ENY-016

Introduction to Plant Nematology [1]

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Plant Parasitic Nematodes

Plant nematodes attack all crops grown in Florida, causing farmers millions of dollars in crop loss annually. Nematodes also are of great concern to the home owner, since they cause severe damage to turfgrasses, ornamentals and home gardens. We are often unaware of losses caused by nematodes since they are hidden from sight and much of the damage caused by them goes unreported or is attributed to other causes.

Morphology and Anatomy

Nematodes that attack plants are worms, mostly microscopic in size (Figure 1), ranging from 0.25 mm to 3.0 mm (1/100-1/8 inch) long. They are generally cylindrical in shape, tapering toward the head and tail. Females of a few species lose their worm shape as they mature, becoming greatly enlarged in diameter and assuming varying forms, such as pear, lemon, or kidney shapes (see discussion of sedentary endoparasites below).

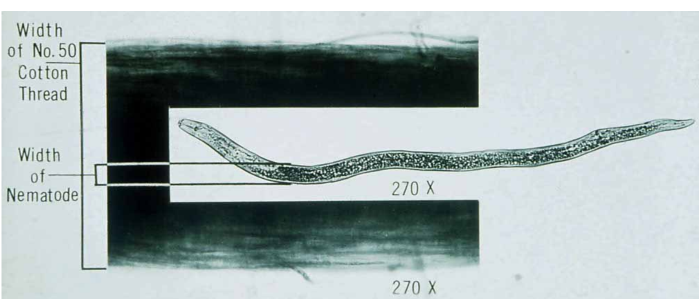

Figure 1. Size comparison of a typical plant-parasitic nematode to a cotton thread.

In spite of their small size, nematodes are complex in organization. Plant parasitic nematodes (Figure 2) possess all of the major organ systems of higher animals except respiratory and circulatory systems. The body is covered by a multi-layered cuticle that bears surface marks which are used when identifying nematode species. The cuticle of most is transparent, so that sufficient anatomical detail can be seen with the aid of a low-power “dissecting” binocular microscope, generally 20 to 60 X, to identify most nematode specimens to genus. Much higher magnification (900 X or more) is often needed to identify species.

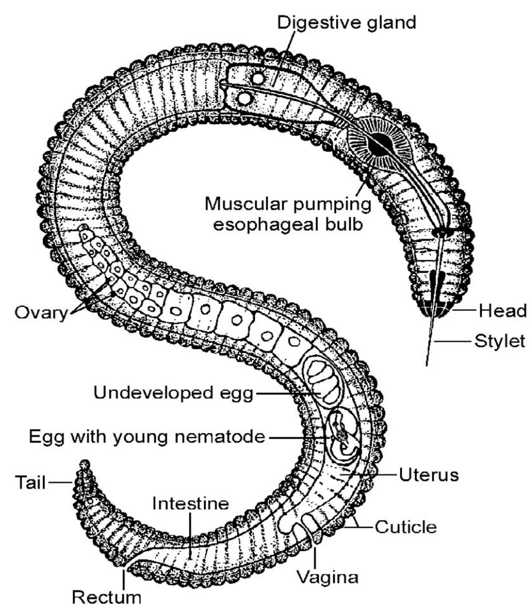

Figure 2. Diagram of a typical plant-parasitic nematode.

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Life Cycle and Reproduction

Plant parasitic nematodes have a simple life cycle of six stages: egg, four juvenile stages, and adult. The embryo develops inside the egg to become the first-stage juvenile. The first-stage juvenile molts inside the eggshell to become a second-stage juvenile, which hatches (Figure 3) from the egg, and in most species must feed before continuing to develop. The nematode molts three more times to become a fully developed adult.

Figure 3. Second-stage juvenile nematode hatching from its egg.
Credits: Photo by U. Zunke, University of Hamburg.

Male and female nematodes occur in most species, and both may be required for reproduction. However, reproduction without males is common, and some species are hermaphroditic ("females" produce both sperm and eggs). Egg production by the individual completes the cycle. The number of eggs deposited by a female varies among species and is affected by their habitat. Most species produce between 50 and 500 eggs, but a few occasionally produce several thousand eggs per female.

The length of the life cycle varies considerably depending on nematode species, host plant, and the temperature of the habitat. During summer months when soil temperatures are in the 80's, many plant nematodes complete their life cycles in about 30 days.

Nematode Feeding and Host-Parasite Relationships

Plant parasitic nematodes feed on living plant tissues. All have some form of oral stylet (Figure 4) or spear, which is used somewhat like a hypodermic needle to puncture the host cell wall. Many (probably all) plant nematodes inject enzymes into the host cell before feeding. These enzymes partially digest the cell contents before they are sucked into the gut. Most of the injury that nematodes cause to plants is related in some way to the feeding process.

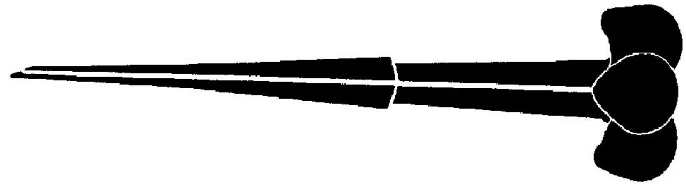

Figure 4. A plant-parasitic nematode stylet is used to puncture plant cells, to inject enzymes, and to ingest cell contents.

Nematodes may feed on plant tissues from outside the plant (ectoparasitic) or inside the tissues (endoparasitic). If the adult female moves freely through the soil or plant tissues, the species is said to be "migratory." Species in which the adult females become swollen and permanently immobile in one place in or on a root are termed "sedentary".

The feeding/living relationships that nematodes have with their hosts affect sampling methods and the success of management practices. Ectoparasitic nematodes that never enter roots may be recovered only from soil samples. Endoparasitic nematodes often are detected most easily in samples of the tissues in which they feed and live (burrowing and lesion nematodes), but some occur more commonly as migratory stages in the soil (root-knot and reniform nematodes).

Those stages of endoparasites, which are inside root tissues, may be protected from nematicides that do not penetrate into roots, such as some soil fumigants. Root tissues may also shield them from many micro-organisms which attack nematodes in the soil. Ectoparasites are fully exposed to pesticides and natural control agents in the soil.

ECTOPARASITIC NEMATODES

Ectoparasitic nematodes are generally migratory. Most feed superficially at or very near the root tip or on root-hairs, but a few have stylets long enough to enable them to feed deeper in the root. Those which cause the most widespread and severe plant injury in Florida are the sting (*Belonolaimus* spp.), stubby root (*Trichodorus* spp.), and awl (*Dolichodorus* spp.) nematodes. These feed at or near root tips and usually inhibit root elongation. Ectoparasites (Figure 5) that rarely cause severe injury to their plant hosts include ring (*Mesocriconema* spp.) and spiral (*Helicotylenchus* spp.) nematodes. They apparently feed primarily on root-hairs and superficial cortical tissues and cause serious injury only to plants that are especially sensitive to drought stress.

Among plant nematodes, only stubby-root nematodes and their close relatives, the dagger (*Xiphinema* spp.) and needle (*Longidorus* spp.) nematodes, are known to transmit plant viruses. The corky ringspot disease of potatoes, a problem in the Hastings area, is caused by a virus which is carried and transmitted by stubby-root nematodes.

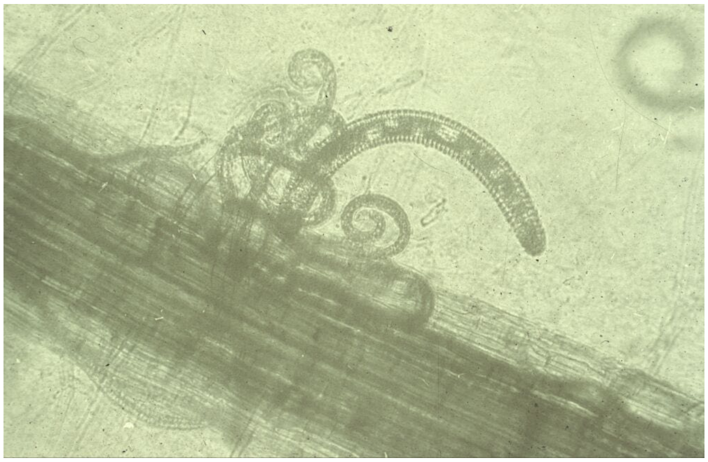

Figure 5. A ring nematode (thicker nematode) and spiral nematodes (thinner nematodes) feeding on a plant root. These nematodes are ectoparasitic nematodes.

MIGRATORY ENDOPARASITES

Migratory endoparasites can move into, through, and out from host tissues at any stage of development (except the egg). Migratory endoparasites generally live and feed in tender tissues such as the root cortex. They burrow (Figure 6) through the tissue, breaking open many cells after feeding on them. Cells surrounding the feeding area are often killed by toxic materials from the disrupted cells. The relatively large areas of dead cells usually turn brown, to become small spots or lesions (Figure 7) big enough to see, and are often easily colonized by fungi. Root rot (Figure 8) diseases are often associated with infestations of migratory endoparasitic nematodes.

Figure 6. Endoparasitic nematodes burrowing within a root.

Figure 7. Root lesions caused by migratory endoparasitic nematodes.

Figure 8. Rotting palm roots resulting from infection with migratory endoparasitic nematodes.

The most important examples in Florida are species of burrowing and lesion nematodes. The citrus burrowing nematode, *Radopholus similus*, causes the spreading decline disease of citrus. It is the subject of strict (and expensive) quarantine regulations for ornamentals, nursery stock, and other growing plants being exported from the state, and can severely limit growth of many ornamental plants. Various species of lesion nematodes live in the roots of most crops grown in the state and may be especially damaging to citrus, peanuts, and commercial fern nurseries.

The foliar (*Aphelenchoides* spp.) nematodes are the most important representatives in Florida of a group of migratory nematodes that attack plants at the soil line or above the ground. They feed on or inside the leaves and buds of ferns, strawberries, chrysanthemums, and many kinds of foliage ornamentals, and cause distortion or death of buds, leaf distortion, or yellow to dark brown lesions (Figure 9) between major veins of leaves. Other nematodes that attack plants above ground cause leaf or seed galls and still others cause deterioration of the bulbs and necks of onions and their relatives, but are not common here.

Figure 9. Symptoms of foliar nematode damage are often angular shaped leaf spots.

Ectoparasitic and migratory endoparasitic nematodes generally deposit their eggs singly as they are produced, wherever the female happens to be in the soil or plant.

SEDENTARY ENDOPARASITIC NEMATODES

Sedentary endoparasitic nematodes are typified by the root-knot (*Meloidogyne* spp.), cyst (*Heterodera* spp.), reniform (*Rotylenchulus* spp.), and citrus (*Tylenchulus semipenetrans*) nematodes. In most of these species, the second-stage juvenile is the "infective" stage, which moves through the soil. Second-stage juveniles locate host roots and enter them (Figure 10). They then establish a suitable feeding site within the root tissues. Once a feeding site is selected, the nematode injects growth regulating substances into the cells near its head, causing some of those cells to enlarge. These "giant" or "nurse" cells become specialized food sources for the nematode. At the same time, the nematode becomes immobile, and the body swells (Figure 11) to a round, lemon, kidney, or ovoid form.

Mature females of the sedentary endoparasitic nematodes generally produce large numbers of eggs that remain in their bodies (Figure 12) or accumulate in masses (Figure 13) attached to their bodies. The nematodes and the giant cells on which they feed are very dependent on each other: if the nematode dies, the giant cells die or lose their highly active condition; if the giant cells die, the nematode dies of

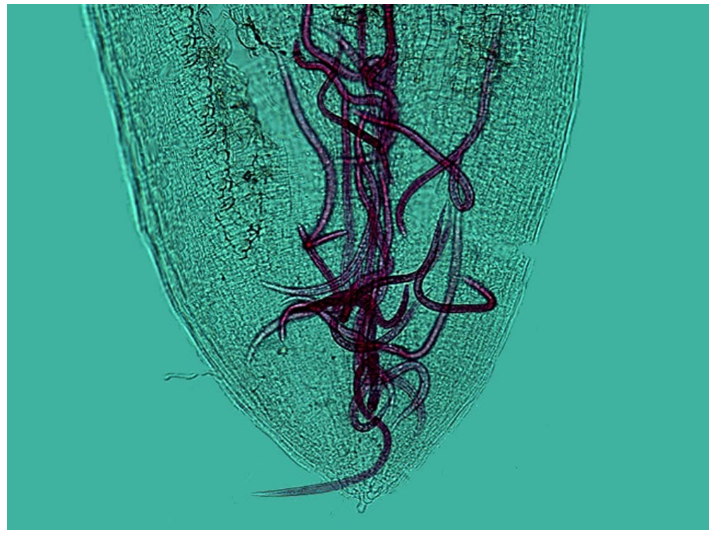

Figure 10. Second-stage juvenile nematodes entering a root tip.

starvation, because it cannot move to a new site. Sedentary

Figure 11. Root tissue pulled-back to reveal a swollen root-knot nematode within.

endoparasites damage their hosts by redirecting use of large amounts of energy and nutrients from normal activities to development of the nematodes and their special feeding sites. The altered tissues of the feeding site also disrupt the vascular system. Roots severely galled by root-knot nematodes also usually deteriorate much earlier from root rots than roots that are not galled: gall tissues are succulent, poorly protected from invasion, and rich in nutrients to help the fungi grow rapidly.

Sedentary endoparasites are the nematodes for which host resistance has most often been identified. Relatively small differences in heritable characteristics within some plant species seem to determine whether or not a specific nematode will be able to establish giant cells in their tissues. Plants in which giant cells cannot be established, or in which they degenerate before a nematode can complete its life cycle, are resistant to that nematode. The attempted infection by the nematode may injure the plant, but the nematode cannot complete its life cycle in it.

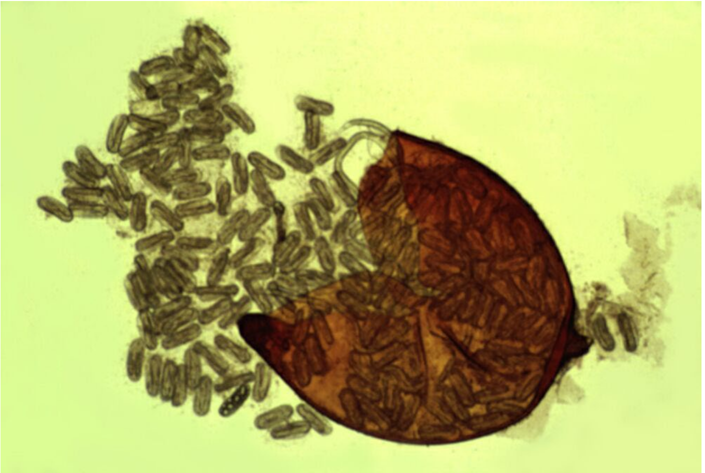

Figure 12. Cyst nematodes retain most of their eggs within their bodies.

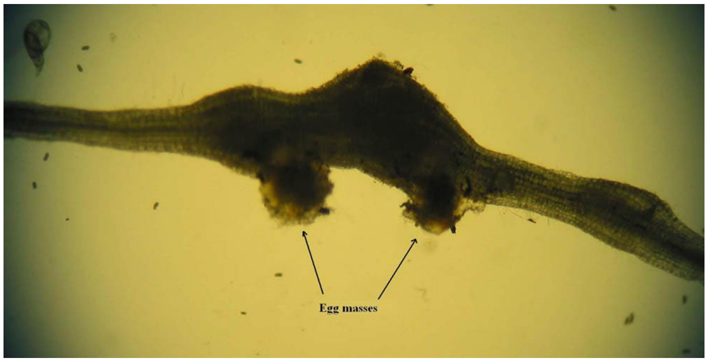

Figure 13. Root-knot nematode egg masses on a root surface.

Diagnosing Nematode Problems

It can be very difficult to decide if nematodes are causing or are likely to cause significant crop injury. If a particular nematode pest was previously found in a site, it probably is still present. Plan to continue to take steps to manage it. In a location for which a complete history is lacking, the identities and population densities of nematode pests, hence the severity of damage which might be expected can usually be determined by laboratory assay of soil and/or plant samples.

Another common diagnostic problem is determining the role of nematodes when established plants are making unsatisfactory growth. This task is often difficult because few nematodes cause distinctive diagnostic symptoms. A sound diagnosis should be based on as many as possible of symptoms above and below ground, field history, diagnostic nematicide tests, and laboratory assay of soil and/or plant samples.

Above-Ground Symptoms

These are rarely, if ever, sufficient evidence to diagnose a root nematode problem. However, they are important because possible nematode problems are almost always first noticed because of abnormal top growth. Certain kinds of symptoms are typical of nematode injury to roots, and should always make one consider nematodes as a possible cause for the inferior performance. They can also be used to help locate the most severely affected areas in the planting after the problem is diagnosed.

Since most plant nematodes affect root functions, most symptoms associated with them are the result of inadequate water supply or mineral nutrition to the tops: chlorosis (yellowing) (Figure 14) or other abnormal coloration of foliage, stunted top growth (Figure 15), failure to respond normally to fertilizers, small or sparse foliage (Figure 16), a tendency to wilt (Figure 17) more readily than healthy plants, and slower recovery from wilting. Woody plants in advanced stages of decline incited by nematodes will have little or no new foliage when healthy plants have substantial flushes, and eventually exhibit dieback of progressively larger branches. "Melting out" (Figure 18) or gradual decline is typical of nematode-injured turf and pasture. Plantings that are stunted by nematodes often have worse weed problems (Figure 19) than areas without nematode injury because the crop is less able to compete with weeds than it should be.

Figure 14. Yellowing of pepper plants resulting from nematode damage to roots.

Figure 15. Healthy lettuce (left) and stunted lettuce that has been damaged by nematodes.Healthy lettuce (left) and stunted lettuce that has been damaged by nematodes.

Figure 16. A bottlebrush being damaged by root-knot nematodes. Notice the thin canopy compared to the healthy plants behind it.

Figure 17. Wilting bean plants resulting from nematode damage to roots.

Figure 18. Patch of St. Augustinegrass declining from nematode damage.

Figure 19. Spurge is a weed often associated with nematode damage to turf grasses.

The distribution of nematodes within any site is very irregular. Therefore, the shape, size, and distribution of areas showing the most severe effects of nematodes will be highly irregular (Figure 20 and Figure 21) within the field. Nematodes move very few feet per year on their own. In the undisturbed soil of groves, turf, and pastures, visible symptoms of nematode injury normally appear as round, oval, or irregular areas which gradually increase in size year by year. In cultivated land, nematode-injured spots are often elongated in the direction of cultivation because nematodes are moved by machinery. Erosion, land leveling, and any other force which moves masses of soil or plant parts can also spread a nematode infestation much more rapidly than it will go by itself. Nematode damage is often seen first and most pronounced in areas under special stresses, such as heavy traffic, excessive drainage because of slope or soil and dry areas outside regular irrigation patterns.

Figure 20. Irregular patches of declining turf illustrate the uneven distribution of nematodes.

Figure 21. An irregular patch of stunted corn shows where nematode populations were highest at planting.

Below-Ground Symptoms

These may be more useful than top symptoms for diagnosing many nematode problems. Galls, abbreviated roots, necrotic lesions in the root cortex, and root rotting may all help in diagnosing nematode problems.

ROOT GALLS AND OTHER ROOT SWELLINGS

The most distinctive nematode symptoms on roots are galls caused by *Meloidogyne* spp. They are small (Figure 22), individual, bead-like or fusiform swellings in some hosts. In other plants, galls may be massive (Figure 23) lumps of fleshy tissue more than l inch in diameter, containing dozens of nematodes. Some hosts, including many grasses, may not form any visible root swelling even though the nematodes successfully establish giant cells, mature, and reproduce. In such cases, an absence of galls does not necessarily prove that there are no root-knot nematodes present or that the plant species in question is not a host for that root-knot nematode.

Figure 22. Bead-like galls on cotton roots result from root-knot nematode infection.

Figure 23. Massive lumpy galls caused by root-knot nematodes on passion flower roots.

Other root swellings must not be mistaken for root knot galls. Some ectoparasitic nematodes may cause root-tips to swell; by the time root-knot galling is visible, at least some of the galls are found distributed along the roots, away from the tip. Nitrogen-fixing bacteria cause swellings on the roots of most legumes (such as clovers, peas and beans). These swellings, called nodules, are easily distinguished from root-knot galls by differences in how they are attached to the root and their contents. Nitrogen nodules are loosely attached to the root, and can generally be very easily removed; root-knot galls originate from infection at the center of root, so they are an integral part of the root (Figure 24) whose removal requires tearing the cortex apart. In addition, fresh nodules should have a milky pink to brown liquid inside them, while root-knot galls have firmer tissues and contain female root-knot nematodes (creamy white beads less than l/32 inch in diameter) inside the gall tissues, near the fibrous vascular tissues of the root.

Figure 24. Root-knot nematode galls (left) are an integral part of the root and cannot be easily removed. Nitrogen-fixing nodules (right) are attached to the root and are easily removed.

ABBREVIATED ROOT SYSTEMS

Abbreviated root systems (Figure 25) may be caused by several kinds of nematodes. Many ectoparasites that feed on root-tips, such as sting, awl, dagger, and stubby-root nematodes, cause root elongation to stop. These root tips sometimes swell to greater diameters than usual when they stop growing in length, and often become much darker in color than uninjured root tips. Lateral roots often emerge from the root a short distance behind the injured main root tip; if a series of lateral roots are injured as they emerge, the end of the root may acquire a bunchy or bushy arrangement of very short roots that is very characteristic of sting or awl nematode injury to grasses and some other plants.

Figure 25. Abbreviated "stubby-root" symptoms resulting from damage caused by ectoparasitic nematodes.

Migratory endoparasites can also cause abbreviated roots. When lesion, burrowing, or lance nematodes injure the fleshy cortex of host roots, fungi that ordinarily could not penetrate the intact root are often able to colonize the injured tissues and, from there, infect the entire root. Rotted mature tissues at the tip of the root are a clue that endoparasitic nematodes and/or root-rot fungi, rather than ectoparasitic nematodes, may have shortened the roots.

ROOT ROT

Rot of large roots and storage organs (potatoes, etc.) is sometimes caused by nematodes alone. The potato rot nematode, *Ditylenchus destructor*, and yam nematode, *Scutellonema bradys* , are two examples. Burrowing nematodes often cause extensive necrosis, which looks much like dry rot, of fleshy tissues of large roots such as those of bananas and many tropical foliage plants.

CYST NEMATODES

An experienced observer can often see cyst nematodes (Figure 26) (*Heterodera, Globodera*, and spp.) on the roots of their hosts without magnification. The young adult females are visible as tiny white beads, about the size of a period on this page. After a female cyst nematode dies, her white body wall is tanned to a tough brown capsule containing several hundred eggs. Important cyst nematodes found in Florida include soybean cyst nematode (*H. glycines*) on soybeans and a few leguminous weeds, beet cyst nematode (*H. schachtii*) on cabbage and related plants, St. Augustine grass cyst nematode (*H. leuceilyma*) on St. Augustine grass, and cactus cyst nematode (*C. cacti*) on Christmas cactus and related plants. *H. cyperi* is a cyst nematode occasionally found infesting nutsedges (*Cyperus* spp.).

Figure 26. The tiny white spots on these soybean roots are female cyst nematodes.

Field History

Field history can provide valuable clues to the identity of nematode and other pest problems. A nematode that has been present in the field in recent years is probably there yet, and is likely to cause injury to susceptible crops if environmental conditions are favorable. Even without specific knowledge of pests in the field, records may help.

If production records show a gradual decline in yields over a period of years, despite no change in cultural practices, nematodes may be indicated. A nematode infestation in a new field usually begins in a small area. It gradually intensifies in the original spot and is spread through the field by cultivation, harvest, erosion, and other factors which spread infested soil or plant parts. Therefore, the total effect of a recently introduced nematode is a gradual production decline for the field, as the percentage of the field that is involved and the severity of damage at any given area in the field increase over the years.

Diagnostic Nematicide Trials

Nematicide treatment may be used to help diagnose the role of nematodes in some situations. Laboratory determination of the kinds and numbers of nematodes present is sometimes not sufficient to determine the role of nematodes in a growth problem, or to predict injury to a crop to be planted. Application of a nematicide which is known to be effective against that pest is sometimes the most clearcut way to determine their importance, or at least the ability of an available treatment to remedy the situation. In such trials, it is best to apply the treatment to at least four areas of the suspect field, leaving adequate adjacent untreated areas for comparison (Figure 27). The nematicide product must, of course, be legal for application to the site and in the manner needed for the test.

Figure 27. In a diagnostic nematicide trial always have untreated areas (front) and treated areas (back) for compairison.

Nematode Assay

A nematode assay is often necessary to complete a diagnosis. A variety of methods may be used to extract nematodes from soil and plant tissues. When they are identified and their relative population densities are known, the amount of risk to the crop from plant-parasitic nematodes can be determined. These risk levels have been assigned by nematologists at the University of Florida and represent the risk of economic loss to that crop. Such risk levels are determined through long-term experience of these nematologists with nematodes and with the crop in both growers' operations and in controlled experiments.

There are many crop/nematode combinations for which we do not have adequate research data to establish accurate risk levels. In these cases, the most important function of a nematode assay is to determine the kinds of nematodes present. For severe pests on high-value crops, the presence of barely detectable populations is often sufficient to justify use of an appropriate control measure such as a resistant cultivar, a nematicide, or a change of nematicide to one more effective for the particular nematodes present.

See ENY-027 Nematode Assay Laboratory (http://edis.ifas.ufl.edu/SR011) for information on collecting and submitting nematode assay samples.

Principles of Nematode Management

Dozens of kinds of nematodes can injure crops; one or more of them occur in most soils in Florida. Although some can cause significant losses when present in low numbers, most do not cause economically significant damage unless their numbers are unusually high or the plant is also subject to unusual levels of stress caused by other factors. Carefully integrating as many as possible of the following components into the management program will help keep most nematode pests below damaging levels, and may simplify the decisions that must be made about selecting and applying nematicides when they are needed.

Prevention

Preventing a nematode problem is far better than trying to treat one after it is established. Many serious nematode pests are wide-spread, but a few are quite limited in distribution. For instance, the soybean cyst nematode is presently known in Florida only in the Panhandle and a few central and northern counties. Other nematodes that occur throughout the state may not occur in every field in a given area, and it is very worthwhile to avoid bringing any pest into a previously uninfested field. For example, if peanut root-knot nematode is in one field but not in a neighboring field, one can avoid carrying that serious pest problem into the uninfested field by knowing that nematodes are spread in contaminated soil and plant parts.

Quarantine refers to a governmental regulatory action taken to prevent importing a pest into a previously uninfested area. It is an attempt to use official regulations to enforce the common sense rules that a grower should apply on his own to prevent spread of pests which have limited distribution.

Since most nematodes enter new areas or spread within an area by movement of soil or infested plants, most quarantine regulations and voluntary sanitation measures are intended to control the movement of contaminated soil and plant material. For instance, soybean cyst nematode can be spread in bits of soil carried with soybean seed from infested land. Federal quarantine regulations in effect for many years prohibited using seed grown in contaminated areas unless it had been thoroughly cleaned, to avoid importing soybean cyst nematode from those areas.

Good sense dictates working areas that are not infested with nematodes before moving to those that are infested, to avoid carrying contaminated soil or plants on his machinery to the uninfested field. Ornamental cuttings to be rooted should be taken only from uninfested plants or portions of plants from above ground which have never been rooted in a potentially contaminated soil. This prevents propagating populations of root-knot and burrowing nematodes that might seriously reduce growth and would cause the plants to be unfit for shipment to many potential markets because of quarantines.

Crop Rotation

Rotation is a very old practice for reducing soil-borne problems. Many nematodes, soil-borne disease organisms, and insects can reproduce and survive on only a few plants. Repeatedly planting a field with the same crop without interruption will enable any organisms that reproduce successfully on that crop to continue to increase. Rotation to non-host crops may cause many of those pests to cease reproduction and allow natural mortality factors to reduce their numbers. By carefully planning the sequence of crops to be planted in a particular field, it is often possible to avoid excessive build-up of pests that are important to all of the major cash crops in the cycle.

In a few instances, it is even possible to include a crop in the rotation that will help to control pests that have built up in preceding crops in the cycle. For instance, hairy indigo planted as a summer cover crop between spring harvest and fall planting of vegetables has been found to sharply reduce the populations of sting and root-knot nematodes in the Sanford area of central Florida. When managed properly as a summer cover crop, the hairy indigo helps reduce the populations of these two serious nematode pests, increases soil organic matter, and contributes some nitrogen to the soil, since hairy indigo is a legume.

Similarly, pangola digitgrass has been used as a rotation crop to control burrowing and root-knot nematodes in vegetable lands in Florida and in the West Indies. However, pangola digitgrass is highly susceptible to sting nematodes, so is not a good choice for land infested with that pest.

The many kinds of nematodes that occur in Florida complicate selection of rotation crops because crops that will reduce some species of nematodes may favor the increase of others. Despite the difficulty, a good rotation program should be a basic component of most land/crop management plans because of the multiple benefits that can be derived from it.

Crop Root Destruction

A cultural practice that receives far less attention than it deserves is the immediate destruction of crop roots at the conclusion of the cropping season. It is a practice heavily emphasized in some areas of the country for high value crops such as tobacco. Fields should be tilled as soon as possible after harvest to kill all plants in the field and destroy their roots. Nematodes, soil-borne diseases, and many soil-borne insects will continue to feed and multiply on crop root systems as long as they remain alive.

In Florida, the prolonged period of high soil temperatures in the fall means that nematodes may have an additional 3-4 months after harvest of most crops before soil temperatures drop low enough that nematode reproduction is halted. When soil temperatures are high, each month that the root system continues to live represents an additional generation and potential increase of about l0-fold for root-knot nematodes and many others. Even in fall, when soil temperatures are gradually declining, a 2 month period represents at least one or two additional generations. Therefore, destruction of root systems as soon as the crop is finished will dramatically reduce the potential for increase of nematodes and other soil-borne pests and should encourage their decline through normal mortality.

Flooding and Fallowing

In certain cases, flooding or fallowing may be used to help reduce numbers of nematode pests. Flooding has long been practiced for control of root-knot nematodes and some other soil-borne pests in muck soils of the Zellwood and Belle Glade areas. It is practical only where the water level can be controlled easily and maintained at a high level for several weeks. It is also important to consider the possibility that flooding may actually spread some soil-borne pests, if the water source is likely to contain disease-causing fungi such as Fusarium or nematodes such as soybean cyst nematode. Where flooding can be practiced, alternating periods of about 2 or 3 weeks of flooding, drying, and flooding again are apparently much more effective than a continuous period of flooding. The soil should be worked during the periods of drying to increase aeration and drying of soil and to prevent weed growth while the soil is exposed. Flooding probably kills nematodes by providing a long period without host plants rather than by some direct physical effect on the nematodes. Fallowing refers to leaving a field with no plants on it for a prolonged period. Most nematodes will decrease after a period of time without an adequate host plant. One study found that fallowing soil for 100 days during the winter lead to a 70% reduction in sting nematodes. Exposure to extremely high temperatures in the surface levels of the soil during the hot Florida summers may also reduce numbers of many kinds of nematodes. However, fallowing may be objectionable from a soil management viewpoint, because of the risk of losing soil organic matter, increased danger of erosion, and loss of productive time. If fallowing is being used to help reduce nematode numbers, the field should be cultivated regularly to prevent growth of weeds and to expose new portions of the soil to the effects of drying and heating. If weeds are allowed to grow without control in a "fallow" plot, many kinds of nematodes may be able to survive and reproduce on the weeds, making the practice ineffective.

Resistance

When it is available, host plant resistance to a specific pest is usually the least expensive and most effective means of minimizing losses to that pest. However, successful use of varietal resistance requires knowing the extent of the resistance and which pests are present in a particular situation. There are "nematode resistant" varieties of tomatoes, soybeans, southern peas, sweet potatoes, cotton, and tobacco available for use in Florida, but each of these varieties has resistance which is effective against only one, two, or at most three, species of nematodes. None are "nematode proof." Therefore, to be able to use the resistance available in a particular crop species, you must know the pest species present in the field. In addition, varieties with the appropriate resistance must be adapted to cultural conditions and requirements of your area. It still is necessary to use other methods to control any other nematodes that are present, because resistance against one or two species does not affect the ability of any other nematodes to injure the crop.

For example, if a farmer wishes to grow soybeans in a field hat is infested with the sting, southern root-knot, and soybean cyst nematodes, he can take advantage of resistance to the root-knot and cyst nematodes in a variety such as 'Kirby' but still must use a nematicide to control sting nematode. Since the sting nematode is much more easily controlled with nematicides than are the other two pests, resistance to root-knot and cyst nematodes in Kirby simplifies the grower's chemical control program considerably. In another field where only the southern root-knot and cyst nematodes exist, no nematicide may be needed.

Biological Control

Nematologists in Florida and around the world are working very hard to identify and learn to manipulate natural enemies [April 2012] of nematodes so they can be used as biological control agents. Many different bacteria and fungi have been able to reduce populations of some kinds of nematodes under laboratory conditions, but successes at field scale are rare. Most organisms recognized to be promising for biological control of nematodes are quite specific in which nematodes they will attack, or have been very difficult to culture in sufficient quantities to be useful for field application, or both. The conditions under which each is most effective are often quite specific and limited. In all, then, commercially effective biological control as a means to reduce the effects of nematodes on lawns still appears to be many years away.

Nematicides

These are chemicals used to control plant parasitic nematodes. Two major groups of nematicides are distinguished by the manner in which they spread through the soil. Soil fumigants are gases in cylinders or liquids which spread as gases from the point where they are injected into the soil. Non-fumigant nematicides include a variety of water-soluble compounds that are applied to the soil as liquid or granular formulations. Most belong to the carbamate or organophosphate families of pesticides. Their distribution in the soil depends on physical mixing during application and moving in solution in soil water. Some are absorbed by the plant and distributed to other parts of the plant ("systemic") where they may be effective for nematode or insect control.

There is no perfect nematicide for all purposes. Nematicides vary in their effectiveness against different kinds of nematodes, ease of handling, cost, effect on other classes of pests (weeds, disease organisms, insects), behavior in different soils, toxicity to different plants, and availability.

There are many cases where some nematicides offer the only effective means of reducing or preventing nematode injury to a crop. There are others in which nematicides provide a quick and easy means of controlling a nematode problem which should not have occurred if the other available management options had been exercised. Sometimes the practical and economic feasibility of using a nematicide depends on the level at which other management components are being maintained in the system. Generally, a higher yield potential and higher capital risk, because of such management components as fertility levels and irrigation, are more apt to justify the expenditure and effort to use a nematicide than are low levels of management or return. The factors affecting the decision to use a nematicide, and to select an appropriate one, are complex.

The succeeding sections that discuss the management options available for various crops grown in Florida include information about nematicides which are legally registered and recommended for specific purposes in this state. Since many pesticide registrations and growing conditions in Florida are substantially different from those in other areas, anyone from out-of-state should not use products or practices recommended in this Guide without consulting local authorities as to their legality and advisability. In all cases, the **Product Label** and supplemental labeling information must provide the legal guidelines for product use. All pesticide use must be consistent with the label.