averaged 50–57% higher (depending on irrigation rate, Table 16.2) than yield in continuous cotton. Early season galling on cotton was significantly higher in continuous cotton, compared to rotated cotton (Wheeler unpublished), although, by late season, there was no difference in root knot nematode densities in susceptible cotton cultivars in the two cropping systems (Table 16.2). There was, however, a larger reduction in root knot nematode density when a partially resistant cultivar was combined with the rotated (wheat/fallow) cotton crop (Table 16.2).

Commercial, partially resistant root knot nematode cultivars have been available since the 1990s. However, there was almost no cotton planted with root knot nematode resistance in Texas and Oklahoma until 2003 (Table 16.3). Between 2003 and 2016, 0.3% (2007) to 8.9% (2009) of the cotton land in Oklahoma was planted with cultivars that had some resistance to root knot nematode. In Texas from 2003 to

Table 16.2 Effect of crop rotation with winter wheat/summer fallow (W-F) and cotton compared with continuous cotton (CC) on cotton yield and root knot nematode density over a 3-year period

Average irrigation[a] amounts on cotton (cm)		Average lint yield (kg/ha)[b]				Average root knot nematodes/500 cm[b] soil in late summer			
		Susceptible[c]		Partially resistant[c]		Susceptible		Partially resistant	
CC[c]	W-F/C[c]	CC	W-F/C	CC	W-F/C	CC	W-F/C	CC	W-F/C
16.8	15.2	657	1,025	704	1,070	1,667	236	1,967	276
20.6	19.3	772	1,160	892	1,182	2,760	1,780	1,913	704
24.6	23.4	829	1,303	986	1,366	2,098	1,631	3,540	840

[a]After plant establishment, there were three irrigation rates applied in a randomized complete block design (see column 1 and 2) with three replications. The first two columns present preplant and in-season irrigation totals, averaged from 2014 to 2016 for the three irrigation rates

[b]The cotton tests were managed by Dr. Wayne Keeling (Texas A and M AgriLife Research). Yields were reported annually in the AGCARES report (2014–2016) at http://Lubbock.tamu.edu

[c]Cultivars that were planted in a split-plot design with irrigation as the main factor and cultivar as the split plot. There was a susceptible (NG 1511B2RF) and partially resistant (ST 4946GLB2) cultivar planted each year in the test area

Table 16.3 Cotton varieties planted in Oklahoma or Texas that are marketed as resistant or tolerant to root knot nematode[a]

Year	Cotton planted (%)		Cultivars marketed as having resistance to root knot nematode
	OK	TX	
2003	0.73	0.49	[b]ST 5599BR
2004	6.09	1.15	ST 5599BR
2005	0.76	0.63	ST 5599BR
2006	1.69	0.74	ST 5599BR
2007	0.34	0.59	ST 5599BR
2008	4.51	0.49	[b]DP 174RF, ST 5458B2F, ST 5599BR
2009	8.88	3.67	DP 174RF, ST 5458B2F
2010	4.80	1.40	DP 174RF, ST 4288B2F, ST 5458B2F
2011	2.78	5.30	DP 174RF, [b]PHY 367WRF, ST 4288B2F, ST 5458B2F,
2012	3.19	4.77	DP 174RF, PHY 367WRF, ST 4288B2F, ST 5458B2F,
2013	0.63	4.65	DP 174RF, PHY 367WRF, ST 4288B2F, ST 4946GLB2, ST 5458B2F,
2014	0.95	5.67	PHY 367WRF, PHY 417WRF, ST 4288B2F, ST 4946GLB2, ST 5458B2F
2015	0.08	9.41	PHY 367WRF, PHY 417WRF, ST 4946GLB2,
2016	2.03	4.07	DP 1558NRB2RF, PHY 417WRF, ST 4946GLB2
2017	0.00	2.18	DP 1558NRB2RF, DP 1747NRB2XF, PHY 427WRF, ST 4946GLB2

[a]Planted percentages of nematode resistant cultivars to total planted cotton in Oklahoma and Texas, were calculated from the annual "Cotton Varieties Planted", published by the USDA Agricultural Marketing Service, Memphis, TX
[b]*DP* Deltapine, *PHY* Phytogen, *ST* Stoneville

2017, the percentages ranged from 0.5% (in 2003 and 2008) to 9.4% (2015). The reduction in nematode reproduction varies with the cultivar. Cultivars with two resistant genes, (DP 1558NRB2RF (Deltapine, currently a subsidiary of Monsanto), DP 1747NRB2XF, PHY 417WRF (Phytogen, a subsidiary of Corteva Agriscience) and PHY 427WRF, can reduce root knot nematode densities substantially more than a single resistant gene cultivar (DP 174RF, PHY 367WRF, ST 5599BR (Stoneville, currently a subsidiary of Bayer CropScience), ST 5458B2F, ST 4288B2F and ST 4946GLB2) (Wheeler et al. 2016).

Crop rotations with non/poor hosts or fallowing (i.e. no crop grown during the summer months) to reduce root knot nematode densities will only be effective if good weed control is maintained. The southern root knot nematode has a wide host range including many weeds (Rich et al. 2008). Therefore, it is not unusual to see galls on weeds in this region in cotton fields or in weedy, fallow fields (Manuchehri et al. 2015). Weeds that blow into the field can also initiate root knot nematode problems, especially if root knot nematodes can survive in the weed's root system. Significant stunting was found on cotton near the edge of a field, that previously had no history of root knot nematode (Wheeler pers. comm.). The cotton roots were heavily galled with *M. incognita*. Russian-thistle (*Salsola tragus* L.) plants had blown that winter/spring into the field. Root knot nematode counts as high as 36,600/500 cm^3 soil were found in research plots that were placed in that area. That high infestation of root knot nematode built up in a single growing season because infected weeds blew into the field.

Prior to 2011, root knot nematode was controlled primarily with aldicarb® applied in furrows at planting, and occasionally, with oxamyl® after plant emergence (typically around 40–45 days after planting). Aldicarb production by Bayer CropScience (Raleigh, NC) was discontinued in 2011 and although it is currently being manufactured and sold by AgLogic Chemical LLC (AgLogic™ 15G, Chapel Hill, NC), aldicarb has not been distributed for sale in Texas or Oklahoma as of 2017. Seed treatment nematicides have also been utilized to manage root knot nematode in cotton. However, having sufficient moisture to wash the seed applied nematicide off the seed coat and into the soil profile has been difficult in arid environments such as the Southwestern United States. This region has less success with chemical control than in environments where rainfall is more common (Wheeler et al. 2013, 2014). The chemicals, abamectin®, fluopyram® and thiodicarb®, are currently labeled as seed treatment nematicides on cotton and are used to varying extents in Texas and Oklahoma. Fluopyram has also been labeled for application in furrows at-planting of cotton. Texas and Oklahoma are not likely to return to a heavy dependence on chemical control of root knot nematodes, that occurred with aldicarb prior to 2011. The per hectare cost of liquid or granular nematicides has doubled since 2011 and there are now more cultivars available with, at least, partial root knot nematode resistance. The loss of aldicarb in 2011 spurred an increased emphasis on breeding for nematode resistant cultivars. Though these cultivars are not particularly well adapted to the growing conditions in the High Plains, they often provide a yield advantage over susceptible cultivars (Wheeler et al. 2009, 2014). Root knot nematode resistant, cultivar yield response is more consistent than that found for chemical protection (Wheeler et al. 2014), when the amount of water (irrigation and rainfall) is insufficient to properly distribute nematicides around a root profile (Faske and Starr 2007).

16.2.1.2 Peanut

Meloidogyne arenaria, also known as the peanut root knot nematode, is commonly found in South Texas (Atascosa and Frio Counties) and Central Texas (Eastland, Erath and Comanche Counties), as well as Northwestern Rolling Plains (Collingsworth County, TX) (Fig. 16.1b) (Wheeler and Starr 1987; Woodward personal observations). In Oklahoma, *M. hapla* is the primary nematode problem on peanut and has been found in Beckham, Bryan, Caddo and Love Counties (Fig. 16.1b). *Meloidogyne hapla* has also been associated with enhanced pod rot problems, caused by *Pythium* spp. and *Rhizoctonia solani* (Filonow and Russell 1991). *Meloidogyne arenaria* is also found in Oklahoma, but less frequently than *M. hapla*. Other root knot nematode species that have been associated with peanuts include *M. javanica* (Comanche, Frio and Mason Counties in Texas (Fig. 16.1b) (Tomaszewski et al. 1994) and *M. haplanaria* in Collingsworth and Comanche Counties in Texas (Eisenback et al. 2003) (Fig. 16.1b). *Meloidogyne haplanaria* was a newly described species found originally in peanut in Collingsworth County, Texas in 1993. Management of root knot nematodes in peanut can be accomplished by rotation with a non-host. Cotton is a host only for *M. incognita*, making it an excellent rotation crop for all the species that affect peanut. Nematode resistant peanut cultivars have been developed to *M. arenaria* and *M. javanica*. The first root knot nematode resistant cultivar developed was COAN, which was released in 1999 by Texas AandM Experiment Station, followed by NemaTAM in 2002 (Starr and Morgan 2002). The runner cultivar Webb was released in 2013 by Texas A&M AgriLife Research and it combines the high-oleic fatty acid trait with resistance to root knot nematode (*M. arenaria*) (Simpson et al. 2013). As with cotton, the nematicide aldicarb was, at one time, utilized to manage root knot nematode in peanut in Texas and Oklahoma. Other contact nematicides such as ethoprop, were registered for use in peanut, but have also been removed from the market. Several fumigant nematicides such as chloropicrin, dichloropropene and metam-sodium, are available, but are often cost-prohibitive. Currently, there is limited use of fluopyram to manage root knot nematode in Texas and Oklahoma.

16.2.1.3 Grasses and Cereals

There are many root knot nematode related problems with turf and other grass species in Texas and Oklahoma. In most cases, species of *Meloidogyne* have not been identified. However, *M. graminis* was found in bermudagrass (*Cynodon dactylon*) in Collin County, TX (Fig. 16.1b) and *M. marylandi* in turf, zoysiagrass (*Zoysia* sp.) and bermudagrass in multiple counties in Texas (Erath, Dallas, Brazos and Refugio Counties, Fig. 16.1b) (Starr et al. 2007). In Oklahoma, *M. marylandi* has been found in multiple locations in Tulsa and Oklahoma Counties and in a putting green in Stillwater, OK (Walker 2014). *Meloidogyne graminis* was originally identified on bermudagrass in Texas (Orr and Golden 1966), however, it is possible this population was, in fact, *M. marylandi* (Starr et al. 2007). Recently, root knot nematode infestations have become more wide spread in Oklahoma as more golf courses renovate creeping bentgrass greens to ultra-dwarf bermudagrasses. There are other species such as *M. incognita,* that also are common on grass species including corn (*Zea mays*), and thought to occasionally limit yields. Species of grasses with reported root knot nematode problems include bentgrass (*Agrostis* sp.), bermudagrass, annual ryegrass (*Lolium multiflorum*) and wheat (*Triticum* sp.). A more comprehensive list of nematode species affecting turf and their management will be discussed in the section on plant parasitic nematodes on turf.

16.2.1.4 Pecans

The pecan root knot nematode, *M. partityla*, is the most common nematode problem associated with pecans in Texas (Fig. 16.1b, Starr et al. 1996). However, it is also possible for other species of root knot nematode such as *M. incognita,* to be associated with pecans. In Oklahoma, root knot nematode also causes problems on pecans in the southern part of the state, although the species involved has not been identified. Root knot nematode-infested orchards often decline in production, even when managed optimally. There are no real options to reduce nematode damage in pecans, once the nematode becomes established in plants.

16.2.1.5 Vegetables and Fruit Trees

Potatoes and other vegetable crops can be severely impacted by various root knot nematode species. In a survey, during 2002–2003, *Meloidogyne hapla* was the most frequently detected root knot nematode species on Texas potatoes (Powers et al. 2005). Root knot nematode can be easily transmitted in potato planting seed. It is probable that infested planting seed caused the first known occurrence of *M. chitwoodi* in Texas (Szalanski et al. 2001), since the affected field had been created from range land only 2 years prior to the detection of *M. chitwoodi*. *Meloidogyne hapla* was also found to severely damage chili peppers near the state line between Texas and New Mexico in the Southern High Plains (Woodward personal observations). Other vegetable and fruit (non-woody) crops which are commonly impacted by various root knot nematode species include beans (*Phaseolus* spp.), beets (*Beta vulgaris*), blackberry (*Rubus* sp.), cole crops (*Brassica oleracea*) including cabbage, cauliflower, brussel sprouts and broccoli, cucurbits including cantaloupe (*Cucumis melo*), cucumber (*C. sativus*), squash and pumpkins (*Cucurbita* spp.), carrot (*Daucus carota sativus*), peas (*Pisum sativum*), peppers (*Capsicum* spp.), okra (*Abelmoschus esculentus*), sweet potato (*Ipomoea batatas*), tomato (*Lycopersicon esculentum*) and watermelon (*Citrullus lanatus* var. *lanatus*). In Oklahoma, *M. incognita* was a significant problem on tomato grown under hydroponic greenhouse conditions (Walker pers.comm.). Fumigation for nematode control is rarely practiced in this region. Non-fumigant chemical options are often insufficient for controlling root knot nematode in vegetable production systems. In rare occasions, root knot nematode resistant cultivars are available, but usually the best management involves crop rotation with a non-host or fallowing the land prior to planting a susceptible vegetable crop.

16.2.1.6 Woody Perennials

Production of grape (*Vitis* sp.) can be impacted by root knot nematode. The largest area of grape production in Texas is in the Southern High Plains, particularly in Terry and Yoakum Counties. Sandy soils dominate in these counties and are heavily infested with *M. incognita*, because they were planted on land with a long history of cotton production. In Oklahoma, it is likely that multiple species of root knot nematode are capable of infesting vineyards. Root knot nematode infested vineyards are mostly found around Tulsa and Oklahoma City. Management in Texas involves planting rootstock with tolerance to nematodes, primarily 1103 Paulsen and SO4.

In Oklahoma, these rootstocks have performed poorly or inconsistently and rootstocks with *V.* x *champinii* heritage are recommended (Carroll). Peach and plum (*Prunus* sp.) and apple (*Malus domestica*) are other fruit tree species affected by root knot nematodes. Various species of trees also affected by root knot nematodes include ash (*Fraxinus* spp.), catalpa (*Catlapa bignonioides*), elm (*Ulmus* spp.), Ficus (*Ficus* spp.), live oak (*Quercus virginiana*), magnolia (*Magnolia* spp.), marberry (*Ardisia* spp.), mimosa (*Albizzia julibrissin*), mulberry (*Morus* sp.), olive (*Olea europea*), Texas kidneywood (*Eysenhardtia texana*) and wax myrtle (*Myrica cerifera*).

16.2.1.7 Flowers, Ornamental Shrub and Other Plants

Root knot nematode can also cause significant problems on flowers grown in Texas and Oklahoma. Texas A&M AgriLife Extension Service developed a guide for rating the relative sensitivity of various ornamentals to root knot nematodes (Texas Plant Disease Handbook). There are numerous species listed, but annual spring flowers that are considered highly susceptible include morning glory (*Ipomoea purpurea*), zinnia (*Zinnia elegans*) and petunia (*Petunia hybrida*). Highly susceptible annual fall flowers include snapdragon (*Antirrhinum majus*), petunia and calendula (*C. officionalis*). Flowering perennials that are highly susceptible to root knot nematodes include Canna (*Canna* x *generali*), hollyhock (*Althea rosea*) and Shasta daisy (*Chrysanthemum maximum*). Medium to large shrubs that are highly susceptible include Abelia (*Abelia grandiflora*) and Cape jasmine (*Gardenia jasminoides*). Small trees species that are either highly susceptible or susceptible to root knot nematode include fruitless mulberry (*Morus alba*), loquat (*Eriobotryta japonica*) and Japanese magnolia (*Magnolia* spp.).

16.2.2 Foliar Plant Parasitic Nematodes, **Aphelenchoides** *spp.*

Plant parasitic foliar nematode species belonging to the genus *Aphlenchoides* spp. have been found on different plant species in Texas, and most frequently on rice (*Oryza sativa*) in the coastal prairie region of Brazoria County (Fig. 16.1c). In Oklahoma, it has only been found on phlox. The species *A. besseyi*, has been reported from the rice growing regions of Beaumont, TX and the Lower Rio Grande Valley (Norton 1959). *Aphelenchoides ritzemabosi* is considered a problem on zinnia in Texas (Texas Plant Disease Handbook). *Aphlenchoides* spp. have been associated with other plants including African lily (*Agapanthus africanus*), Australian tree fern (*Sphaeropteris cooperi*), autumn sage (*Salvia greggii*), bean, bermudagrass, blue beard (*Caryopteris* sp.), Boston fern (*Nephrolepis exaltata bostoniensis*), button fern (*Pellaea rotundifolia*), hay scented fern (*Dennstaedtia punctilobula*), Japanese painted fern (*Athyrium niponicum*), Philippine violet (*Barleria cristata*), spleenwort (*Asplenium*), staghorn fern (*Platycerium* sp.) and yarrow (*Achillea ageratifolium millefolium*) (National Plant Diagnostic Network).

16.2.3 Stem and Bulb Nematode

Ditylenchulus dipsaci, the stem and bulb nematode, is an economically important nematode species that is problematic on alfalfa (*Medicago sativa*) in Oklahoma. This nematode has been identified in a few locations in Texas, but is found throughout the eastern and central potions of Oklahoma (Fig. 16.1c). While it is not widespread on alfalfa, it can be devastating in individual fields (Damicone 2013). *Ditylenchus dipsaci* will increase to damaging levels when the winter and early spring weather is cool and wet. The first cutting of alfalfa usually experiences the most severe damage, since hot weather in the summer will limit the nematode buildup. Infected plants are stunted with twisted and crinkled leaves. Severely damaged plants die, resulting in thin stands. The nematode cannot be controlled through chemical means. An integrated approach is recommended, which includes limiting the spread of the nematode into new fields and crop rotation for 2–4 years with non-hosts. Since the nematode can be spread by hay, it is important when cutting an infected field to harvest when the top 5 to 8-cm of soil is dry, and to thoroughly clean harvest equipment free of hay and soil before moving to a new field.

16.2.4 Other Important Plant Parasitic Nematodes of Oklahoma and Texas

16.2.4.1 Plant Parasitic Nematodes on Turf

The most common nematodes found in bentgrass golf course putting greens in Oklahoma are ring (*Mesocriconema* spp.), stubby root (*Paratrichodorus* spp.), stunt (*Tylenchorhynchus* spp.) and spiral (*Helicotylenchus* spp.) nematodes (Walker et al. 2002). Since the removal of fenamiphos® from the market, the frequency and diversity of nematode infestations has increased. In Texas, based on experiences of an extension specialist in turf (W. Crow, University of Florida), the sting nematode (*Belonolaimus* spp.) was considered the most important nematode, although the most frequently found plant parasitic nematodes are the lance nematode (*Hoplolaimus* spp.), stubby root, ring and lesion (*Pratylenchus* spp.) (Crow 2000). The sting nematode was only found in 11% and 1% of bentgrass samples submitted to the Turfgrass diagnostic clinic in Oklahoma and the Plant Diagnostic Clinic in Texas, respectively (Table 16.4). The sting nematode was found frequently in the southeastern part of Texas and in counties in Oklahoma having sandy river bottom soils (Fig. 16.1c). It has been most frequently identified in bermudagrass and creeping bentgrass, as well as on zoysia grass, peanut, soybean and corn. This nematode,

Table 16.4 Percentages of plant parasitic nematodes[a] associated with turf grasses[b] in Oklahoma and Texas from 1995 to 2017[c]

	Bentgrass		Bermudagrass		Bluegrass		Zoysiagrass		Mixed Turf
	OK[d]	TX	OK	TX	OK	TX	OK	TX	TX
Nematodes	% of total number of samples								
Ring	89	22	18	11	27	0	42	11	41
Stunt	80	0	6	0	27	0	8	0	15
Spiral	47	26	16	4	13	100	8	11	7
Root knot	1	0	20	37	0	0	0	11	7
Sting	11	1	4	9	0	0	0	0	0
Lance	11	18	4	3	27	0	0	0	0
Stubby root	12	3	6	2	0	0	25	0	7
Sheath	2	21	0	3	0	0	0	0	2
Lesion	18	0	4	0	7	0	0	0	16
Total number of samples submitted	271	87	50	150	15	1	12	9	61

[a]Ring nematode included *Criconemella* spp., Family Criconematidae, *Criconemoides* spp. and *Mesocriconema* spp.; Stunt nematode included *Tylenchorhynchus* spp. and Family Tylenchorhynchidae; Spiral nematode is *Helicotylenchus* spp.; Root knot nematode is *Meloidogyne* spp.; Sting nematode is *Belonolaimus* spp.; Lance nematode is *Hoplolaimus* spp.; Stubby root nematode included *Paratrichodorus* spp. and *Trichodorus* spp.; Sheath nematode is *Hemicycliophora*; and lesion nematode is *Pratylenchus* spp.

[b]Bentgrass included *Agrostis* spp. and *A. stolonifera*; Bermudagrass included *Cynodon* spp. and *C. dactylon*; Bluegrass included *Poa* and *P. pratensis*, and in Oklahoma also included mixtures of *Poa* and bentgrass; Zoysiagrass included *Zoysia* spp. and *Z. japonica*

[c]The data presented in this table was obtained from the records maintained by the National Plant Diagnosis Network and covered the years from 1995 to 2017

[d]Data was obtained from N. Walker turfgrass diagnostic laboratory in 2011

which requires a high sand content (>80%), is probably the most damaging nematode on turf grasses. Furthermore, soil content of golf course greens can be ideal for the sting nematode as the United States Golf Association requires a sand content of 90% for construction of greens (United States Golf Association 2004). Root knot nematodes are the most economically important nematodes typically found in bermudagrass samples (20% in OK and 37% in TX, Table 16.4). *Meloidogyne marylandi*, which can cause substantial damage on turf, is widespread in Texas (Starr et al. 2007), even though it has only recently been identified in Oklahoma (Walker 2014). The lance and sheath nematodes are found more frequently in bentgrass samples in Texas compared to Oklahoma. The stunt nematode is found more frequently on turf in Oklahoma compared to Texas. In addition, *Peltamigratus christiei* has been reported on warm-season turfgrass species in Oklahoma (Crow and Walker 2003).

Management of nematodes on turf in Oklahoma and Texas is challenging due to heat and drought stress. Recently, several new chemical control options have been introduced to the market, but the optimal choice should be tailored to the specific nematode species present. No single chemical control option is effective against all the nematodes found on turf. It is important to reduce the overall stress placed on turf when damaging levels of nematodes are present. Mowing heights should be raised, turf should be thoroughly irrigated to encourage deep root systems and installation of fans can help reduce turfgrass decline when nematode populations are elevated. Soil fertility should be managed carefully.

16.2.4.2 Citrus Nematode, *Tylenchulus semipenetrans*

The citrus nematode is widely distributed in at least, 93% of citrus orchards in the Lower Rio Grande Valley (Robinson et al. 1987). The citrus nematode can be responsible for a slow decline in plant health. Root growth is significantly reduced as nematode populations increase in infected plants. Under sufficiently high nematode populations, root growth is substantially retarded to cause abnormally small and reduced fruit production. For an efficient management scheme, it is important to start with clean soil, free of the nematode and nematode free rootstock. There are some nematode resistant rootstocks, but typically, susceptible rootstocks are grown in the region (Reynolds et al. 1974). Chemical control, after plant establishment, is limited to oxamyl, which is not always effective (Timmer 1977; Timmer and French 1979). Fluopyram also has a label for citrus, but is recommended for newly established trees or those with root systems distributed around drip irrigation systems. No published research is available yet on performance.

16.2.4.3 Soybean Cyst Nematode, *Heterodera glycines*

The soybean cyst nematode (SCN) has been present in the eastern part of Oklahoma since the 1980s (Tylka and Marett 2014). This nematode has been found in 17 counties in Oklahoma and in 5 counties in Texas (Fig. 16.1d). In Texas, there is almost no soybean production within the counties that were once infested with *H. glycines* (Fig. 16.1d), but have not been positive for SCN since the 1990s (Wheeler personal observations). Both root knot nematode and soybean cyst nematode can cause problems in soybean in Oklahoma. The best management for these two nematode problems comprises crop rotation and use of nematode-resistant soybean cultivars. There does not appear to be SCN type information on soybean cyst nematode for this region. Rotation crops recommended for soybean cyst nematode include alfalfa, canola, corn, cotton, forages, rye, wheat, oats, peanut and sorghum. The appropriate rotation for root knot nematode would depend on the species of root knot nematode present.

16.2.4.4 Reniform Nematode, *Rotylenchulus reniformis*

The reniform nematode was originally found in four counties of the Lower Rio Grande Valley (Norton 1959). However, in 1982 it was found in cotton near New Home, Texas in the High Plains (Robinson 2007). It appears that the cotton producer also farmed in the Lower Rio Grande Valley and, therefore, most likely spread the nematode on infested equipment. The last state-wide survey (Starr et al. 1993) indicated that the reniform nematode was in 12 counties, with a few additional counties that have been identified since then (Wheeler personal observations) (Fig. 16.1c). The reniform nematode is still less frequently found than root knot nematode on cotton in Texas. However, where it does occur, losses are often much higher than those caused by the root knot nematode. It was estimated that reniform nematode losses in cotton fields average 40% (Robinson 2007), which can be contrasted with 26% losses associated with *M. incognita* in cotton in the High Plains of Texas (Orr and Robinson 1984). Reniform nematodes have also been found occasionally on vegetables and citrus in Texas. The relatively slow spread of the reniform nematode is surprising, compared to most other cotton-producing states in the U.S. The damage caused by the reniform nematode increased substantially between 2000 and 2005 in Alabama, Arkansas, Louisiana, Mississippi and Tennessee (Robinson 2007). The reniform nematode is not found west of Texas or in Oklahoma.

The stunting of cotton, caused by reniform nematode, is dramatic when it is distributed in patches in a field. Within 5–10 years, newly infested fields typically become more uniformly infested. Management is primarily with crop rotation using sorghum or corn. After an initial infestation, generally 1 year of rotation with a non-host is sufficient, but over time, it becomes necessary to rotate to a non-host crop for 2–3 years to eliminate the severe stunting seen in cotton. Resistant germplasm has been identified in *Gossypium* species other than *G. hirsutum* (Robinson et al. 2004, 2007) and successfully introgressed into *G. hirsutum*. However, no reniform nematode resistant cultivars have been commercialized. It has been difficult to combine the nematode resistance with adequate yield potential. The variety PHY 417WRF, which has two resistance genes to root knot nematode, allows less reproduction by the reniform nematode than other commercial varieties (Woodward and Wheeler unpublished). This cultivar, while not particularly high yielding in non-reniform nematode fields, consistently yields at least 25% higher than other cultivars in reniform nematode fields (Woodward unpublished).

Chemical control, by fumigation, has been successful at reducing damage caused by reniform nematode. This nematode is often found in soils that have a lower sand content than soils favored by root knot nematodes (Robinson et al. 1987; Starr et al. 1993). These soil types have smaller pores for movement of gas, often resulting in a more limited distribution of fumigant, than through a coarse textured soil. The reniform nematode is also distributed deeper in the soil than the root knot nematode, and therefore, requires deeper fumigation and higher rates. Control of reniform nematode with 1,3 D (dichloropropene) is recommended at a rate of 47 l per hectare at a depth of 51-cm (Wheeler personal observations). In contrast, to control root knot nematode, 28 L/ha of 1,3-D to a depth of 30-cm is usually adequate. The chemical 1,3-D has been used in the High Plains by producers to reduce reniform nematode populations in a few cases. However, it has been difficult to obtain this product in Texas, results of fumigation can be poor, particularly when applied shallow or at rates less than 47 l/ha, and the Texas Department of Agriculture certification to apply soil fumigants has become more difficult to obtain. Furthermore, the cost of the product has discouraged producers from using 1,3-D.

The reniform nematode is so damaging at relatively low densities, that even a 50% reduction in the reniform nematode density can result in no yield improvement (Wheeler et al. 2008). Non-fumigant nematicides such as fluopyram at planting and oxamyl applied around 35–45 days after planting have been used, when available, to control reniform nematode, but it is not clear if either product alone or used in conjunction will be effective. The nematicide aldicarb was heavily utilized in reniform nematode fields at-planting previous to 2011, and was also combined with oxamyl. This combination was somewhat effective. Yield losses are still substantial when non-fumigant pesticides are utilized in reniform nematode fields.

16.3 Conclusions

Nematode problems exist on many crops in Texas and Oklahoma including cotton, peanut, turf grass, citrus, alfalfa, pecans and soybean. The most effective management options for soybean cyst, root knot and reniform nematodes typically involve cultural methods, crop rotation with non/poor hosts and use of cultivars that reduce nematode reproduction. Unfortunately, these options can not be used with nematode problems on turf grass, citrus, alfalfa and pecans. Use of pesticides is practiced most commonly with nematicide seed treatments (cotton and soybean), in-furrow, at-plant nematicide applications (cotton, peanut) and post-plant establishment (turf, citrus and cotton). Crop losses due to nematodes can be severe and often insufficient or uneconomical options exist to substantially reduce these losses.

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