UNIVERSITY OF FLORIDA
IFAS EXTENSION

ENY608

Nematodes[1]

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Four species of plant parasitic nematode are economically important on citrus in Florida. They are the burrowing nematode, *Radopholus citrophilus*, causal agent of 'spreading decline of citrus'; the citrus nematode, *Tylenchulus semipenetrans*, causal agent of 'slow decline of citrus'; two species of lesion nematode, *Pratylenchus coffeae* and *P. brachyurus*, causal agents of 'citrus slump'; and the sting nematode, *Belonolaimus longicaudatus*. Nematode distribution and population levels coupled with grove and environmental conditions affect the severity of the problem and the need for nematode management programs. Many of the new groves in south Florida planted on virgin palmetto land do not contain species of nematodes harmful to citrus. At the other extreme are young citrus trees interset between heavily infested mature trees and exposed to very high populations of nematodes soon after planting.

Nematodes alone do not cause the death of citrus trees, but they can have serious debilitating effects on trees. Infested trees are generally smaller and less healthy throughout the grove life, although young citrus trees infested with *P. brachyurus* may outgrow the nematode problem. Once introduced into a grove, nematode problems are not easily corrected. Tree response to postplant chemical treatment is not immediate, frequently requiring a period of one to two years of repeated treatment for some tree revitalization. Since nematicide treatments do not eliminate all nematodes in soil or root tissues, additional treatments are required to continually suppress nematode populations and maintain higher grove productivity. Preplant nematode management programs are important for maximizing young tree growth and eventual long term productivity because it may not be possible to achieve satisfactory tree growth with postplant chemical management programs alone.

CITRUS NEMATODE

The citrus nematode, *Tylenchulus semipenetrans*, causal agent of 'slow decline' of citrus, is a small microscopic worm which feeds within the roots of citrus. It is found in most citrus producing regions of the world, including Florida, where a large proportion (53-89%) of the citrus acreage is known to be infested. Although crop losses associated with citrus nematode in Florida are largely unknown and vary from one tree to another in a grove and from one

1. This document is ENY608, one of a series of the Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date January 1993. Revised November 1993. Reviewed May 2003. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.
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producing region of the state to another, the average for all citrus producing regions of the world has been estimated at 8-12%. The most severe effects of infestation by the citrus nematode on Florida citrus are generally observed under conditions of rapid growth, such as in greenhouse and field nurseries and replant situations or under conditions unfavorable for root growth.

'slow decline'.

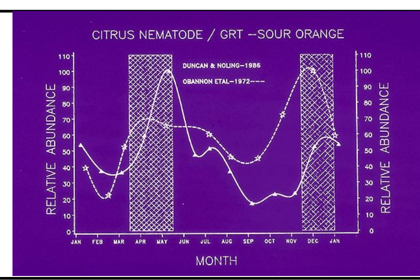
Life History

The citrus nematode has a relatively simple life cycle consisting of the egg, four larval stages and the adult male and female. Development of first stage larvae proceeds within the egg where the first molt occurs. Second stage larvae hatch from eggs to infect young citrus feeder roots. Citrus roots are susceptible and readily invaded until secondary vascular tissue develops. Smaller feeder roots do not develop such tissue and are always susceptible to the nematode. Following invasion, young larval stages penetrate deeply into feeder root cortical tissue where they become immobile, establishing permanent, specialized feeding sites within the root. Second stage larvae molt 3 times, increasing in size with each molt to form large posteriorly swollen saccate females. Adult females deposit 75-500 eggs in a gelatinous material which is secreted from the female on the root surface. Under suitable conditions, the eggs hatch and new larvae emerge to complete the life cycle within 4-8 weeks depending on temperature. Citrus nematode development is rapid within optimal soil temperatures of 78-82°F.

Population Dynamics

In Florida, citrus nematode populations decline rapidly following tree removal. However, low populations may persist in soil for many years in the absence of host plant roots. Nematode population growth is slow on newly replanted young trees until the foliar canopy develops and shades the soil and provides more favorable soil temperatures for nematode infection and development. Flatwood soils, with higher clay and organic matter content, also favor earlier increase in nematode populations. Closer tree spacing, increasingly common in new groves and replant sites, may also accelerate citrus nematode growth due to the rapid closing of canopies between adjacent trees.

Once established, populations of the citrus nematode fluctuate greatly during the year and from one year to the next. Seasonally, two population peaks are known to occur in mature trees, being closely associated and commonly following major spring and fall periods of root flushing. Root flushing and population cycling are closely interrelated because susceptible root tissues are produced prior to or during periods of soil temperatures conducive for citrus nematode development. The first citrus nematode population peak usually occurs in April-May following the spring root flush and again in November-December, following a fall root flush. Nematode sampling during these times should maximize the probability of nematode recovery from soil and root samples and for determining whether potential nematode problems exists. Considering the variation in nematode populations during the year, spring and fall nematode sampling may also provide a more meaningful benchmark for predictive purposes, relating citrus nematode population levels to yield losses and the need for costly nematode management programs.



two population peaks.

Symptoms

Root feeding by the citrus nematode results in the breakdown of root cells which are then frequently invaded by secondary organism which eventually kill the root. The death of many roots over a period of years causes reductions in tree growth and size and a gradual dieback of the tree canopy, increased leaf drop during periods of environmental stress and a reduction in uniform fruit size and yield. Typical symptoms include yellowing of leaves and general symptoms of malnutrition or salt imbalance, sparse foliage, and defoliated branch ends. Symptoms may become particularly evident during periods of environmental stress, as in wilting prematurely under conditions of moisture stress. General symptoms of slow decline are thus related to the condition of the citrus root system and in many cases to salt imbalances within foliar tissues.

While high populations of *T. semipenetrans* can cause rapid deterioration of the root system during the early stages of tree development, aboveground symptoms of slow decline may not always be readily apparent. Reduction in foliar growth closely parallels root destruction by increasing nematode populations. In citrus nematode infested soils, newly replanted trees may decline within 1-5 years depending on the overall maintenance of the tree. Citrus nematode effects are initially less severe and symptoms of slow decline develop more slowly when infested trees are planted into nematode free soil. This occurs because of rapid growth of roots into nematode free soil and the slow outward migration of citrus nematode from the originally infested soil or root tissue.

During the early stages of tree development, above ground symptoms of slow decline may not always be readily apparent, emphasizing the need for nematode sampling to confirm problems of slow decline. High populations of *T. semipenetrans* can cause rapid deterioration of the root system. In citrus nematode infested soils, newly replanted trees may decline within 1-5 years depending on the overall vigor and maintenance of the tree. Citrus nematode effects are initially less severe and symptoms of slow decline generally develop slowly when infested trees are planted into nematode free soil.

Damage

Many factors other than nematodes can influence the rate and extent of tree decline. These factors include: prevailing environmental conditions, soil type, organic matter content of the soil, and soil drainage characteristics. Citrus groves in Florida's coastal region in which the normally deep citrus root systems are restricted within beds by high water tables often sustain greater root damage due to suboptimal soil moisture and are considered to be areas in which citrus is susceptible to greater damage by *T. semipenetrans*. Fine textured, poorly drained, flatwood soils with high organic matter content are known to favor citrus nematode reproduction and the development of other root rot problems which act in combination to reduce tree size, vigor and yield. Disease incidence and severity is thus related to nematode population levels infecting the tree and to the influence of other pests and stresses in the environment.

The longterm impact of the citrus nematode on tree growth and productivity can be viewed as a simple summation of the population levels (successive generations) which have developed and fed on the tree since planting. With time and population increase, damage inflicted to the citrus root system increases, influencing nematode reproduction and the rate of tree decline. Conditions for growth, including nematode stress, affect not only the time at which fruiting maturity is reached, but the individual harvest levels and ultimately, cumulative yield, a measure of the overall tree longevity and productivity.

The citrus nematode is also known to influence channeling of carbohydrates produced in leaves, formation of storage reserves, and nutritional or chemical imbalances in infested trees. In coastal flatwood producing areas where citrus irrigation water is frequently high in soluble salts, high concentrations of salts are known to accumulate in leaves of infested trees. As problems of salt water intrusion into Florida aquifers and as the pumping depth of irrigation wells increases, symptoms typical of salt toxicity which are similar to those of slow decline, can be expected to develop. Problems of salt imbalance, aggravated by citrus nematode, should therefore increase where irrigation waters high in soluble salts are used.

Yield during each fruiting cycle is related to the nematode population currently parasitizing the root system, as well as to the previous effects of nematodes on the tree in terms of size and condition of roots, nutritional and salt imbalances, and storage of carbohydrate reserves. The current status of the citrus tree reflects not only the biological and environmental stresses currently upon the crop, but is also a consequence of all historical stresses.

The stress history of the grove is visually reflected in current tree vigor and yield potential. Within a grove different tree size or condition is related to growth potential (yield) regardless of nematode infestation level. Yield response in the following fruit crop must therefore be considered with respect to current vitality or vigor of the tree and then to nematode population level.

Growth and yield reductions have been frequently observed with increasing numbers of females within root tissues and to larval densities in the soil. Recent studies in Florida showed that tree decline and poor yield were associated with increased root infestation levels of citrus nematode. At the present time infestation levels which economically justify nematicide treatment are not known. Estimates of potential loss due to the citrus nematode is complicated by cyclic nematode population growth, carry over stress effects from one crop to the next, the interaction between pest and plant stresses and by the capacity for vigorous trees to support (tolerate) larger populations than decline trees.

Sampling

For diagnostic and management purposes, individual tree or grove samples are obtained to estimate nematode population levels within soil or citrus root tissue. Only after the different kinds (species) of nematodes have been identified and their levels quantified, is it possible to ascertain whether nematodes will constitute a threat or are potential causes for observed decline of specific trees or areas within the grove.

The time, location, cropping history, and the different kinds of nematodes present within the grove can help to determine in large degree, sampling strategy and the need for nematode management. For example, nematode populations may be below detectable levels on some replant sites, such as in freeze-killed groves. It is difficult to decide in such cases whether precautionary treatments, such as use of resistant rootstocks or preplant fumigation should be considered. In other cases, trees are reset into existing mature groves which contain nematode infested soil and roots following tree removal, tree clipping, or during intersetting. Management of nematodes is much more important in these sites since it is difficult for young root systems to develop and prosper in heavily infested soil. Nematode sampling prior to tree removal or planting (compositing soil and roots from many different replant sites) is therefore very important for assessing potential nematode problems. In contrast, replant sampling may not be required in groves with a history of nematodes and where the host-free period is short.

During the early and even mature stages of tree development, above ground symptoms of slow decline may not always be readily apparent, emphasizing the need for continued nematode sampling to confirm changing problems of slow decline. In this case the objective is to characterize the change in parasite burden on trees rather than to simply determine presence or absence.

In mature groves, attempts should be made to standardize sample collection during seasons of peak population growth and from zones of highest feeder root and nematode abundance. As indicated in previous sections, highest feeder root densities occur in the top 2 feet of soil directly under the tree canopy and decrease rapidly with distance from the trunk towards the row middle. In addition, two population peaks of the citrus nematode seasonally occur, the first peak usually occurring in April-May following the spring root flush and again in October-December, following a fall root flush. Nematode sampling in these locations and during these times should maximize the probability of nematode recovery from soil and root samples and for determining whether potential nematode problems exists. Considering the variation in nematode populations during the year, spring and fall nematode sampling may also provide a more meaningful benchmark for predictive purposes, relating citrus nematode population levels to yield losses and the need for costly nematode management programs.

To insure a representive grove sample (average condition) the following general sampling instructions are provided.

Single Tree Samples

When diagnosis of a specific tree problem or grove condition is desired, paired samples are often taken to determine the involvement of nematodes. Soil cores from dripline or undercanopy areas of a diseased or decline tree(s) are removed with a soil sampling tube, auger, trowel, or shovel. Sampling to a depth of 10 to 12 inches is recommended. As many as 6 to 8 cores or soil fractions, including roots, are then composited to form a single sample. In such cases it may be helpful to submit an additional sample from trees which do not exhibit the symptom for comparison. For paired, comparative samples, soil cores should be collected in identical number and location.

Grove Samples

When management considerations involve a large grove area, soil and root tissues from many different randomly selected trees within the block are combined to form the representive or average sample. Individual cores or soil fractions from as many as 20 trees should be carefully mixed together to form a single composite sample. Sampling of citrus feeder roots from each of the sample locations (when possible) should also be included within the soil sample.

Samples should be consistently collected in a random fashion from the dripline or preferably undercanopy area of trees. A single sample should represent no more than a 5 to 10 acre block of grove. The time and location of within grove sampling should also be selected to avoid extremely dry or wet soil conditions under which nematode populations can rapidly decline to low levels.

To avoid future confusion, all samples should be properly labeled or coded to insure the identity of grove or site location. Since nematode populations quickly decline under hot, cold, and or dry conditions, soil and root samples should never be subjected to freezing, overheating or to prolong exposure to direct sunlight. Samples should always be submitted to a qualified laboratory as soon possible after collection.

Management Considerations

Increased growth and early fruit production are highly desirable objectives for young citrus tree management programs. Current production policy emphasizes accelerated returns on investment because of anticipated reduction in grove longevity due to citrus blight, tristeza, and cold damage. Many production inputs (eg. water and nutrients) can have relatively rapid and dramatic growth effects soon after applications are initiated. In contrast, nematode management inputs generally require longer economic recovery periods because nematode damage is less severe and benefits to tree growth and productivity develop slowly. Economic justification for nematode management is further complicated because young citrus trees are subject to many other plant stresses, which are also capable of reducing tree growth during the evaluation period. It is often impossible to separate these various stresses from those solely due to nematodes. Because stresses imposed on the tree act cumulatively to influence tree growth, longevity, and fruit production, profits generated by the grove over time must be closely scrutinized. The introduction of nematodes after planting, on contaminated soil or infested plants, may further complicate the evaluation process.

Nematode management in citrus presently relies heavily on exclusionary measures, use of resistant rootstocks, cultural practices, and preplant and postplant nematicide treatment.

Exclusion

Exclusionary measures are the most effective means of control for many plant parasitic nematodes including *T. semipenetrans*. Production and planting of certified nematode-free nursery stock is important for preventing the introduction of the nematode into a new grove, thereby avoiding the problem before it starts. Problems of slow decline should never develop in newly planted areas in south Florida if sanitation practices are adopted, since citrus nematode is not known to occur in virgin palmetto lands. The citrus nematode is not native to Florida, and is disseminated primarily by infected nursery stock. If the citrus nematode is introduced into a grove, it may be further redistributed via movement of contaminated soil and root tissues through tillage practices or in flood or ditch irrigation waters.

State sponsored nursery site certification programs have prevented the widespread dissemination of nematode-infested nursery stock. Lands found to be infested with burrowing, citrus, lesion or sting nematodes cannot be certified for commercial citrus nursery use. Prior to 1987, citrus nematode was considered to have three different biological races. Two of the races, the bush and grass races, have recently been described as species different from *T. semipenetrans*. Lands found to be infested with bush and grass infesting nematodes are no longer subject to regulatory exclusion for commercial citrus nursery establishment.

Resistant Rootstocks

Use of nematode resistant rootstocks is another effective means of control which should be considered, particularly when a grove has a previous history of slow decline. Most citrus rootstocks used commercially in Florida are readily attacked by and support reproduction of the citrus nematode. Two rootstocks, Swingle citrumelo and Trifoliate orange, have demonstrated good resistance to citrus nematode development. Trifoliate orange has not been used extensively in Florida due to small tree and fruit size and blight susceptibility. However, it does provide an important germplasm source for future citrus nematode resistant rootstocks. Swingle is extensively used in new plantings. It is also resistant to tristeza, and to feeder root-rot caused by *Phytophthora parasitica*, and is also reasonably cold-tolerant. The combined use of nematode-free and resistant rootstocks will prevent or restrict citrus nematode population development, reducing citrus crop losses and grove production costs associated with other types of nematode management.

Cultural Practices

Nematode management is of no value if young trees are grown under poor cultural practices. For example, providing for good water drainage in flatwood soils is essential for proper aeration of citrus roots and Phytophthora disease management. Maintaining trees with adequate water and nutrients is also important since nematode damage is related primarily to root dysfunction and damage is generally most severe in trees under stress.

Chemical Control

Chemical control measures are frequently employed to manage citrus nematode populations prior to or following planting. Two broad classes of nematicides, fumigant and nonfumigant, are currently registered within Florida for commercial nematode management as shown in the *Florida Citrus Pest Management Guide*: Nematodes . Preplant fumigants effectively control *T. semipenetrans* in Florida and many other citrus-producing regions of the world and frequently result in improved tree growth as in canopy dimensions, trunk diameter, and/or fruit production. When infected trees are removed, damaging soil and root population of citrus nematodes may remain viable and infective in soil for many years. Under these conditions, preplant fumigant nematicides are generally recommended for control of citrus nematode and other root rotting pathogenic organisms in the soil, particularly when susceptible rootstocks are used. It is also advisable to wait at least a few months after pulling a tree before attempting to fumigate or replant citrus. Rapid reduction in nematode population levels during this period is related to the absence and decomposition of root material in soil. Fumigant treatments are also more effective when decomposition of root material has occurred.

The real benefit from soil fumigation is to get trees off to a good start. It should also be recognized, however, that benefits derived from soil fumigation may not persist throughout the life of the tree. Growth responses, when they occur, are generally most evident in trees 1-4 years old. After fumigation with 1,3-D, Vapam or methyl bromide, marked reductions of nematode and fungi populations in soil have been measured. However, using contaminated soil to construct water rings around newly planted trees or to bank young trees for cold protection, may reintroduce nematodes and fungi within months of fumigation. In this case the good start may be shortened or never obtained.

Although fumigant nematicides are generally very effective in controlling plant parasitic nematodes, they may have negative side effects. In some cases the diversity of organisms, including antagonists of nematodes and other pathogens, may be reduced considerably. For example, the number of different fungi which recolonize the fumigation site may only represent a few species in comparison with those in untreated soils. Subsequently, numbers may attain even higher levels than those in nonfumigated soil due to the lack of competitors. Nutritional deficiencies in newly plant nursery trees are also known to occur due to reduction or total elimination of mycorrhizae (beneficial fungi necessary for root absorption of phosphorus, zinc, and copper in nutrient deficient soils). Planting delays following fumigation and fertilization regimes that provide young seedlings with sufficient levels of available nutrients may partially correct the problem.

The effect of fumigating closely-spaced interset replant sites within a producing grove is not known, nor is interset fumigation recommended at this time. Chemical pruning of citrus roots from adjacent trees within the fumigated zone should be expected. Potential damage to producing trees will be related to reduction in rooting volume, which will be a function of rate and dispersal characteristics of the fumigant used. Failure to control root sprouting and any pathogenic organisms harbored within them may also contribute to lack of satisfactory growth response to fumigant treatment.

Postplant Nematicides

Following tree removal or in new plantings, citrus nematode soil population levels are generally low and population growth is slow during the first few years of young tree growth. Correspondingly, use of postplant nematicides for young tree establishment has not consistently resulted in improved growth and early production as a result of nematode control. With time and population increase, symptoms of decline or growth retardation do occur. At these times, postplant use of nonfumigant nematicides may be economically justified for nematode control. Since nematode induced crop losses cannot be currently defined for all nematodes and grove conditions, postplant nematicide treatments should be initially pursued on an experimental basis. The decision is often a difficult one since low preplant population levels may escape detection.

For mature trees, yield increases following nematicide treatments have been observed in both current and succeeding years, although with much variation within and between years. Growth response to nematicide treatment is related to population levels at treatment, nematicide efficacy, and the levels of stress avoided during the period following treatment and prior to harvest. In recent studies on the use of postplant nematicides for control of citrus nematode, yield response following nematicide treatment decreased as overall grove yield performance increased. Increased growth and yield response in subsequent years following nematicide application is dependent on the levels to which nematodes are reduced and the extent to which the tree is 'revitalized' over the entire period of nematicide use. As the vigor and yield potential of trees improve, continued nematicide use may no longer be economically justified on an annual basis since the value of unrealized yield is less than the treatment costs.

Justification for nematicide use should be based on economic criteria comparing benefits and costs. The point at which yield increases over the untreated acreage is equal to the cost of the nematicide treatment is defined as the break-even point. Break-even points are also used to indicate the change in grove production required to pay control costs for different box prices. As box price or grove productivity decline, the change in production required to pay control costs increases. Grower experience combined with careful grove records, will help determine whether the number of box increase in fruit yield per tree or per grove acre can be achieved. In making this decision, a grower must recognize that changing weather patterns influence citrus tree growth and fruit yield, pest development, and disease severity. These unpredictable influences, affect the efficacy of the nematicide used, the productivity of the grove and indirectly the price of the crop. Additional complexity is caused by nematicide related yield increases which may occur in the following crop or be spread over a number of years, or related to control of other organisms than just nematodes.

If a grower is concerned about a declining grove and *T. semipenetrans* has been identified at high levels in nematode samples, then application of post plant nematicides should be considered. Changes in cultural practices which influence tree quality through water and nutrient availability (e.g. root pruning in tillage practices) should also be considered since nematode decline is aggravated when trees are under stress.

Recent studies on the distribution of citrus feeder roots indicate that the majority of roots in the top 2 feet of soil grow directly under the tree canopy and decrease rapidly with distance from the trunk toward row middle. Root distribution is also strongly influenced by tillage practices and irrigation methods. Low volume microjet or drip irrigation systems concentrate citrus roots in the wetted areas whereas disking in the row middles for weed control significantly reduces shallow feeder root abundance beyond the dripline. Citrus nematode populations are distributed in the same way as feeder roots since that is their only food source within the grove.

Nematode control following use of postplant nematicides occurs primarily within the zone of application and to a lesser degree, due to the systemic activity of the pesticides, within and around roots outside of the zone of application. Proper placement of nematicides under the tree canopy may significantly improve overall nematode control by targeting applications to areas of highest feeder root and nematode density. However, treatment of roots at the dripline and under the tree canopy may not be possible in many cases because granule applicators are not sufficiently offset to apply and incorporate nematicides beneath the canopy of the tree . Other factors including damage to surface feeder roots, particularly in groves with shallow root systems or during periods of environmental stress, or fruit loss or limb damage in groves with low canopy skirts, must also be considered. On rootstocks which sprout in response to injury, under-canopy incorporation of granules could also severely increase sprout incidence. Therefore, better methods of nematicide delivery need to be developed and evaluated. The future development and registration of effective liquid nematicides that can be incorporated with irrigation could eliminated some of these problems and presumably increase yield response to nematode management in heavily infested groves.

canopy of the tree.

The interrelation between citrus nematode population growth and root flushing also strongly suggests the importance of timing of nematicide application to nematode control. Treatments are likely to be most effective if made in the spring or fall prior to root flushing as soil temperatures become optimum for nematode development. Protecting young roots during flushes presents citrus nematodes, which survive the nematicide treatment, with older root systems less suitable for penetration and development.

BURROWING NEMATODE

Spreading decline (Plate 4, Plate 5), caused by the burrowing nematode, *Radopholus citrophilus*, is a disease of citrus known only to occur in Florida. Distribution within Florida is confined almost exclusively to the deep, sandy coarse-textured soils of the central ridge. The burrowing nematode has a wide host range which includes over 350 plant species, many of which are common weeds while others are of global economic importance. Discovered in 1953, yield reductions of 40-70% were commonly observed. Tree damage, symptom expression and yield losses are primarily attributable to the near complete destruction of citrus feeder roots below a soil depth 30 inches.

Plate 4.

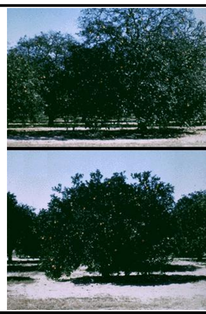


Plate 5.

Life History

The burrowing nematode is a migratory endoparasite, in which all stages except adult males, can penetrate and feed on root cells. Following penetration, nematode feeding on successive root cells forms a tunnel or 'burrow' within cortical root tissues, thus deriving its name. With time and continued feeding, burrows begin to coalesce and increase in size to form larger cavities within the root cortex. These burrows or cavities are often then colonized by other soil microbes which contribute to root death. Citrus tree root systems within burrowing nematode infested groves are nearly devoid of feeder roots below a soil depth of 30 inches. As a result of root cell destruction by nematodes or root decay by secondary pathogens, nematodes actively migrate out of the root and spread locally to other roots or trees within the grove.

The life cycle of the burrowing nematode is a relatively short 18-22 days, with eggs laid almost exclusively within root tissue. Following egg hatch, the nematode passes through four larval stages to become adult male or female. Female reproduction can occur with or without males. Although the longevity and fecundity of mature females has not been adequately measured, it is known that mature females are capable of producing as many as 120 eggs, laying an average of 3 eggs per day.

Temperatures suitable for development extend within a narrow range of 70-80°F, with an optimal range of 73-77°F. Population growth is limited at temperatures above or below the developmental range. Highest populations generally occur in roots below a soil depth of 30 inches. At this depth, diurnal fluctuations in soil temperature and moisture are dampened and maintained within an apparent optimal range for the nematode. In general, coarse sandy soils with large pore spaces and adequate but constant soil moisture appear to favor nematode migration, root damage, and population increase.

Symptoms

Aboveground symptoms of burrowing nematode occur as a result of root destruction. Visual symptoms usually appear about a year after initial infection depending on environmental conditions and grove management practices. Infected trees do not die but develop a general unthrifty appearance with sparse foliage and small leaves and fruit with little or no new flush growth. Twig and branch dieback, particularly within the upper tree canopy is generally apparent. Under drought conditions, infected trees wilt prematurely, which is often followed by significant leaf and fruit drop.

For individual trees, aboveground symptoms appear similar and are often confused with those of citrus blight. To characterize a burrowing nematode problem, the pattern or area of decline trees within the groves can often provide valuable diagnostic information. For burrowing nematode, the disease spreads outwardly (as much as 50 ft/year) in all directions from the source tree, resulting in a nonrandom decline within specific, delimited areas of the grove. This patten of decline of adjacent trees within and between rows often characterizes spreading decline from citrus blight. In contrast, citrus blight generally occurs as a sporadic, random decline of individual, or small groups of trees within the grove. Since burrowing nematode does not interfere with water flow within vascular elements of the root or trunk, water uptake tests combined with nematode samples can quickly distinguish spreading decline from citrus blight.

Population Dynamics

Like the citrus nematode, recognizable seasonal cycles of high burrowing nematode populations occur as a result of favorable temperatures and seasonally defined flushes of new citrus tree root growth. Highest populations of burrowing nematode generally occur in May through June and again from October through December of each year. Once established and distributed within the rootzone, they continue to destroy each periodic new flush of roots which is then followed by a decline in population density. Lowest population levels generally occur during summer (July-August) and winter (January-April).

Given an abundance of feeder root supply, populations of the burrowing nematode can increase rapidly due to its high reproductive potential and short life cycle. The capacity for population increase was exhibited in one study which showed that a colony initiated from a single female could increase to a level of over 90,000 eggs, larvae and adult stages in a period as short as 12 weeks. Based on average seasonal changes in soil temperature, completion of 9 generations of the nematode are thought to be possible in Florida.

As a result of root cell destruction and depletion of food supplies, nematode populations decline with nematodes actively migrating out of diseased roots in search of new food supplies. In the absence of roots, burrowing nematode survival in soil has been estimated to be 6 months or less. However, recovery of burrowing nematode from living roots in deep soil has been observed up to 3 years after tree removal.

Damage

The burrowing nematode is thought to currently infest less than 1% of Florida's citrus acreage, but its effect on most citrus rootstocks in the deep sands of the central ridge area are much more severe than that of citrus nematode. Spreading decline, as the name implies, is a grove condition in which a visually apparent loss of tree vigor and productivity actively spreads from one tree to another in sequence through a grove. The rate of disease spread may be as much as two or three trees per year. In the deep, coarse sandy soils typical of the areas within its distribution, burrowing nematodes typically destroy 25-30% of the feeder roots within the 12 to 30 inch soil profile, and as much as 90% of the roots below 30 inches. Feeder root damage is not often apparent within the surface 12 inch soil profile. When dry periods put extra stress on trees, those damaged by burrowing nematodes often fail to recover as fully as uninfested trees, and become progressively weaker with each period of stress. Yield losses, which can be extensive (40-70%), have not been clearly redefined for improved irrigation and horticultural practices.

Sampling

Since 1955 the Florida Department of Agriculture & Consumer Services (FDACS) Division of Plant Industry (DPI) has maintained responsibility for sample survey services for detection and mapping of burrowing nematode grove infestations. Because burrowing nematode is found at highest density within roots at soil depths below 30 inches, deep root samples are used for within grove distribution survey. The number and location of sampling sites within the grove is based on visual determinations of trees exhibiting decline symptoms. Depending on size and grove condition, many samples may be required to accurately determine grove distribution of burrowing nematode.

From each decline tree, two soil cores are removed to a depth of 4 feet and the roots recovered from each of the samples. Samples from each of two trees are then composited to form a single root survey sample. Sampling during periods of peak abundance such as in late spring (May, June) or fall (Oct-Dec) should improve chances of detection.

Management Considerations

Management of spreading decline currently focuses on restricting the spread of the nematode through nursery-stock certification, sanitation, physical barriers, cultural practices, use of resistant and tolerant rootstocks, and use of nematicides.

Exclusion

As so aptly named, spreading decline characterizes a disease which is capable of rapidly spreading through a grove via root contact between adjacent trees. Within grove movement, which may be as much as 50 ft (15m) per year, occurs in all radial directions from the source tree. Because citrus tree root growth (Citrus Root Growth and Soil Pest Management Practices-Publication HS-122) can often extend as far as two rows from its point of origin, a natural bridge is formed to facilitate within and between grove movement. Once introduced, populations can increase rapidly. In addition to nursery tree certification programs, exclusionary measures involving physical barriers or buffer zones separating infested from noninfested areas must also be employed to restrict the spread of the burrowing nematode once it has been introduced into a grove.

Buffer zones are established only after the grove infestation has been mapped and the margins of the grove infestation determined by extensive tree and soil sampling surveys. A bare soil, root free buffer zone is then constructed around the infested area by removing trees well in advance of the margins of the known infestation. Removal of at least two rows of trees to produce 50 to 60 ft of bare soil separating infested from noninfested grove areas is usually warranted. Use of trenching machines are then recommended to mechanically prune and restrict citrus root growth along each boundary side of the buffer zone. Herbicides are also recommended to prevent weed growth, since many weed are known to serve as alternate hosts for the nematode and pathways for bridging the buffer zone. To further minimize potential movement across the buffer, postplant nematicide applications are recommended to suppress burrowing nematode populations along the border of the infested area.

prevent weed growth.

Failure to contain burrowing nematode within defined areas with the use of buffer zones occurs primarily because of grower disregard of sanitation practices and position of trenching operations. For example, periodic trenching within undercanopy areas, close to the tree trunk, will insure a greater likelihood of excluding root growth into the buffer zone than trenching performed at the tree dripline or within the buffer middle. Traffic control and cleaning of grove equipment is also of paramount importance since movement easily occurs via contaminated soil and root fragments adhering to tillage equipment surfaces. It is critical that proper cleaning and disinfestation of trenching machines occur prior to use on the non-infested buffer margins. As suggested previously, failure to maintain clean cultivation within the buffer zone is also likely to result in cross contamination from infested areas. Grove irrigation and fertilization programs must also be designed and implemented so as to omit treatments within the buffer zone, thereby reducing opportunity for root growth extension across buffers.

Cultural Practices

Many of the problems with burrowing nematodes can now be mitigated through consideration of other grove horticultural practices. For example, severe problems due to burrowing nematode may have been reduced somewhat following the widespread adoption of overhead or undercanopy sprinkler irrigation systems. Since burrowing nematode damage occurs principally within the deeper portion of the citrus root system, cultural practices must be adopted or modified to support and protect the remaining shallow portion of the citrus root system. Water and fertilization programs within spreading decline groves should therefore consider irrigation schedules based on soil moisture deficits exclusively within surface soils, utilizing frequent, shallow irrigations as a basis for maintaining a healthy, shallow root system. Herbicides rather than tillage cultivation practices are also recommended so as to minimize water and nutrient depletion by weeds and to avoid mechanical pruning of feeder roots in shallow soil during the tillage operation.

Resistant Rootstocks

Two rootstocks are currently recommended for use against spreading decline, Milam lemon and Ridge Pineapple sweet orange. Both are Phytophthora susceptible, particularly Ridge Pineapple sweet orange. Unfortunately, two biotypes of burrowing nematode have been identified from field and greenhouse inoculation experiments which are capable of reproducing and increasing on both resistant rootstocks. Biotype 1 reproduces poorly on Milam lemon and only moderately on Ridge Pineapple. Biotype 2 reproduces well on each rootstock and causes significantly more reduction in plant growth than biotype 1. The geographic distribution of the two biotypes in Florida is unknown, nor is there any practical means of determining their presence within a grove. It is therefore possible that continued development of resistance breaking biotypes may occur within groves, limiting the long term effectiveness and utility of resistant rootstocks as a means of nematode control.

OTHER NEMATODES

Although detrimental to soil structure, use of bare fallow may be the only currently available means of avoiding damage due to *P. coffeae*. Unlike the burrowing nematode, *P. coffeae* attacks both shallow and deeper portions of the citrus root system. It has a short life cycle and nematode populations can increase rapidly to damaging levels, making it difficult to effectively manage *P. coffeae* with nematicides. Unfortunately, the period of bare fallow required to eliminate the nematode by starvation is not known. No rootstocks are known to be resistant to sting or lesion nematodes (most notably, *P. coffeae*).

SUMMARY

In summary, nematode control measures can be divided into 4 major categories including exclusion, resistant rootstocks, cultural practices, and chemical control. Growers should recognize that none of the measures can be relied upon exclusively for nematode management in Florida citrus. For example, when certified nematode-free trees are planted into nematode infested soil, the additional costs to acquire the certified trees are lost. Likewise, the planting of nematode infested trees into fumigated soil detracts from the benefits of soil fumigation for nematode control. When practical and economics permit, each management procedure should be considered for use in conjunction with all other available measures for nematode control and used in an integrated program of nematode management.