AN INDEPENDENT NEWSLETTER FOR TURF MANAGERS

TurfGrass TRENDS

Volume 4, Issue 10

October 1995

Nematode Disorders of Turfgrasses: How Important are They?

by Eric B. Nelson

Nematodes are wormlike aquatic animals (Figure 1) that live in marine and fresh waters, in thin water films on soil particles, and as parasites within the tissues of other living organisms, including man (see Table 1). This diverse group of animals is second only to arthropods in the number of species present in nature. Regardless of the regions of the world and the habitats in which they are found, the vast majority of nematode genera are parasites of vertebrate animals.. Only a small percentage of all nematodes are plant parasites, with a considerably smaller subset of those being parasites of turfgrasses.

Nematodes Not Taken Seriously as Important Turfgrass Pests

While plant parasitic nematodes are clearly recognized as important pests of agricultural and some horticultural crops, particularly in the warmer regions of the world, their role as pests of turfgrasses is not always apparent. Managers of warm-season turf-

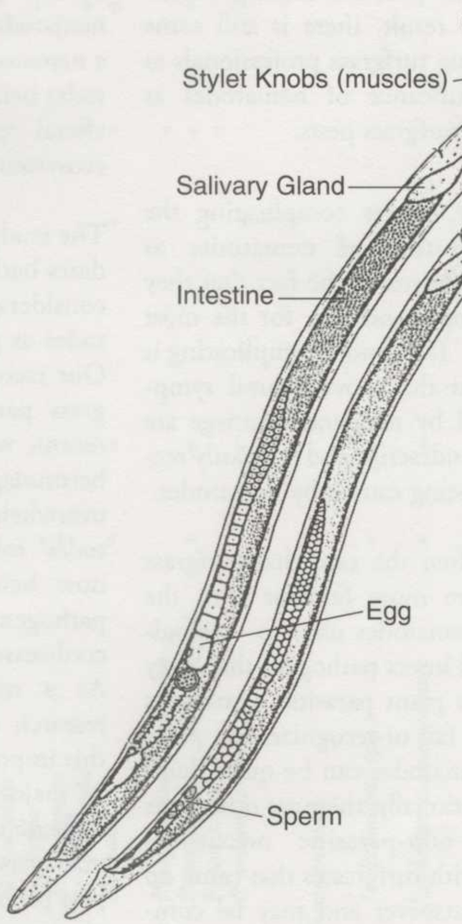

Figure 1. Diagramatic representation of a typical male and female plant parasitic nematode. (Figures 1, 2, and 4 adapted from G.N. Agrios, *Plant Pathology*, 3rd edition, San Diego, CA: Academic Press 1988.)

IN THIS ISSUE

TurfGrass TRENDS

Maria L. Haber
Publisher
Andria C. King
Editor
Christopher Sann
Field Editor
Dr. Richard J. Hull
Science Advisor
Jeanne Stannek
Marketing Manager
Joan Siregar
Circulation Manager
Andria C. King
Layout & Production

TurfGrass TRENDS
1775 T Street NW
Washington, DC 20009-7124
Phone: 202-483-TURF
Fax: 202-483-5797
Internet: 76517.2451 @ CompuServe.com

TurfGrass TRENDS (ISSN 1076-7207) is published monthly. The annual subscription price is $180.00.

Table 1. Distribution of Different Types of Nematodes

Habitat	Number of Genera	% of Total
Marine and Freshwater	730	31.9
Soil (Free-Living)	429	18.7
Plant Parasites	166	7.3
Turfgrass Parasites	18	0.8
Invertebrate Parasites	187	8.2
Vertebrate Parasites	759	33.2
Totals	2289	100.1

grasses have recognized nematodes as a significant problem for nearly 45 years. Those managing cool-season grasses, however, have not entirely accepted nematodes as problem-causing organisms. As a result, there is still some debate among turfgrass professionals as to the significance of nematodes as cool-season turfgrass pests.

One of the factors complicating the clear recognition of nematodes as problem organisms is the fact that they are microscopic and live, for the most part, in soil. Even more complicating is the fact that the above-ground symptoms caused by nematode damage are relatively nondescript and not easily recognized as being caused by nematodes.

It is also often the case that turfgrass managers are more familiar with the beneficial nematodes used to biologically control insect pathogens than they are with the plant parasitic nematodes and, hence, fail to recognize that plant parasitic nematodes can be quite damaging. Additionally, there are numerous free-living non-parasitic nematodes associated with turfgrasses that cause no damage whatsoever and may be commonly observed in healthy as well as problematic turf. These types of nematodes, along with the biological control nematodes, feed on other microorganisms, particularly bacteria, fungi, and algae, and by doing so, they play an important ecological role in food webs in soil ecosystems. Turfgrass managers who use microscopes are often misled by the presence of these free-living nematodes into thinking that they have a nematode problem; in fact, the nematodes being observed are a normal beneficial part of the turfgrass soil ecosystem.

The study of plant parasitic nematodes dates back to 1743. Since that time, a considerable understanding of nematodes as plant parasites has developed. Our recognition of nematodes as turfgrass parasites, however, is relatively recent, with the first report being on bermudagrass back in 1953. Despite overwhelming ignorance of the nematodes' role as turfgrass pests, they are now being recognized as important pathogens of both warm-season and cool-seasons grasses all over the world. As a result, renewed interest and research efforts are being directed to this important group of turfgrass pests. A major goal of this review is to increase the awareness among turfgrass managers of nematodes as important pest problems on cool-season as well as on warm-season turfgrasses. For a list of the principal cool-season and warm-season turfgrass damaging nematodes and their host turfgrasses, refer to Tables 2 and 3.

Table 2. Root-Infecting Nematodes on Cool-Season Grasses

Common Name	Latin Name	Creeping Bentgrass	Colonial Bentgrass	Velvet Bentgrass	Annual Bluegrass	Kentucky Bluegrass	Red Fescue	Hard Fescue	Tall Fescue	Chewing Fescue	Annual Rye	Perennial Rye
I. Endoparasitic Nematodes												
Cyst Nematode	*Heterodera major (H. avenae)*								+		+	+
	H. punctata	+	+									
	H. iri	+		+	+							
Root Knot Nematode	*Meloidogyne graminicola*				+							
	M. graminis					+			+			
	M. hapla						+					
	M. incognita	+				+						
	M. microtyla		+			+	+				+	
	M. naasi	+	+		+	+	+		+	+	+	+
Lesion Nematode	*Pratylenchus brachyurus*					+						
	P. neglectus	+	+			+	+		+			+
	P. penetrans					+						
	P. pratensis		+	+	+		+					
II. Ectoparasitic Nematodes												
Awl Nematode	*Dolichodorus* spp.	+	+	+				+				
Dagger Nematode	*Xiphenema americanum*	+	+			+						
Grass Root Gall Nematode	*Subanguina radicicola*				+							
Lance Nematode	*Hoplolaimus tylenchiformis*	+	+		+	+						
	H. concaudajuvencus									+		
Needle Nematode	*Longidorus breviannulatus*	+										
	L. sylphus	+										
Pin Nematode	*Paratylenchus hamatus*					+						
	P. nanus									+	+	
	P. projectus	+	+			+	+	+			+	

Continued on page 4

Table 2., Continued from page 3

Common Name	Latin Name	Creeping Bentgrass	Colonial Bentgrass	Velvet Bentgrass	Annual Bluegrass	Kentucky Bluegrass	Red Fescue	Hard Fescue	Tall Fescue	Chewings Fescue	Annual Rye	Perennial Rye
Ring Nematode	*Criconemella cylindricum*					+						
	C. ornata	+				+						
	C. curvata	+			+							
Sheath Nematode	*Hemicycliophora* spp.											
Spiral Nematode	*Helicotylenchus cornurus*	+			+							
	H. digonicus	+	+			+						+
	H. erythrinae	+	+			+						+
	H. microlobus					+						
	H. nannus										+	+
	H. platyurus					+						
	H. pseudorobustus	+										
	H. pumilus					+						
Stubby Root Nematode	*Paratrichodorus christiei*					+	+	+				
Stunt Nematode	*Tylenchorhynchus claytoni*	+	+		+	+						
	T. dubius	+	+			+						
	T. lamelliferus											+
	T. maximus					+						
	T. nudus					+						

Table 3. Root-Infecting Nematodes on Warm-Season Grasses

Common Name	Latin Name	St. Augustine-grass	Bermuda-grass	Zoysia-grass	Bahia-grass	Centipede-grass	Manilla-grass
I. Endoparasitic Nematodes							
Burrowing Nematode	*Radopholus similus*		+		+		
Cyst Nematode	*Heterodera leuceilyma*	+					
Cystoid Nematode	*Meloidodera charis*	+					
Lesion Nematode	*Pratylenchus brachyurus*	+		+		+	
	P. hexincisus		+				
	P. penetrans			+			
	P. zeae		+				
Root Knot Nematode	*Meloidogyne arenaria*		+				
	M. graminicola		+	+			
	M. graminis	+	+	+	+		
	M. hapla	+	+				
	M. incognita		+				
	M. marylandi		+	+			
II. Ectoparasitic Nematodes							
Awl Nematode	*Dolichodorus* spp.	+	+			+	
Dagger Nematode	*Xiphenema americanum*	+	+	+		+	+
Lance Nematode	*Hoplolaimus tylenchiformis*	+	+	+	+		+
	H. galetus	+					
	H. concaudajuvencus		+				
Needle Nematode	*Longidorus breviannulatus*			+			
	L. elongatus			+			
Pin Nematode	*Paratylenchus hamatus*		+				

Continued on page 6

Table 3., Continued from page 5

Common Name	Latin Name	St. Augustine-grass	Bermuda-grass	Zoysia-grass	Bahia-grass	Centipede-grass	Manilla-grass
Ring Nematode	*Criconemella cylindricum*	+					+
	C. ornata		+				
	C. rustica	+				+	
	Criconemella spp.	+	+	+	+	+	+
Sheath Nematode	*Hemicycliophora typica*	+					
	Hemicycliophora spp.	+	+			+	
Spiral Nematode	*Helicotylenchus erythrinae*	+	+	+			
	H. melancholicus		+				
	H. nannus		+	+			
	Helicotylenchus spp.					+	+
Sting Nematode	*Belonolaimus gracilis*	+					
	B. longicaudatus	+	+		+	+	+
	Belonolaimus spp.		+			+	
Stubby Root Nematode	*Paratrichodorus christiei*	+					
	P. primitivus		+				
	P. proximus	+					
	Paratrichodorus spp.			+		+	+
Stunt Nematode	*Tylenchorhynchus acutus*		+				
	T. claytoni			+			
	T. martini			+			

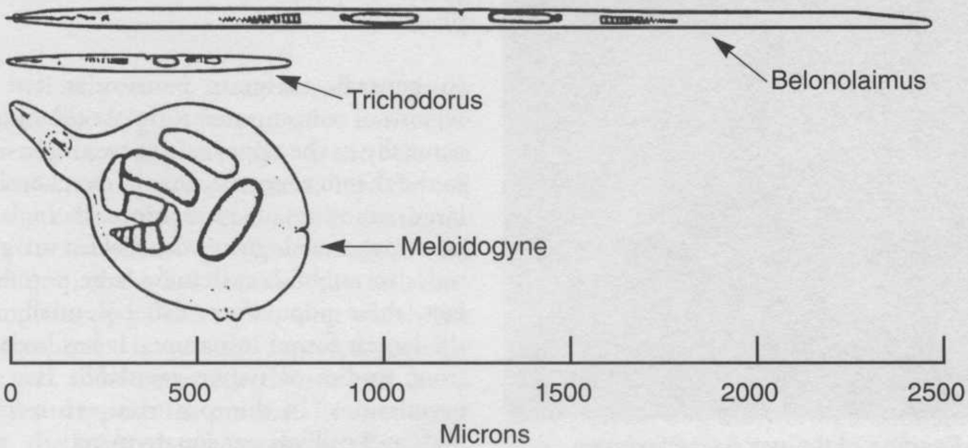

Figure 2. Relative sizes of some of the major turfgrass nematodes.

Nematodes are Microscopic Eel-Shaped Roundworms

Plant parasitic nematodes are generally microscopic worms ranging in length from 1/50 to 1/8 inches. Some nematodes, particularly those in the genus *Longidorus*, may reach lengths of 1/4 inch. Both juveniles (i.e., larvae) and adults of most species of nematodes are worm-like in shape. However, in some genera, particularly *Meloidogyne* and *Heterodera*, the adult female becomes swollen and spherical- or pear-shaped (Figure 2), once the larvae within her begin to develop.

Nematodes reproduce by laying eggs. Inside the egg, a larva will develop through one molt prior to hatching. After hatching, the larvae appear as small versions of the nematode adult. The larvae grow in size by going through a series of molts. Typically, four molts are required to reach the adult stage in which the females are reproductively fertile. In general, both males and females are required for reproduction. However, in some instances, such as with *Meloidogyne* and *Heterodera*, the female can reproduce parthenogenetically by producing female offspring from unfertilized eggs.

Nematode Population Development Depends on Soil and Plant Factors

The time it takes for a given nematode species to complete its life cycle from egg to egg is dependent upon the presence of a suitable host and favorable environmental conditions. It generally takes three to four weeks, under optimum conditions, for a nematode to complete its life cycle. However, this cycle may be much shorter when soil temperatures are warm (>60 F) and much longer when soil temperatures are cooler (<50 F). It is fairly easy to envision how nematodes can be more damaging in warm soils, since the number of individual nematodes generated in one season can be substantially greater.

Turfgrass nematodes live in the soil for most of their lives. Thus, they can be greatly affected by soil environmental conditions such as temperature, pH, moisture, and aeration. All of these factors may affect their feeding behavior, survival, and movement. Although the distribution of nematodes in soil is highly variable, populations tend to cluster according to those combinations of conditions that are most favorable for their feeding and reproduction.

Photography courtesy of Dr. Eric B. Nelson

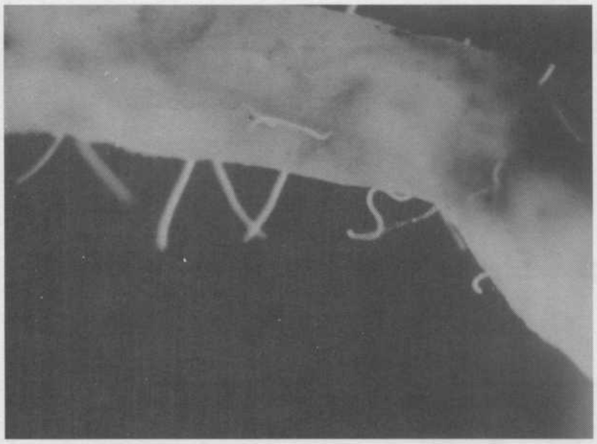

Figure 3. Feeding of the ectoparasitic lance nematode, *Hoplolaimus galeatus*, on roots of St. Augustinegrass.

Nematodes reach higher population levels and cause more plant damage in sandy soils than in heavy clay soils. This is largely related to the behavior of water in a porous soil medium and its effects not only on the nematode, but on the plant too. Nematodes are generally more able to swim freely in water films through large pores in a sandy soil than through the small water-filled pores of a clay soil. Although nematodes are aquatic organisms, they do not survive well in water-saturated soil conditions as the availability of oxygen is nearly always severely limited. Most nematodes penetrate roots more readily when soils are moist, but drain freely, such as is the case in sandy soils. Despite the fact that nematode populations reach high levels in sandy soils, they generally decline to lower levels in regions where winters are relatively severe.

Turfgrass Nematodes Depend on Suitable Hosts for Survival

Since plant parasitic nematodes are obligate parasites, feeding only on living host cells, they require access to a host in order to reproduce and survive (Figure 3). In the absence of a suitable host, most nematodes will starve and die within a few months. The larval stages of some nematodes, however, will simply wither and remain quiescent for many years. Some adults and larvae will also survive in frozen soil or may overwinter in living or dead roots. The eggs of many genera will also survive in soil for many years, even in the absence of a host plant.

In general, turfgrass nematodes are found in regions of concentrated turfgrass root mass. This is generally in the upper one to two inches of soil and in the thatch zone. Because of the characteristically large amount of root biomass in a turfgrass planting, there is great potential for turfgrass nematodes to establish extremely large populations. In fact, these populations can potentially be among the largest found in nature. It has been estimated from studies of native grasslands that nematode populations in the root mass can reach levels as high as 9 million per square meter!

In the absence of turfgrasses, many parasitic nematodes can survive by feeding on weeds, since all turfgrass nematodes have generally broad host ranges.

Plant Parasitic Nematodes Possess Stylets

Plant parasitic nematodes are most easily recognized by the presence of a stylet near the mouth parts (Figure 4). As a result, most plant parasitic nematodes are easily distinguished from the sapro-

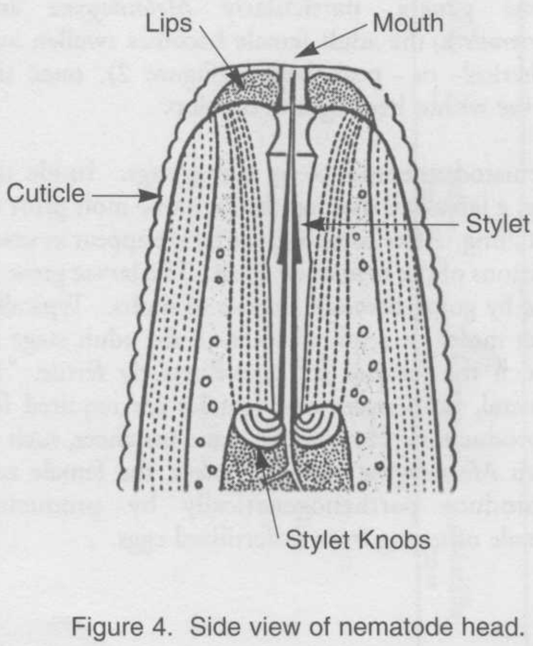

Figure 4. Side view of nematode head.

phytic nematodes which feed on other microbes and organic matter with the aid of an open feeding tube.

Stylets are hollow, pointed, spear-shaped structures that function like hypodermic needles and allow nematodes to puncture plant cells. Once cells are penetrated, the nematode injects saliva into the cell to digest the cell contents and obtain nutrients. With some nematodes (e.g. *Paratrichodorus* and *Tylechorhynchus*), the saliva liquifies the cell contents around the tip of the stylet, after which the digested cytoplasm is rapidly ingested, usually killing the cell. The nematode then moves on to the next cell and repeats the process. In most other nematodes, the injected saliva induces physiological changes, in the host cell and adjacent cells, that facilitate the feeding of the nematode.

Generally, the direct mechanical injury of plant tissues caused by the injection of the stylet into root tissues causes little or no damage. The cell changes induced by the feeding process give rise to many of the symptoms associated with nematode damage. Some of these symptoms are a result of the enzymatic breakdown of host tissues during nematode feeding. Others result from the induction of abnormal cell enlargement or the suppression or over-stimulation of cell division. Root feeding activity often impairs the plant's ability to take up water and nutrients and, in some cases, may alter many physiological processes in the plant. Nematode infections can severely reduce the amount of carbohydrate stored in the root system. Oftentimes a considerable amount of carbohydrate is released from nematode-infected roots into the surrounding soil, enhancing the activities of soil-borne fungal pathogens. More specialized changes in host physiology occur as a result of infection by sedentary endoparasitic species such as *Meloidogyne* species. Penetration into and feeding on the root induces a change within a few cells in the root cortex such that they are transformed into specialized feeding cells that provide nourishment for these nematodes for their entire life.

Nematode Feeding Habits Vary

With the exception of species of *Anguina* and *Ditylenchus*, which are foliar-feeding nematodes on turfgrasses, all of the economically-important turfgrass nematodes feed on root systems. Plant parasitic nematodes have been classified either as **ectoparasites** or as **endoparasites** on the basis of their feeding behavior on root systems. These nematodes are further classified on the basis of whether they are **migratory** (i.e., they move about freely from one feeding site to the next) or **sedentary** (i.e., they establish one permanent feeding site). Ectoparasitic species do not normally enter the root tissue, but feed only on cells near the root surface. Nearly all ectoparasitic species affecting turfgrasses are migratory ectoparasites. Because they can move freely from cell to cell, the level of damage from migratory ectoparasitic species can be quite severe. Sometimes the feeding time may be as short as 5 to 10 seconds per cell. The ring nematode (*Criconemella* spp.), on the other hand, is an ectoparasitic genus, but it has a sedentary feeding habit. Ectoparasitic nematodes, regardless of whether they are sedentary or migratory, generally spend their entire life outside of the root system.

Endoparasitic nematodes spend at least part of their life inside a root, where they feed on root cortical cells. **Migratory endoparasites** move around inside the root cortex going from one feeding site to the next and causing extensive damage to the root system. These types of nematodes deposit eggs in the lesions created by the feeding and burrowing activity where juveniles hatch, increasing the population as the lesion grows. More typically, endoparasitic nematodes are **sedentary endoparasites** (e.g., *Heterodera* and *Meloidogyne* species), establishing permanent feeding sites within the root system.

Symptoms from Root-Infecting Nematodes Not Easily Identified

When root-infecting nematodes feed on turfgrass roots, the above-ground symptoms one sees are fairly non-characteristic, appearing as reduced or stunted growth, yellowing and thinning of the turfgrass foliage, or premature wilting in hot, dry weather. These types of symptoms, in fact, are not diagnostic of any particular disease-causing agent and may often appear as possible damage from other turfgrass pathogens or from nutrient defi-

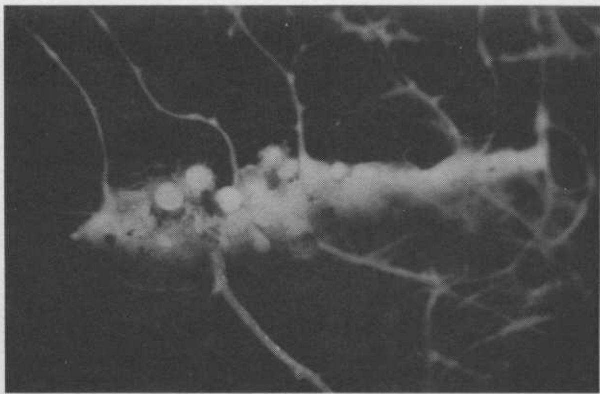

Figure 5a. Root galls on annual bluegrass resulting from the feeding of the root knot nematode.

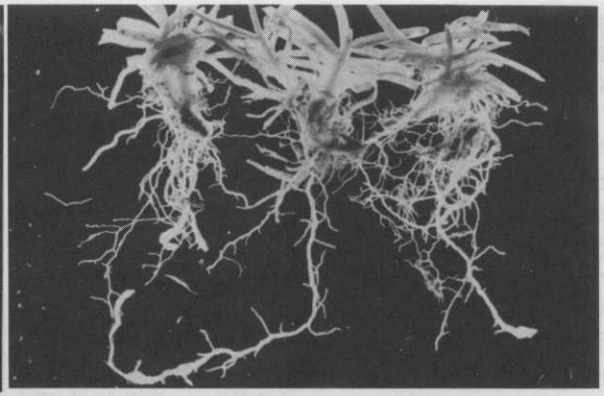

Figure 5b. Root Knot nematode damage on bermudagrass.

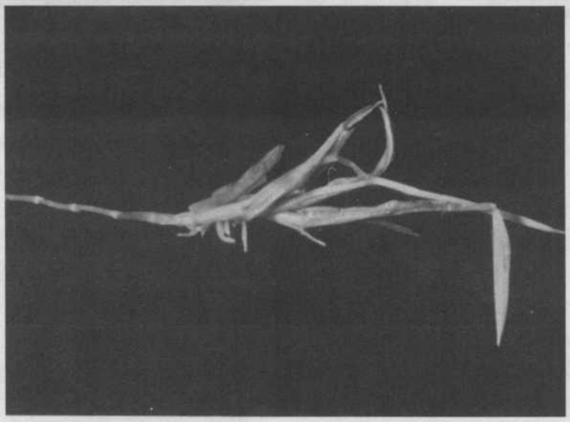

Figure 5c. Stubby, stunted roots of creeping bentgrass arising from root-feeding nematodes.

ciencies. Extreme care should be exercised when trying to diagnose nematode problems from above-ground symptoms alone.

Although most nematode feeding occurs during periods when turfgrass plants are actively producing new roots (i.e., spring and fall for cool-season grasses and late summer for warm-season grasses), in many cases, nematode-damaged turf only becomes obvious when plants are under stress, particularly heat and/or drought stress. Similarly, other root stress factors such as soil compaction, poor drainage, insect damage, infection from other root pathogens, or pesticide-induced stresses will also enhance foliar symptoms of nematode damage to root systems. In other cases, nematode damage may be an additional stress that acts as "the straw that breaks the camels back." In other words, in more favorable conditions the plant could have survived a certain amount of nematode feeding if other stress factors had not been present.

Figure 6. Stunted roots of bermudagrass resulting from the feeding of the sting nematode, *Belonolaimus longicaudatus*.

Even though the exact appearance of symptoms may not be useful in diagnosing nematode problems, the pattern of above-ground symptoms may indicate whether nematodes are involved. Usually nematode-related symptoms will appear in irregular-shaped areas with no distinct boundaries between affected and healthy turf. Symptoms occurring in well-defined patches are usually indicative of problems caused by agents other than nematodes.

Root symptoms are often the most revealing and are one of the more diagnostic features of nematode damage. Root symptoms may appear as knots, galls, lesions, excessive root branching, swollen root tips, stunted root systems, or even rotted roots, particularly if other root-infecting pathogens are present (Figures 5a,b,c). In some cases, infected root systems have fewer lateral roots than healthy root systems. Stunting of the root

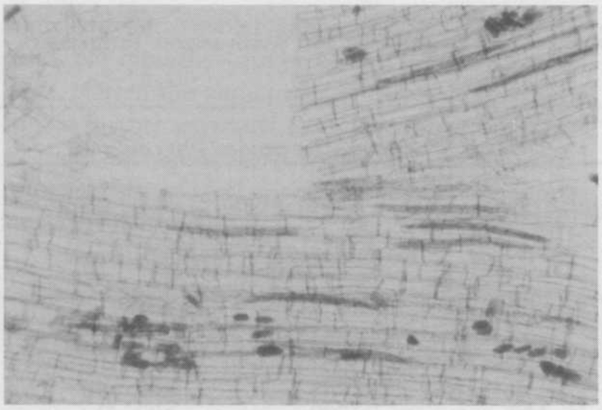

Figure 7. Juveniles and adults of the lesion nematode, *Pratylenchus penetrans*, in turfgrass roots. Nematodes have been stained to enhance their visualization in root tissues.

systems is one of the more commonly observed symptoms, regardless of the nematode species (Figure 6). In some cases, lesions that are particularly indicative of damage from ectoparasitic species form on roots. Swollen root tips may also be indicative of damage from stubby root nematodes or root knot nematodes.

Analyzing Roots and Soils for Nematode Populations: A Critical Diagnostic Step

When nematodes are suspected of being a problem, based on field observations of foliar symptoms and root systems, accurate identification of the causal nematodes is essential. In a typical analysis, nematodes are either stained within the infected plant tissues for direct observation (Figure 7), or are allowed to crawl out of the infected plant tissues or from the soil in which the affected plants were growing. The latter method allows the diagnostician to obtain relatively accurate population counts as well as determine the identities of the parasitic nematodes. For the most accurate population estimates, it is critical that soil samples be taken as soon as possible after symptoms are first observed. If the turfgrass stand becomes too severely damaged, population estimates will be substantially lower. Since the obligatory parasitic nature of turfgrass parasitic nematodes requires that a sufficient food source for reproduction and survival be maintained, nematode populations are often much higher in adjacent, apparently healthy, turf than in highly affected areas.

It is best to sample from declining turf as opposed to severely injured turf. It is best to sample from the edge of the symptomatic turf as opposed to the center of the area. The most appropriate time to sample cool-season turfgrass soils for nematodes is in the spring, about a month after the turf greens up and soil temperatures exceed 50 F. An additional sampling should be made in the autumn when turf may be more symptomatic. Warm-season turfgrass soils should be sampled in the late summer.

Sampling patterns depend on the symptoms present and the size of the affected area. If the turf is exhibiting a gradual decline, samples should be taken randomly through-out the area (in a zig-zag pattern, for example). A minimum of six subsamples should be taken from an area that is approximately 21,000 ft^2 in size. All samples should be taken to a depth of approximately four inches so that a sufficient amount of root system and surrounding soil will be available for analysis. Subsamples may be taken with a cup cutter, a 1-in. soil sampling probe, or a bladed trowel. Subsamples should be mixed together and placed in a plastic bag to prevent moisture loss and shipped immediately. Avoid exposure to heat or direct sun-

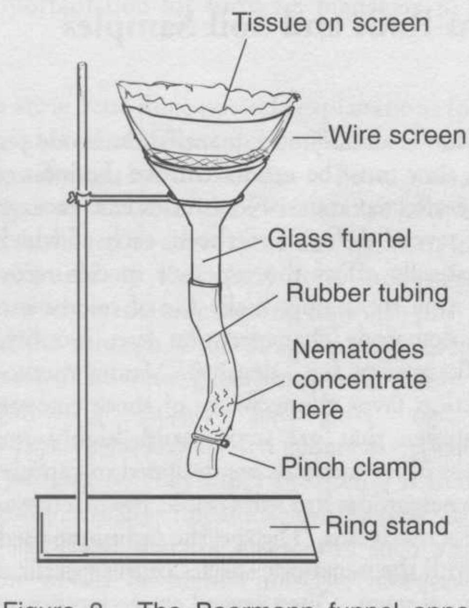

Figure 8. The Baermann funnel apparatus used for recovering nematodes from infested soil and from infrected turfgrass tissues.

Table 4. Damage Thresholds for Various Nematodes on Representative Cool-season and Warm-season Turfgrasses

		Damage Threshold (Nematodes/100 cm^3 soil)			
		Cool-Season Grasses		Warm-Season Grasses	
Nematode	Species	Bentgrass	Tall Fescue	Bermudagrass	St. Augustinegrass
Awl	(*Dolichodorus* spp.)	150	50	10	10
Dagger	(*Xiphenema americanum*)	200	150	300	200
Lance	(*Hoplolaimus galeatus*)	150	100	40	40
Lesion	(*Pratylenchus* spp.)	150	150	150	150
Ring	(*Criconemella* spp.)	1500	150	1000	500
Root knot	(*Meloidogyne* spp.)	100	2000	300	80
Sheath	(*Hemicycliophora* spp.)	200	80	200	80
Spiral	(*Helicotylenchus* spp.)	600	1000	1000	1000
Sting	(*Belonolaimus longicaudatus*)	20	12	20	unknown
Stubby Root	(*Paratrichodorus christiei*)	100	150	100	40
Stunt	(*Tylenchorhynchus* spp.)	300	100	100	200

(Modified from Couch, 1995 and Dunn, 1993)

light. It is best NOT to moisten samples. Refer to the July 1995 issue of *Turfgrass TRENDS* for a list of diagnostic laboratories that process nematode samples.

Extraction Methods Affect the Types of Nematodes Recovered from Root and Soil Samples

In order to identify and quantify nematode populations, they must be extracted from the infested soil or the affected root. Nematodes can be extracted using several different methods, each of which will dramatically affect the types of species recovered. Extraction techniques make use of one or more of three nematode characteristics: size, motility, and specific gravity (i.e., density). Some methods of extraction favor the recovery of those ectoparasitic nematodes that are active and highly mobile, whereas other methods are designed to capture "all" of the nematodes in a soil sample, the inactive as well as the active forms. The specific technique used may vary with the nematode species or the specific developmental stage. Often several extraction procedures are used simultaneously in order to more completely and accurately assess the true nematode population in the soil or plant tissue sample.

One of the most common methods of nematode extraction from roots or soils is the Baermann funnel or Baermann pie pan method (Figure 8). Whereas other methods of extraction are suitable for isolation of nematodes from soil samples, the Baermann funnel technique is the method of choice for extracting nematodes from root tissue. It is often used specifically for recovering migratory ectoparasitic species from soil or plant tissue, juveniles of root knot or cyst nematodes, and migratory endoparasitic species from root tissues. This technique takes advantage of the fact that most nematodes in turfgrass roots are mobile. When root tissue is placed in water, the nematodes emerge from the root tissues into the water where they settle under the force of gravity.

The Baermann funnel technique can also be used in a similar manner with soil samples. Typically, nematodes move in a thin water film surrounding soil particles. Because most nematodes do not move fast enough to swim when they reach water-filled pores, they will settle under the force of gravity, as do those emerging from root tissues, and become concentrated at the lowest point of the extraction apparatus.

Extraction techniques used primarily with soil samples include direct soil sieving in which the soil is mixed with water and the resulting suspension is poured through a series of nested sieves progressing from larger to smaller opening sizes. The nematodes are typically caught on a 270 to 325 mesh sieve. Often the nematodes in this type of sample can be further separated by more sophisticated laboratory techniques, such as the centrifugation technique which is ideal for slow moving nematodes such as *Criconemella*.

Damage Thresholds Aid in Management Decisions

Nematodes do the vast majority of their damage to turfgrass plants *en masse*. While individual nematodes themselves cause little harm, in sufficiently high population levels, they can affect a lot of damage in a short amount of time. Not all nematodes are equally damaging at a given population level. This is related, in part, to their different reproductive rates and feeding habits, as well as to the different susceptibilities of different turfgrass varieties. The population required for economic damage on a given host species is often referred to as the **damage threshold**. A listing of the known damage thresholds for various nematodes of different turfgrass species is presented in Table 4. It should be noted that the damage threshold is unknown for most nematode species on many of the major cool- and warm-season turfgrasses. Therefore, one should use caution in trying to extrapolate from one nematode-host combination to another. Furthermore, nematodes rarely occur in affected soil samples as populations of a single species. Most commonly several different species are found associated with the same root system. This makes damage thresholds difficult to use in a practical way. Additional care should be taken in using damage thresholds inasmuch as they should only be used as general reference points for making management decisions.

Nematodes Often Interact with Turfgrass Pathogens

Because of the soil environment in which root-infecting nematodes live, the opportunity for significant interactions with fungal turfgrass pathogens is great. However, these types of interactions have not been studied extensively. Nearly 20 years ago, it was shown that the presence of the stunt nematode, *Tylenchorhynchus dubius*, increased the severity of a Fusarium disease on Kentucky bluegrass turf. In a more recent study, it was found that there was a significant interaction between a different species of stunt nematode, *Tylenchorhynchus nudus*, and the summer patch pathogen, *Magnaporthe poae*, resulting in enhanced levels of summer patch disease at temperatures >82 F. In another study, increased levels of the lance nematode, *Hoplolaimus galeatus*, were associated with a slight increase in dollar spot disease on Kentucky bluegrass turf.

These types of interactions have been studied in the most detail for agricultural crops. Strong interactions of various nematodes with root-rotting fungal pathogens have been described. Nearly all of the genera of nematodes affecting turfgrasses have known interactions with root rotting pathogens in other crops. Most notable are species of *Meloidogyne* and *Pratylenchus*. Other nematodes, such as *Longidorus* and *Xiphenema*, are known to transmit viruses in agricultural plants. However, since viruses rarely, if ever, cause economic damage to turfgrasses, it is unlikely that this interaction is an important one for turfgrass managers to consider.

There are at least three possible explanations for the increased level of disease development on turfgrass plants affected by nematodes. First, nematode feeding may cause a plant stress that allows the fungal pathogen to cause more damage than it otherwise would if the plant were not stressed. Alternatively, nematode feeding may also provide a wound site through which fungal pathogens might penetrate. The latter situation is more likely with root-infecting fungal pathogens such as *Magnaporthe poae* and related genera as opposed to foliar pathogens. The other possibility is that the nematode actually transmits the fungus to the plant. I believe that the chances of such a transmission would be highly unlikely, however, as there is no known instance of fungus-transmitting nematodes in the numerous cases of nematode-fungus interactions described for agricultural crops.

Turfgrasses Differ in Their Tolerance of Nematode Damage

A number of strategies, including genetic, cultural, biological, and chemical, have been employed to manage nematode problems on turfgrasses. For long-term nematode management in turfgrasses, both genetic and cultural practices offer the greatest potential for effective management. Although there is no known varietal resistance to nematodes in turfgrasses, some varieties of turfgrass species vary in their ability to support certain, but not all, nematodes. For example, varieties of Kentucky bluegrass range from being a favorable host (e.g., Aristida, Atlas, Baron, Delta, Fylking, Nuggett, Sydsport, and others) to a non-host (e.g., Cougar, Fusa, and Steinacher) for the lesion nematode, *Pratylenchus neglectus.*

For warm-season grasses, bahiagrass is generally more tolerant of most parasitic nematodes than other warm-season turfgrasses. Differential tolerance among bermudagrass varieties has also been reported. For example, Tifway is somewhat tolerant of the sting nematode, *Belonolaimus longicaudatus,* whereas the cultivars Midiron, Tifdwarf, Tifgreen, Tifgreen II, Tifway II, and Tufcote are all extremely sensitive. Similar tolerance level variations to various parasitic nematode species exist among other turfgrasses.

Cultural Practices Help Reduce Plant Stress

In choosing cultural nematode management practices, one should keep in mind that the immediate goal is to minimize plant stress. The most common practices affecting nematode populations and the severity of plant damage are watering and fertility practices, as well as the use of organic amendments. Watering heavily to increase the depth of water penetration and so encourage a deeper and more robust root system will allow turfgrass plants to withstand more nematode feeding without showing above-ground damage. Excessive fertilization should be avoided, since this can enhance the succulence of root tissues and make them more attractive to nematode feeding. However, be sure to avoid any nutrient deficiencies, as this results in a stress that often predisposes plants to infection.

As always, other stresses should be avoided. Precautions should be taken to minimize such predisposing factors as soil compaction, excessively low mowing heights, other pest stresses, and heat and drought stresses.

Soil Amendments Enhance Natural Biological Control

Soil amendments offer the potential to greatly improve the physical, chemical, and biological soil properties that enhance nematode control. A wide variety of organic amendments are being used at an ever-increasing frequency in turfgrass management. These include such things as peats, composts, sludges, plant extracts, and industrial byproducts. Many of these types of amendments affect nematode population levels both directly and indirectly. For instance, during the decomposition of some organic amendments, organic acids are released that, along with some other volatile compounds released under certain other soil conditions, are toxic to a range of nematode species. These amendments, therefore, have a direct effect on nematode population levels.

Generally, soils high in organic matter support higher levels of microbial activity, maintain better nutrient and water-holding properties, have reduced soil compaction, enhanced thatch degradation, and ,often, enhanced turfgrass root development, compared to soils low in organic matter. The most significant aspect of organic amendments is the effect they have on populations of competing and predatory microorganisms. Since many of these microbes provide natural biological control of root-feeding nematodes, the amendments indirectly affect nematode population levels. A more detailed discussion of this topic can be found in the accompanying article.

A Limited Number of Turfgrass Nematicides are Available

In a number of cases, the most effective way of reducing populations of parasitic nematodes in turfgrasses is to apply nematicides, few of which are currently available to the turfgrass manager. Nematicides fall into two different groups: fumigant nematicides and non-fumigant nematicides. Fumigant-type nematicides can only be applied prior to seeding and are used primarily to ensure that the new site is nematode free. Methyl bromide has been the fumigant of choice for many turf managers; its use, however, has been scheduled for elimination and its' use is being phased out over the next 5 years. Other commonly-used fumigant nematicides include Telone® C-17, Vapam®, Busan®, Sectagon®, and Basamid®.

Most commonly, turfgrass managers are faced with nematode damage on established turf. For such situations, only a limited number of non-fumigant nematicides are available. These include Nemacur®, Mocap®, and Triumph®. All of these nematicides are applied to the turf surface and watered-in with sufficient irrigation or rainfall to transport the nematicide to the root zone. The efficacy of these materials varies considerably from site to site and is related to the degradation of the chemical by soil microbes and to the ability of the chemicals to penetrate the thatch zone and move into the soil.

The three available non-fumigant nematicides also vary in their modes of plant protection and in the spectrum of nematodes controlled. For example, Nemacur® is a systemic nematicide which is taken up and translocated throughout the plant. This nematicide is, therefore, effective not only against ectoparasitic nematode species, but also against the endoparasitic species. Although Nemacur® is effective against a wide range of nematode species, it is equally toxic to humans, birds, and wildlife. Because of its environmental impact, special precautions should be taken with Nemacur® to avoid the risk of exposure.

Nemacur® persists in soils for up to 12 weeks, but moves through soil rather slowly. This allows soil microbes time to adapt the capability to utilize Nemacur® as a food source. Studies have shown that prolonged use of Nemacur® on the same site encourages the buildup of soil microbes capable of degrading the nematicide, making it ineffective. It is, therefore, suggested that Nemacur® be used only when absolutely necessary and, if possible, in rotation with other available nematicides.

Unlike Nemacur®, Mocap® is a contact nematicide and , therefore, is not taken up and translocated by the turfgrass plant. As a result, Mocap® is not effective in controlling endoparasitic nematode species. Mocap® is most effective against sting, spiral, ring, and stubby root nematodes and moderately effective against other ectoparasitic species.

In order to be most effective, Mocap® should be watered-in to transport the material to the root zone and to reduce the risk of exposure. Watering-in also reduces some of the undesirable garlic odor associated with the product. In addition to its nematicidal properties, some phytotoxicity has been observed to a wide range of ornamental plants as well as to several turfgrass species, particularly bentgrasses and perennial ryegrass mowed at green cutting heights. Also, Mocap® may be damaging to most seedling turfgrasses and its use on newly seeded areas should be avoided until plants are well established.

Triumph® is used primarily as an insecticide for the control of mole crickets in warm-season turfgrasses. However, the current label indicates that the material is especially effective against sting and lance nematodes, but should only be applied when the intended use is for mole crickets or other insects. Further evaluations are necessary to more completely assess the suitability of Triumph® for the control of these and other turfgrass nematodes.

Variety of Factors Influence Nematicide Performance

One of the most important considerations with nematicide applications is the timing. Nematicides must be applied at a time when the buildup of populations and feeding can be minimized. Even then, the effect of most nematicides is only temporary; nematode populations are never eliminated completely with a single nematicide application. Since nematode eggs are resistant to nematicide treatments, it is important that nematicides be applied after egg hatch. Application of nematicides to soils where the temperatures exceed 60 F ensures that most nematode species are in the adult or larval stages when they are most susceptible to the nematicide. It should be recognized, however, that nematode species vary considerably in their sensitivity to various nematicides. You should consult with your nearest turfgrass pathologist or nematologist for help in selecting the most appropriate nematicide.

Other critical factors determining the efficacy of nematicides are soil properties such as soil texture and organic matter content. In general, nematicides are most effective in sandy soils low in organic matter and least effective in heavy soils rich in organic matter. Fortunately, nematicides are most effective in those soils where nematodes are generally more damaging.

Because nematicides must reach the root zone to be effective, it is best to apply them immediately after performing cultivation practices, such as core aeration and vertical mowing, that facilitate their movement into the soil. It is also best if the soil is reasonably moist prior to the application of the nematicide. Immediately after application and before it has a chance to dry on turfgrass foliage, the nematicide should be watered-in.

Watering and fertility practices are critical to the recovery of turfgrasses damaged by nematodes. It is important to maintain conditions that allow turfgrass roots to regenerate and to proliferate. This means improving the physical, chemical, and biological conditions in the soil and maintaining proper pest control practices. It is important that these cultural practices be implemented concurrently with the nematicide application to prevent nematode populations from returning to pre-nematicide levels.

Without attention to these management factors, control with nematicides will likely be unsatisfactory.

In Conclusion

It is hopefully quite apparent that plant parasitic nematodes are important turfgrass pests. They can be equally damaging on both cool-season and warm-season grasses, yet the damage inflicted by nematodes is easily confused with damage from other turfgrass pests. Examining root systems provides the best confirmation of nematode damage. When nematode damage is suspected, accurate identification and population counts are important in determining management actions. Although few nematicides are available for the control of turfgrass-damaging nematodes, a variety of cultural practices and varietal selections are available for nematode management. While much remains to be learned about nematodes and nematode control in turfgrass ecosystems, current research efforts are underway to address a number of the important problems associated with nematode detection and control.

Terms to Know

Actinomycetes - any of various aerobic or anaerobic bac teria of the family Acinomycetaceae, some of which are pathogenic for men and animals

Collembola - the scientific name for springtails

Endoparasitic - a parasite which lives inside the body of its host

Exoparasitic - a parasite which lives outside the body of its host

Migratory - moving from place to place
Sedentary - remaining in the same place or region, not migratory

Saphropytic - living on dead or decaying matter

Biological Control of Plant Parasitic Nematodes Affecting Turfgrasses

by Eric B. Nelson

The biological control of turfgrass pests is an exciting new area of research and commercialization. However, the biological control of parasitic nematodes on turfgrasses has not kept pace with that of other turfgrass pests. This is partly due to general ignorance of the nematodes' role as pests in turfgrass plantings. Currently there are no commercially-available biological products for the control of turfgrass nematodes. A great number of recent studies, however, have focused on the biological control of many different plant parasitic nematodes that affect crops. Many of the same species studied are also parasitic on turfgrasses. It is very likely that our understanding of biological control of nematodes in other crops can be applied directly to turfgrasses. Other current studies are directed specifically toward the biological control of turfgrass nematodes. My intent, therefore, is to review some of the research being done in this area and to present a prognosis for the future development of biological controls for parasitic nematodes in turfgrasses.

Soil Environment and Biological Control

It has often been observed, in agricultural soils, that when certain pesticides are applied or when soils are partially-fumigated prior to planting, certain species of nematodes frequently increase. These types of observations tend to support the notion that other microbes in soils naturally limit the population increases of plant parasitic nematodes. Soil is one of the more biologically-complex environments known. It is now well accepted that nearly all soils exist in a state of biological balance, in which a variety of living organisms exist in stable communities or assemblages of organisms. This biological stability provides numerous checks and balances on developing populations in soils. This means, for example, that nematodes parasitic on plants have parasites and predators of their own. Likewise, the predators and parasites of nematodes also have their own set of predators and parasites. It is this type of association that keeps populations of nematodes from increasing astronomically in many soils. When something is done to disturb that balance, such as the application of a pesticide or the imposition of a plant stress, population growth is generally a direct consequence. It is, therefore, important to gain a better understanding of the types of organisms in turfgrass soils that could very well be playing significant roles in limiting the population growth of parasitic nematodes.

Microarthropods Affect Nematode Populations

Over the years we have learned a great deal about the types of organisms affecting nematode populations. In general, the organisms involved in the biological control of plant parasitic nematodes are either parasites or predators of nematode eggs, juveniles, or adults. They may be either microscopic animals such as other nematodes, mites, and collembola, or commonly recognized biological control microorganisms such as viruses, bacteria, fungi, actinomycetes, and protozoa.

Of the former group, mites and collembola have been the most studied. These are perhaps the most abundant microarthropods associated with plant roots. Collembola are known for their ability to perforate the cysts of *Heterodera* species and devour the eggs and developing juveniles within. Mites are also known predators of *Heterodera* species. As populations of mites increase in the soil, populations of cyst nematodes decrease. However, if populations of the nematode become too low, then the population of the mite also declines.

As it stands, we currently know little about how these kinds of organisms interact with plant parasitic nematodes and how they might be handled and commercialized for effective biological control. As far as I know, these organisms are not being realistically considered for the biological control of turfgrass nematodes.

Nematode-Trapping Fungi: A Marvel of Nature

Of all of the microorganisms that have been studied for their biological control potential, nematode-trapping fungi tops the list. The existence of these organisms has been known for over 100 years and, during that time, they have been studied in exhaustive detail. Despite that fact, however, there are only a couple of commercially-available biological control products based on preparations of nematode-trapping fungi.

Nematode-trapping fungi are rather remarkable organisms that have evolved a range of strategies for attracting, capturing, and devouring nematodes. These fungi can be separated into two groups based on the complexity of their capturing mechanisms. Some of these fungi are quite happy living in the soil on dead and decaying organic matter without being particularly interested in nematodes. Others, however, have a strong preference for nematodes as a source of food, with little selectivity for plant-parasitic types. There are over 100 species of fungi

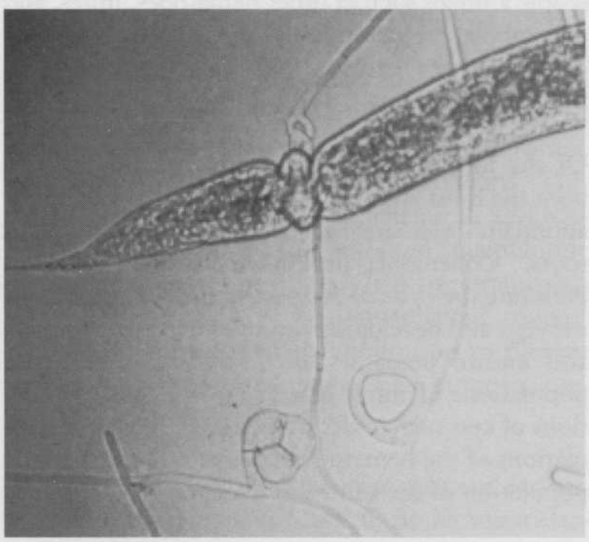

Figure 1. Nematode caughti in constricting hyphal ring.

that are known to either actively or passively capture nematodes.

Although passive nematode-trapping fungi prefer sources of food other than nematodes, these fungi develop hyphal networks that are sticky to nematodes. Nematodes swimming by get stuck in these networks and the fungi then penetrate and devour the nematodes through the production of numerous enzymes.

Active nematode-trapping fungi are more predacious. Generally, the more attractive these fungi are to nematodes, the more aggressive are the trapping mechanisms. Some fungi both attract and capture nematodes with the aid of adhesive knobs and hyphal branches with sticky ends. Still others, such as *Arthrobotrys oligospora*, produce hyphal rings that constrict nematodes as they pass through and touch them (Figure 1). For the greater part of their life, these latter types of nematode-trapping fungi live in soil as saprophytes without producing constrictive rings. However, as these rings are invariably present in conjunction with nematodes, it appears that the presence of nematodes actually induces the formation of these traps. In addition to the trapping mechanisms, many nematode-trapping fungi produce toxins that paralyze the nematode prior to digesting its body.

Many Microbes are Parasites of Nematodes

There are numerous species of bacteria, fungi, and actinomycetes that have been shown to be antagonistic towards plant parasitic nematodes. Nearly all of the important turfgrass nematodes have been the subject of at least one of these studies. There are numerous root-associated bacteria that are capable of protecting roots from nematode feeding. These bacteria, however, usually prefer very specific host genotypes.

Many of the species of microbes found associated with nematodes are endoparasitic fungi and bacteria that enter the nematode through natural openings as spores or cells. Inside the body of the nematode, these organisms digest the nematode only to release a new "crop" of spores on the nematode cadaver. Many other organisms, particularly fungi, produce enzymes that both digest nematode eggs and, by destroying the cuticle, reduce nematode motility.

One of the best studied organisms that affect various species of nematodes is the spore-producing bacterium *Pasteuria penetrans.* Spores of *P. penetrans* are sticky and adhere to the cuticle of the nematode, usually around the head and mouth parts. Upon germination of the spores, the germ tube penetrates the cuticle. Inside, the bacterium is free to proliferate, liberating more infective spores. Once the host dies from the infection, the spores are released into the soil where they can attach to another nearby nematode. A number of turfgrass nematode genera are susceptible to infection by *P. penetrans.*

Organic Amendments Enhance Natural Biological Control

Years ago, nematode control relied almost exclusively on the addition of organic matter to soils. We have come to learn the reasons for many of the beneficial properties of soil organic matter and recognize that these effects are largely realized due to the increased level of microbial activity that follows the use of organic amendments. In some cases, specific microbial antagonists such as trapping fungi are stimulated, reducing populations of plant parasitic nematodes.

Organic amendments induce dramatic changes in soil microbial communities and their effects on nematode behavior. For example, chitin amendments have been shown to increase the populations of chitinolytic bacteria in amended soils and, at the same time, to reduce the populations of several nematodes, particularly root knot, cyst, and stunt nematodes. Furthermore, applications of composted sewage sludge to golf course putting greens significantly reduces the populations of lance, ring, and sting nematodes in the soil.

Organic amendments may also affect nematode populations by releasing toxic compounds during degradation in soil. For example, many different organic acids toxic to plant parasitic nematodes are released during tissue decomposition in soil. These compounds are generally non-toxic to free-living nematodes.

A Future for Nematode-Suppressive Plants?

A number of plants are found throughout nature that produce naturally-occurring nematicides. One of the more common such plants is marigold (*Tagetes* spp.). The roots of marigold plants apparently release compounds that repel plant parasitic nematodes. Additionally, extracts and oil cakes of some oilseed crops such as neem, mahua, castor oil plant, and peanut have also been shown to have nematicidal properties. Although the compounds derived from these plants are not available,, it is important to recognize that such interactions can be found in nature and that one day, we may have a battery of natural plant products available for use on turf.

Future of Biological Control Products Uncertain

Although there are no nematode biological control agents commercially available in the United States, there are several that may be developed in the near future. Only a couple of such products are available internationally and, despite the current research efforts world-wide, it is unlikely that specific biological control products will be available for turfgrass applications in the foreseeable future. This is due primarily to the small market size for such a product coupled with the lack of recognition of nematodes as important turfgrass pests. However, since currently available nematicides for turfgrass applications are being steadily eliminated, either directly or due to their not being re-registered, it is likely that their loss will be the impetus to move the biological control of turfgrass nematodes forward. In the meantime, it is important to utilize as many of the turfgrass cultural manipulations as possible in an attempt to enhance natural levels of biological control in turfgrass plantings.

Dr. Eric B. Nelson is an Associate Professor of Plant Pathology at Cornell University, where he is affiliated with the Department of Plant Pathology. He has degrees in botany from Indiana University and plant pathology from Ohio State University. Dr. Nelson is active in research on the ecology and control of soilborne plant pathogens, concentrating on biological control of plant diseases. He also conducts extension programs in turfgrass pathology. His most recent contribution to *TurfGrass TRENDS* appeared in the July 1995 issue.

In Future Issues:

- Keys to Winter Weed Control in Southern Turf
- Risk-taking and Pest Management
- Rewriting (?) the Rules at EPA
- Intuitive Pest Modeling
- Herbicide Effects on Bermudagrass Turf
- Annual Bluegrass Management
- Plant Growth Regulators and Annual Bluegrass
- Herbicide Reisistance
- Reduced Herbicide Usage for Crabgrass and Goosegrass

TurfGrass TRENDS

1775 T Street NW
Washington, DC 20009-7124
ADDRESS CORRECTION REQUESTED

FIRST CLASS
US POSTAGE
PAID
WASHINGTON, DC

10/95