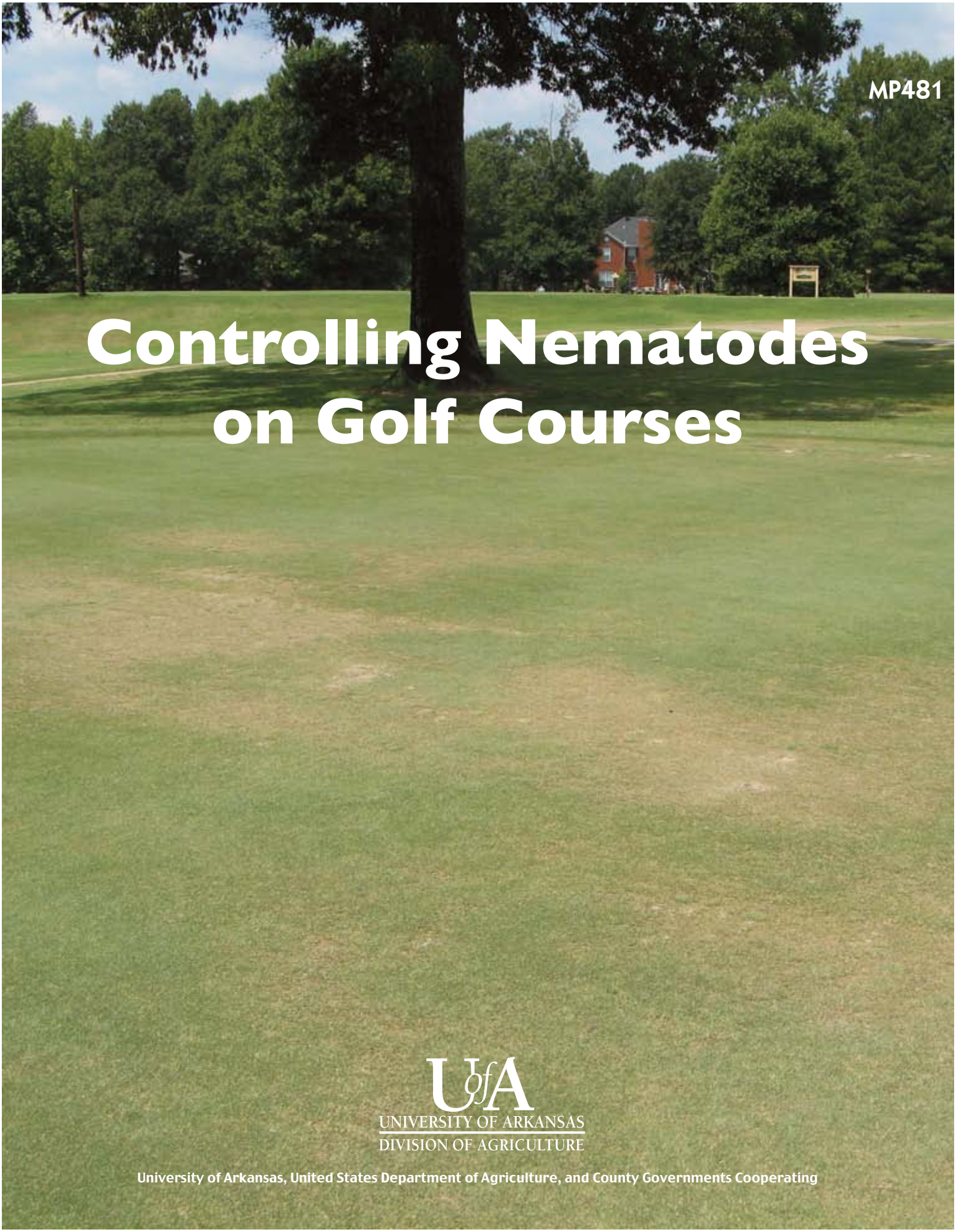

MP481

Controlling Nematodes on Golf Courses

UofA
UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

University of Arkansas, United States Department of Agriculture, and County Governments Cooperating

Authors

DAVID MOSELEY is county Extension agent - 4-H - agriculture, Logan County. **AARON PATTON**, Ph.D., is assistant professor - turfgrass specialist, Department of Horticulture, Fayetteville. **RONNIE BATEMAN** is pest management program associate, Southwest Research and Extension Center, Hope. **TERRY KIRKPATRICK**, Ph.D., is professor - nematologist, Southwest Research and Extension Center, Hope. They are employees of the University of Arkansas Division of Agriculture.

Controlling Nematodes on Golf Courses

Nematodes are important economic pests of golf courses in Arkansas. These pests are particularly problematic in golf course putting greens. Nematodes are microscopic, unsegmented roundworms 1/300 to 1/3 inch in length (12) (Figure 1) that live in the soil and can parasitize many crops, including turfgrasses.

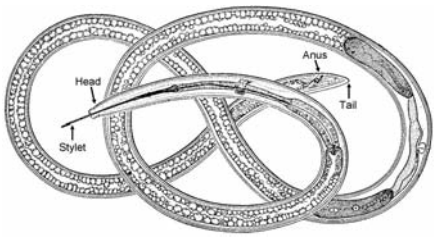

Figure 1. Schematic drawing of a plant parasitic nematode *(adapted from N. A. Cobb, Nemapix, Vol. 2).*

Although most nematodes are actually beneficial (feed on fungi, bacteria and insects or help in breaking down organic matter), there are a few species that parasitize turfgrasses and cause damage, especially in sandy soils. All parasitic nematodes have a stylet (Figure 1), a protruding, needle-like mouthpart used to puncture the plant cell, inject digestive juices and ingest plant fluids. Nematodes feed on turfgrass roots and are most abundant when the turfgrass is actively growing – in the spring and fall for cool-season grasses and in the summer months for warm-season grasses. In addition to direct damage, nematodes may also enhance turf damage by fungal pathogens. Nematode feeding may aid fungal infection and development and increase the level of damage that is caused. Soil fungal pathogens known to form disease complexes include Fusarium, Rhizoctonia and Pythium species. Control methods for nematodes, including preventative and curative measures, are discussed later in this publication. Fungi can be adequately controlled with proper fungicide applications.

There are two general classes of nematodes differentiated primarily by the shape of their stylets. The most common class has a stomatostyle that is a hollow spear with distinct knobs at the base (Figure 2). The sting (*Belonolaimus* spp.), lesion (*Pratylenchus* spp.) and root-knot (*Meloidogyne* spp.) nematodes are damaging turf nematodes belonging to this class.

Figure 2. Stomatostyle-type stylet of a lesion nematode *(photo by C. Högger, Nemapix, Vol. 2).*

Figure 3. Odontostyle-type stylet of a dagger nematode *(photo by T. Vrain, Nemapix, Vol. 2).*

A second class of parasitic nematode has an odontostyle rather than a stomatostyle-type stylet (Figure 3). The odontostyle stylet has flanges at the base rather than knobs and a larger lumen (opening). This larger lumen is significant because it is large enough to allow viruses, such as the St. Augustine Decline virus, to be transmitted from infected plants to healthy plants.

Life Cycle

There are six stages in the nematode life cycle including an egg stage and the adult. There are four juvenile stages that allow the nematode to increase in size and, in some species, to change shape. These juvenile stages are similar to the larval stages found in insects. Nematodes are aquatic animals and, therefore, require water to survive. Nematodes live and move in the water film that surrounds soil particles. Soil type, particularly sand content, has a major impact on the ability of nematodes to move, infect roots and reproduce. For most nematodes that are a problem in turf, well-drained sandy soils with soil moisture at or near field capacity are optimum for nematodes to flourish. For this reason, nematodes are most problematic on high-maintenance putting greens and sand-capped tees and fairways.

Feeding Habits

Nematodes feed as either ectoparasites or endoparasites. Ectoparasitic nematodes spend

their entire life cycle outside the host roots, feeding and reproducing in the soil surrounding the root system. Many ectoparasites cause only limited damage to the roots by their feeding. Population densities that are relatively high are required for appreciable turf damage. An exception is the sting nematode (*Belonolaimus*) that is the most economically damaging nematode pest of turf. Sting nematodes are large and have a long, slender stylet. Feeding by only a few sting nematodes can result in root systems having a stubby appearance and the absence of root hairs. With severe infestations, plants may show little or no new root development during the spring and summer. Because sting nematodes require soil with an 80 percent or greater sand content for reproduction, putting greens, particularly those established according to USGA root zone specifications, are ideal environments.

Endoparasites and semi-endoparasites actually enter the root to feed and reproduce. There are two types of endoparasitic and semi-endoparasitic nematodes – migratory and sedentary. Some are classified as semi-endoparasitic nematodes because they feed partially embedded in tissue with a portion of the body outside. True endoparasitic nematodes enter completely into the root. Migratory endoparasitic nematodes enter and move through roots, feeding as they go, and can leave and reenter the root at will. Sedentary nematodes enter the root as juveniles and create a permanent feeding site where they stay for the rest of their life cycle. Lance (*Hoplolaimus*) is a migratory semi-endoparasite (Figure 4), cyst (*Heterodera leuceilyma*) is a sedentary semi-endoparasite, root-knot (*Meloidogyne* spp.) is a sedentary endoparasite and lesion (*Pratylenchus*) is a migratory endoparasite.

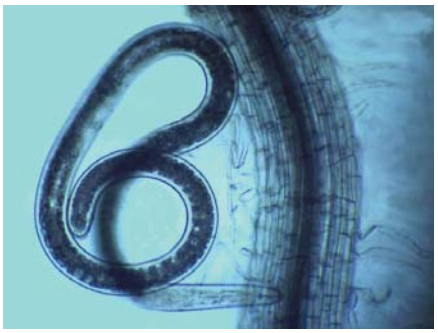

Figure 4. Migratory semi-endoparasitic lance nematode feeding on a plant root *(photo by U. Zunke, Nemapix, Vol. 2).*

Symptoms and Signs

In turfgrasses, there are few definitive symptoms or signs for consistent diagnosis of a nematode problem. Generally, the symptoms of nematode damage are similar to those of other pest problems, nutritional deficiencies or environmental stresses (Figures 5 and 6). However, greens or fairways where there are irregular areas in the turf without distinct borders; areas of yellow, stunted plants; wilting; and thin, weedy turf would be extremely good candidates for suspecting a nematode problem. Actual signs of nematode infection, such as root galls due to the root-knot nematode or the presence of cysts attached to roots, may sometimes be evident. An additional symptom of nematode damage is lack of response to irrigation, fungicides, insecticides and fertilizers. Aboveground symptoms do not typically occur until injury to the turfgrass root system is well advanced (12), and since the root system is damaged by nematode feeding causing a reduction in fine root hairs, turfgrasses may not readily respond to applications of fertilizer or irrigation. Additionally, turf may be unresponsive to applications of fungicides and insecticides since these products will not control nematodes. Once nematode populations reach a critical threshold, turfgrass death may occur (Figure 7).

Figure 5. Typical nematode damage – irregular areas without distinct border including yellow, stunted turf that is thin and not responsive to fertilizer or irrigation *(photo courtesy of N. Walker).*

Figure 6. Mild symptoms from nematode infection can appear similar to many other plant stresses including drought, nutrient deficiencies, pH problems and other common symptoms seen in damaged turf.

Figure 7. Once nematode populations reach a critical threshold, turfgrass death may occur as seen in this Meyer zoysiagrass lawn.

Important Nematodes in Turfgrass

Sting Nematodes

Sting nematodes are ectoparasites that are more damaging to turfgrass than any other nematode species (8). Sting nematodes reach up to 3 mm long, reproduce sexually and complete their life cycle in 18 to 24 days. In Arkansas, the only place sting nematodes are found is in golf courses, particularly in putting greens and sand-capped tees or fairways. Sting nematodes generally feed at the root tip causing the roots to cease growing and the turf to exhibit nutrient and water deficiencies. As a result, these areas could be over-irrigated and fertilized in an attempt to get a response from the turf (13, 15). Symptoms of sting nematode damage can include wilt, stunted growth, nutrient deficiency, irregular patches and added growth of weeds (such as prostrate spurge) (Figure 8). Unlike many other nematode species, turf areas with heavy sting nematode infestations can be completely killed.

Figure 8. TifEagle putting green showing symptoms of sting nematode damage.

Lance Nematodes

Lance nematodes are migratory semi-endoparasites (Figure 9). Adults can reach up to 1 mm long. Lance nematodes are the most common nematode problem nationwide because they are adapted to many soil environments. Generally, damage thresholds are higher than for sting nematodes, but since lance nematodes can feed and reproduce on a wider variety of soil types, damage can be found extensively in native soil fairways and tees in addition to older putting greens with higher organic matter.

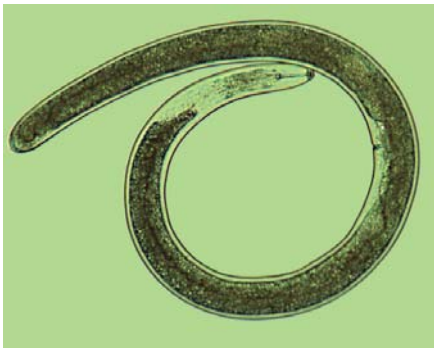

Figure 9. Female lance nematode (*Hoplolaimus* spp.) *(photo by J. D. Eisenbac, Nemapix, Vol. 2).*

Lance nematodes generally affect warm-season grasses. Since they are endoparasitic, lance nematodes are harder to control with chemical nematicides (7). Because lance nematodes feed inside the root, damage throughout the root system may occur. Root tips can also appear dead, and small feeder roots may be limited. Aboveground symptoms of lance nematode damage to turfgrasses include patches of yellowing, dying and poorly rooted turf (Figures 10 and 11). It is hard to diagnose lance nematode damage just by observing symptoms since the symptoms are similar to other stresses, including insect damage, disease, drought and nutrient deficiency.

Figure 10. Lance nematode damage to bermudagrass rough *(photo courtesy of N. Walker).*

Figure 11. Decrease in bermudagrass rooting (right) caused by lance nematodes *(photo courtesy of N. Walker).*

Root-Knot Nematodes

Root-knot nematodes are sedentary endoparasites. They penetrate the root with their entire body and then form a permanent feeding site where they remain for life. Root-knot nematodes are the most well-known and most economically important nematode in many agronomic and horticultural crops. Although they are not as damaging to turfgrasses, there are several species that can be damaging. A sign of root-knot nematodes is root gall formation in response to their infection (Figure 12). Although galls can be easily observed on the roots of

most crops, they can be difficult to see on turfgrass roots. Roots may look normal on the outside, but galls can be seen if the root is dissected longitudinally. Symptoms of root-knot nematodes can include darkened, rotted roots; chlorotic areas of turf; and limited response to fertilizer, fungicide or irrigation.

Figure 12. Root-knot nematode, *Meloidogyne* spp., feeding on barley (photo by G. Caubel, Nemapix, Vol. 2).

Other Ectoparasites

Other ectoparasites known to parasitize turfgrasses in Arkansas include spiral (*Helicotylenchus* spp.), stunt (*Tylenchorhynchus* spp.), pin (*Paratylenchus* spp.), dagger (*Xiphinema* spp.), awl (*Dolichodorus* spp.), ring (*Criconemoides* spp.), sheath (*Hemicycliophora* spp.) and stubby-root (*Trichodorus* and *Paratrichodorus*).

Spiral, Stunt, Sheath and Pin Nematodes – The feeding by spiral, stunt, sheath and pin nematodes results in shriveled roots that are reflected as short and sparse root systems. Spiral nematodes, named for the shape of the inactive nematodes, are not economically damaging on most turfgrasses in the southeast, with the exception of seashore paspalum, which can be severely damaged (9). At high population densities or in situations where turf is already stressed from other causes, sheath, stunt and pin nematodes can be damaging to several turfgrass species.

Dagger and Awl Nematodes – Dagger nematodes may damage roots of many turf species. Symptoms include sparse, discolored roots systems lacking feeder roots. Dagger nematodes also belong to the class of nematodes that are known vectors of plant viruses, although viruses in turfgrasses in Arkansas are not a significant problem. Generally, dagger nematodes are not considered to be a significant threat to golf course turf in Arkansas.

Awl nematodes may cause severe damage to turfgrasses and are similar to sting nematodes in their damage potential. Fortunately, awl nematodes are rarely found in Arkansas.

Ring and Stubby-Root Nematodes – Both ring and stubby-root nematodes may cause significant damage to turf if population densities are high enough. With both nematode species, feeding results in tiny lesions on the roots, and under high nematode pressure, roots become discolored and stubby. Centipedegrass is highly susceptible to ring nematodes, but bermudagrass, bentgrass and St. Augustinegrass can also be damaged.

Two species of stubby-root nematodes, *Paratrichodorus minor* and *Trichodoridae obtusus,* are known to damage turfgrasses. Although both species can be damaging to a number of turfgrasses, *T. obtusus* causes more damage to bermudagrass and St. Augustinegrass (9).

Other Endoparasites

Other endoparasites known to parasitize turfgrasses are lesion (*Pratylenchus* spp.) and cyst (*Heterodera leuceilyma*) nematodes. Lesion nematodes cause roots to have black spots (lesions) or even severe root rot. Although not well studied, lesion nematodes are not thought to be very damaging (9). As with root-knot, cyst nematodes form a permanent feeding site. These nematodes are semi-endoparasitic, with the females partially embedded in the root. The eggs are formed inside the body of the mature female (the cyst), where they remain even after she has died and dropped off into the soil. Cyst nematodes are very resilient because the eggs can remain viable inside the cyst until a suitable host is near. The cyst also provides partial protection to the eggs and/or juveniles when nematicides are applied (9). Fortunately, cyst nematodes are not known to cause major damage in Arkansas turfgrasses.

Diagnosing Nematode Problems

Nematode problems in turf are often misdiagnosed as being the result of poor cultural practices, diseases, insect damage, soil compaction, nutrient deficiencies, poor drainage, drought or other environmental stresses. To accurately diagnose a nematode problem, a soil sample must be

collected from the affected area and be assayed by a nematology laboratory where trained professionals can determine if there are parasitic nematodes present at levels that could cause the observed damage.

The process of taking a soil sample for nematode assay involves collecting random subsamples in a zigzag pattern (Figure 13) from the area in question similar to the procedure that would be used for a soil sample for nutrient analysis. Soil samples for nematode analysis should be taken to a depth of 4 inches – since this is where the majority of the roots are located – with 15 or more subsamples making up a representative sample of the area. It is important to submit separate samples of both healthy and unhealthy turf to accurately reflect the population density of the area.

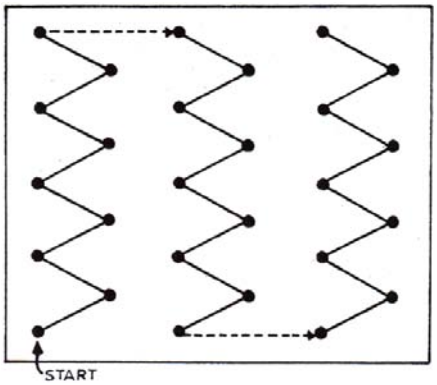

Figure 13. Sampling pattern for turfgrass area with suspected nematode problems. In a similar pattern, also collect a sample from a healthy-looking area.

Never sample only dead or severely damaged areas. Samples collected in areas with severe damage (dead turf) may not contain many nematodes, since there are few roots available for nematode feeding. Collect samples in areas bordering the damaged area and from healthy-looking areas as well as from severely affected areas. Sample putting greens or fairways separately because it is important to know specifically where nematode infestations are and where they are not. This information will help in implementing sanitary maintenance practices as well as control options that are discussed further in the "Control" section.

Combine the subsamples for a particular sample as they are collected. A convenient method is to use a small bucket or other container that is easy to carry. When 8 to 12 subsamples are collected, mix the soil thoroughly and place approximately 1 pint into a quart-sized plastic bag. Bags should be sealed to retain soil moisture and kept out of direct sunlight – placing samples into a small insulated cooler (without ice) is a safe and convenient method for protecting the sample until it can be sent to the nematology laboratory. Label each sample on the outside of the plastic bag with your name, address, putting green number (or other short sample identifier) and county. Ziploc storage bags are ideal for this use because they generally have a labeling space on the outside.

Deliver the sample to your county Extension agent as soon after it is collected as possible. If samples must be stored for a few days (up to one week), keep them in an insulated cooler at cool (air-conditioned) room temperature. NEVER store the samples in the refrigerator or store them on ice in the insulated cooler. The county agent will help you complete a Nematode Sampling Submission Form (AGRI-483) which must accompany your sample. These forms may also be obtained from the Arkansas Nematode Diagnostic Laboratory web site (http://www.aragriculture.org/nematodes/).

The Arkansas Nematode Diagnostic Laboratory is located in Hope, Arkansas, at the University of Arkansas Southwest Research and Extension Center, 362 Highway 174 North, Hope, AR 71801 (phone: 870-777-9702). A $10 cost-recovery fee is charged for each sample assayed. Results are generally available within a few days of receipt by the laboratory. Results can be sent electronically, by fax or by surface mail.

More information about nematodes and the diagnostic lab can be found at the University of Arkansas Cooperative Extension Service web site (http://www.uaex.edu).

Interpreting the Results

Once assay results are complete, the next step is to interpret the results. The assay report will include information on the individuals who collected and submitted the sample, the sample identifiers and tabular results of all plant-parasitic nematodes that were found. Note that the results are reported in a standardized fashion as nematodes per 100 cm^3.

Table 1 lists the most common parasitic nematodes for turfgrass and their estimated threshold levels needed to cause moderate

TABLE 1. Nematode common name and genus, threshold level, damage potential, feeding habit and root symptoms. Modified from Tables 1 and 2 from Anonymous (1), Table 1 from Crow (4) and from Davis et al. (10).

	Threshold[a]				
Common Name (Genus Name)	Medium	High	Damage Potential[b]	Feeding Habit	Root Symptoms
	- - - #/100 cc (cm^3) - - -				
Sting (*Belonolaimus*)	10 (25[c])	25 (50[c])	1	Ectoparasite	Cropped, stubby roots; large lesions.
Lance (*Hoplolaimus*)	40	120	1	Endoparasite (migratory)	Roots sloughing away. Slight swellings and brown lesions.
Root-knot (*Meloidogyne*)	80	300	1	Endoparasite (sedentary)	General swellings and galls. No reaction to applications of irrigation, fertilizer or pesticides.
Spiral (*Helicotylenchus*)	700	1500	2	Ectoparasite	Roots wilted, cropped off, discolored.
Spiral (*Peltamigratus*)	150	300	2	Ectoparasite	Roots wilted, cropped off, discolored.
Stunt (*Tylenchorhynchus*)	100+		2	Ectoparasite	Roots wilted, cropped off, discolored.
Dagger (*Xiphinema*)	51+		2	Ectoparasite	Roots wilted, cropped off, discolored.
Stubby-root (*Paratrichodorus*)	150	300	2	Ectoparasite	Stubby roots, attacks root tips, lesions may be present.
Stubby-root (*Trichodorus*)	40[cd]	120[cd]	2	Ectoparasite	Stubby roots, attacks root tips, lesions may be present.
Lesion (*Pratylenchus*)	51+		2	Endoparasite (migratory)	Black spots, root rot.
Sheath (*Hemicycliophora*)	200	400	2	Ectoparasite	Stubby roots, attacks root tips, lesions may be present.
Cyst (*Heterodera leuceilyma*)	10[c]	40[c]	2	Endoparasite	Swollen, white females or brown cyst on roots.
Ring (*Criconemoides*)	500 (150[e])	1000 (300[e])	3	Ectoparasite	Discolored roots, tiny lesions.
Pin (*Paratylenchus*)	500+		3	Ectoparasite	Roots wilted, thin.

[a]These thresholds were developed based on observations in other states and may be adjusted occasionally as more data is collected in Arkansas on nematode pathogenicity to turfgrasses. If nematode assays indicate that you have more than the medium threshold for a given nematode species, damage may become evident if turf incurs additional environmental stress. If nematode assays indicate that you have more than the high threshold for a given nematode species, root systems are likely damaged and turf quality is likely declining. Threshold levels are determined under otherwise normal conditions. It should be noted that in the presence of other stresses (drought, disease, insects), the threshold is effectively lowered.

[b]Damage potential: 1 = very damaging or moderately damaging to turf and very common or common occurrence in Arkansas; 2 = moderately damaging to turf and uncommon in Arkansas; 3 = damaging to turf only at high populations and uncommon or rare in Arkansas.

[c]Indicates threshold numbers for St. Augustinegrass.

[d]Indicates numbers for genus *Trichodorus*.

[e]Indicates threshold level for ring nematode in centipedegrass.

[+]Indicates baseline threshold number based on counts per 100 cc (cm^3) soil.

TABLE 2. Nematodes and the turfgrasses most affected by each (11, 14)

Turfgrass	Sting	Lance	Root-knot	Spiral	Stunt	Dagger	Stubby-root	Lesion	Cyst	Ring	Pin
Warm-season grasses											
Bahiagrass	X	X		X							
Centipedegrass	X			X			X			X	
St. Augustinegrass	X	X	X	X			X		X		X
Bermudagrass	X	X	X	X			X				
Zoysiagrass	X	X	X				X				
Seashore paspalum	X	X	X	X			X				
Cool-season grasses											
Creeping bentgrass	X	X	X	X	X	X	X	X		X	
Kentucky bluegrass	X			X			X				
Perennial ryegrass	X			X			X				
Tall fescue	X			X			X				

or high levels of damage. While these threshold values may be used as a general guide, it is important to remember that damage due to the nematode is strongly related to overall turf health and turf species (Table 2).

Healthy turf can withstand higher nematode levels than stressed turf. Control methods may be warranted if any one nematode species surpasses the medium threshold limit. If multiple nematode species are present at levels less than the medium threshold limit, it is more difficult to determine if control is warranted. The nematode and turf species, overall turf health, site history and other factors must be considered. Although nematode damage is not absolutely additive, control measures may be warranted if nematode counts are slightly below the threshold limit for multiple nematode species. In these situations, it is highly recommended that a nematologist or turf specialist be consulted concerning a control strategy.

For example, let's say you have 30 lance nematodes (75 percent of the medium threshold) and 60 root-knot nematodes (75 percent of the medium threshold). Both nematode species are present at population densities less than the threshold, but combined they total 150 percent of the medium damage threshold. Nematode damage is not absolutely additive, so you cannot simply add up the relative percentages for all species that are present (10), but if two or more nematode species each reached 90 percent of the medium threshold, chemical control may be warranted. On the other hand, if several nematodes are found at 30 percent of the medium threshold, a combined total of 100 percent likely will not require chemical control (10). As indicated, the overall health of the turf, the environment, past experience and other factors will influence control decisions, and the assistance of a nematologist or turf specialist is strongly recommended.

Control Options Before Planting

Very little nematode resistance or tolerance is known in turfgrasses. There are key differences between species in their susceptibility to certain nematodes (Table 2). Notably, cyst nematode only parasitizes St. Augustinegrass, and Bahiagrass is generally more tolerant to nematodes than other turf species (9). Bermudagrass is typically more tolerant to nematode feeding than zoysiagrass because of the deeper root system of bermudagrass (Figure 14, page 8). Susceptibility is known to differ among cultivars within certain species, but there are few definitive reports on these differences.

Nematodes are often found as problems in established turf. In some situations, nematodes may already be present in the native soil at the time greens or tees are established, while in some cases, the nematodes are transported to

the site in the sand or soil used in forming the greens. In either case, it is best to avoid or eliminate the problem during golf course construction or renovation. There are two proactive approaches to help avoid nematode problems: fumigation and sanitation.

Figure 14. A large patch of bermudagrass appears (right of mailbox next to curb) symptom-free in this Meyer zoysiagrass lawn weakened by nematodes.

Soil Fumigation

Pre-plant soil fumigation can be helpful in preventing infestations on new putting greens and tees. Soil fumigants are liquids or gases that volatilize in the soil and control a wide range of soil-borne pests including nematodes. Four compounds available for soil fumigation include (1) methyl bromide, (2) metham or metam-sodium, (3) dazomet and (4) 1,3-dichloropropene (Curfew) (Table 3).

Methyl bromide has been the most commonly used product for soil fumigation, but it is currently being phased out due to its environmental risks and will soon be unavailable. Methyl bromide is a colorless, nearly odorless liquid or gas. A plastic film cover must be placed over the treated area to trap the fumigant vapors in the soil.

Before using methyl bromide, the soil should be tilled and organic matter (dead plants, weeds, etc.) should be removed. Soil should be moist but not saturated, and the soil temperature should be > 66°F prior to treatment. The treated area should be covered for 24 to 48 hours. The cover should then be removed and the soil aerated for 24 to 72 hours before planting. Methyl bromide may only be applied by custom applicators.

Metam-sodium, sold under several trade names including Metam-Sodium®, Vapam® and Turfcure®, is a liquid that breaks down to form the highly toxic and volatile chemical methyl isothiocyanate upon contact with moist soil. Metam-sodium should be applied to moist soil with a temperature > 60°F and either covered with plastic or sealed into the soil by irrigation. Because of the risk of phytotoxicity, the treated area should not be planted for 21 days after application. Disadvantages of metam-sodium use include the lowered effectiveness when used without a cover and the longer waiting period before planting.

Dazomet, sold under the trade name Basamid®, is a granular formulation that must be applied accurately and uniformly and then incorporated into the soil by tilling. An alternative option is to apply dazomet to a scalped area (or sod removed) and aerified and/or verticut followed by 0.125 (1/8) inch or less of irrigation. Depending on soil temperature, areas typically should be ready to replant within one to two weeks following application. Its use and effectiveness are very similar to metam-sodium. Dazomet is typically applied by custom applicators.

Lastly, 1,3-dichloropropene is used extensively in commercial agriculture as Telone®. In turf, it is sold as Curfew. It is both a pre- and post-plant fumigation chemical and is the only soil fumigant safe to use in established turf. This material may be used in Arkansas golf courses under a special local need label (24C). As with the other fumigants, 1,3-dichloropropene may only be applied by custom applicators.

Sanitation

Sanitation practices are extremely important in preventing the spread of nematodes. Nematodes can be imported or spread with contaminated equipment, new sod, sand or soil. When building a tee box or putting green, the new sod or soil should be tested for nematodes prior to planting. Similarly, when repairing weak or dead areas of turf by bringing sod or plugs from one area of the golf course to another, do not transplant nematode-infested turf into areas without nematodes.

Another potential problem may occur when changing cups on putting greens. Do not spread nematodes within a particular green or from one green to another. If sod or soil is to be moved from one place to another on a green, it may be beneficial to assay different parts of the putting green for nematodes, especially if symptoms are not consistent across the green. Keep cultivation equipment clean since nematodes can be spread through infested equipment. For example, when aerifying, spiking or verticutting, work last on areas that have or are suspected to have nematodes and wash equipment thoroughly after use in nematode-infested areas.

TABLE 3. Pre- and post-planting chemical control options.

Chemical	Rate per 1,000 ft^2	Comments
Pre-plant Fumigants		
Methyl-bromide	8 lb (350 lb/A)	Prior to application, the soil should be moist but not saturated and the soil temperature should be > 66°F. Till the soil before application. For best results, cover the treated area with plastic to trap the fumigant vapors in the soil after application. The treated area should be covered for 24 to 48 hours. The cover should then be removed and the soil aerated for 24 to 72 hours before planting. Methyl bromide is typically applied by custom applicators and is a restricted-use pesticide.
Vapam HL (42% metam-sodium)	0.86 to 1.7 gal (37.5 to 75 gal/A)	For best results, Vapam should be applied to moist soil with a temperature between 60°F and 90°F and the area covered with plastic after application. It is most effective when covered after application. The treated area may be planted 21 days after application.
Basamid (Dazomet)	5 to 12 lb (220 to 530 lb/A)	Basamid is applied as a granular formulation. Basamid is typically incorporated into the soil by tilling. An alternative option is to surface apply Basamid to a scalped area (or sod removed) and aerify and/or verticut followed by 0.125 (1/8) inch or less of irrigation. Depending on soil temperature, areas typically should be ready to replant within one to two weeks following application. Basamid is typically applied by custom applicators.
Pre- and Post-plant Fumigants		
Curfew (1,3-dichloropropene)	8.8 to 14.7 fl oz (3 to 5 gal/A)	Can be applied to established turf on golf courses. Curfew is applied with a tractor-mounted slit injection system that delivers the fumigant in a liquid state 6 to 8 inches deep. The product should be irrigated into the root zone immediately following application. Curfew is only applied by custom applicators. Curfew is a restricted-use pesticide.
Post-plant Nematicides		
Nemacur 10G (Fenamiphos)	2.3 lb (100 lb/A)	Nemacur is a restricted-use pesticide because of its high toxicity. It can only be used on golf courses. The product should be applied with a high spray volume (> 25 gallons/A) and irrigated into the root zone immediately following application. Do not treat seedling or immature turf and do not treat more than 10 acres daily. **Nemacur production has been stopped, and it is no longer available in the U.S. Existing supplies can still be used until they are gone.**
Nemacur 3 Turf (Fenamiphos)	9.7 fl oz (3.3 gal/A)	

Control Options in Established Turf

Cultural Practices

Cultural practices are fundamental in the prevention of severe nematode damage, and appropriate cultural practices are vital since chemical control options are limited. Well-managed turf can withstand some nematode infection with little noticeable damage. Generally, cultural practices that promote root health and vigorous growth will aid in damage prevention. A few notable cultural practices include increasing the mowing height, use of lightweight mowing and rolling equipment to minimize compaction, proper balance in fertility and pest management practices and core or deep tine aerification. Irrigate deeply and less frequently in combination with afternoon syringing – wetting the leaf blades and not the soil surface – to promote deep rooting. This practice may help by encouraging the nematodes to move deeper in the soil in search of moisture and away from the majority of the root system (11).

If nematode population densities are high and the turf root system is severely damaged, foliar applications of nitrogen will be more readily available to the plant than granular applications. Avoid applying more than 1.0 lb/1,000 ft^2

of nitrogen in any one application, as this will promote shoot growth while promoting little root growth. Under-fertilization should also be avoided since damaged plants need some fertility to encourage recovery and new root growth (5). When granular fertilizers are applied, there is limited research suggesting that organic fertilizers may help reduce nematode population densities in sandy areas by increasing soil organic matter, which may encourage nematode-antagonistic microorganisms. Although deep and infrequent irrigation is ideal for enhancing root growth, light and frequent irrigations applied to the depth of rooting may be necessary on nematode-infested putting greens to keep these areas from wilting.

Biological Control

Certain biological and organic products can help minimize nematode damage, but limited efficacy is generally reported under severe infestations (2). Many of these products are known nematode bacterial and fungal antagonists or naturally occurring plant compounds that are nematicidal. A few examples include Clandosan, Neo-Tec, DiTera, mustard seed meal and mustard bran. Mustard bran as well as extracts from *Euphorbia* spp. are reported to work in the laboratory, and testing is currently ongoing in the field. The environmental and human safety attributes of these biological products make them extremely attractive potential nematode control methods for golf courses and for home lawns, athletic fields and commerciall andscapes.

Chemical Control

In some situations, nematode severity is sufficiently high that chemical control is the only effective option (Table 3). Chemicals that are currently labeled for controlling nematodes on golf courses are all toxic to man and animals (5) and must be applied by certified custom applicators.

Curfew® (1,3-dichloropropene) is perhaps the most popular chemical nematicide used on golf courses in the southern U.S. This product can be used either as a pre-plant fumigation chemical or it can also be applied to established turf (Figures 15-18), enhancing the utility of the product substantially. Curfew® is a broad spectrum nematicide that controls all major economic nematode species on turf, including sting nematodes (6), but it is not effective against soil-borne fungal pathogens. Curfew® is applied by a tractor-mounted injection system 6 to 8 inches deep (3), and the turf should be watered after application (Figure 19). Use of this product is allowed in Arkansas under a special local need label, and Curfew® may only be applied by certified custom applicators.

Figure 15. Application of Curfew to a creeping bentgrass putting green. Photo taken immediately following application *(photo courtesy of Linda Satter).*

Figure 16. Close-up view of slits from application of Curfew to a creeping bentgrass putting green. Photo taken immediately following application *(photo courtesy of Linda Satter).*

Figure 17. Recovery of creeping bentgrass putting green following application of Curfew. Photo taken 8 days after application *(photo courtesy of Linda Satter).*

Figure 18. Close-up view of the recovery of creeping bentgrass putting green following application of Curfew. Photo taken 8 days after application *(photo courtesy of Linda Satter).*

Although the application procedure causes some minimal damage to the turf, complete recovery usually occurs 7 to 14 days after application.

Figure 19. Bermudagrass fairways being irrigated following Curfew application *(photo courtesy of Linda Satter)*.

For a list of certified applicators or other information regarding Curfew application in Arkansas, contact Dow AgroSciences or see http://www.dowagro.com/turf/prod/curfew.htm.

Conclusions

Nematode control in turf is challenging due to limited control options. Nematodes generally do not move more than a few feet during their entire life cycle, but they can be moved long distances on equipment, turf or soil. Consequently, sanitation practices are vital to ensuring nematode-free turf. Cultural practices are also extremely important in controlling nematodes and the damage they cause. Preventing other turf stresses through good management practices for fertility, irrigation and pest management will promote turf health in general. Additionally, it is beneficial to monitor nematode populations in putting greens, tees and fairways to anticipate potential problems. If nematodes become severe, it may be necessary to utilize chemical nematicides to maintain turf health.

Additional Information

Additional publications are available at http://www.uaex.edu/.

Additional information about turfgrass management is available at http://turf.uark.edu/.

Additional information about nematodes is available at http://www.aragriculture.org/nematodes/.

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Printed by University of Arkansas Cooperative Extension Service Printing Services.

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MP481-PD-6-10N