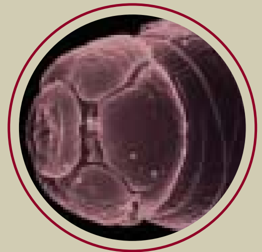
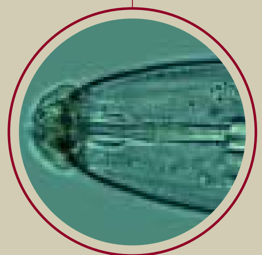
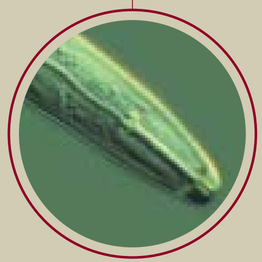
COTTON NEMATODES

YOUR HIDDEN ENEMIES

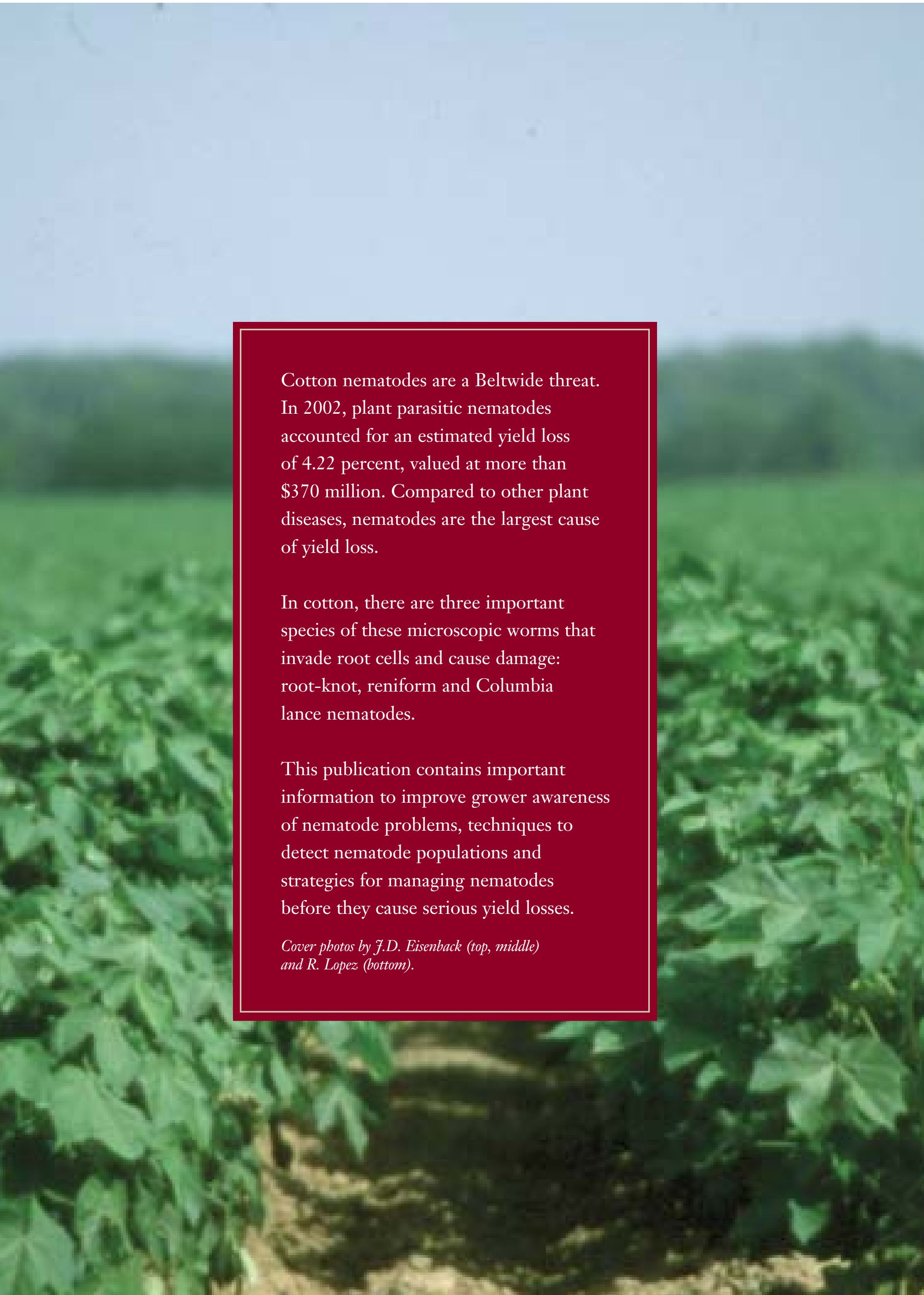
IDENTIFICATION AND CONTROL







Produced by the Beltwide Cotton Nematode Research and Education Committee



Cotton nematodes are a Beltwide threat. In 2002, plant parasitic nematodes accounted for an estimated yield loss of 4.22 percent, valued at more than $370 million. Compared to other plant diseases, nematodes are the largest cause of yield loss.

In cotton, there are three important species of these microscopic worms that invade root cells and cause damage: root-knot, reniform and Columbia lance nematodes.

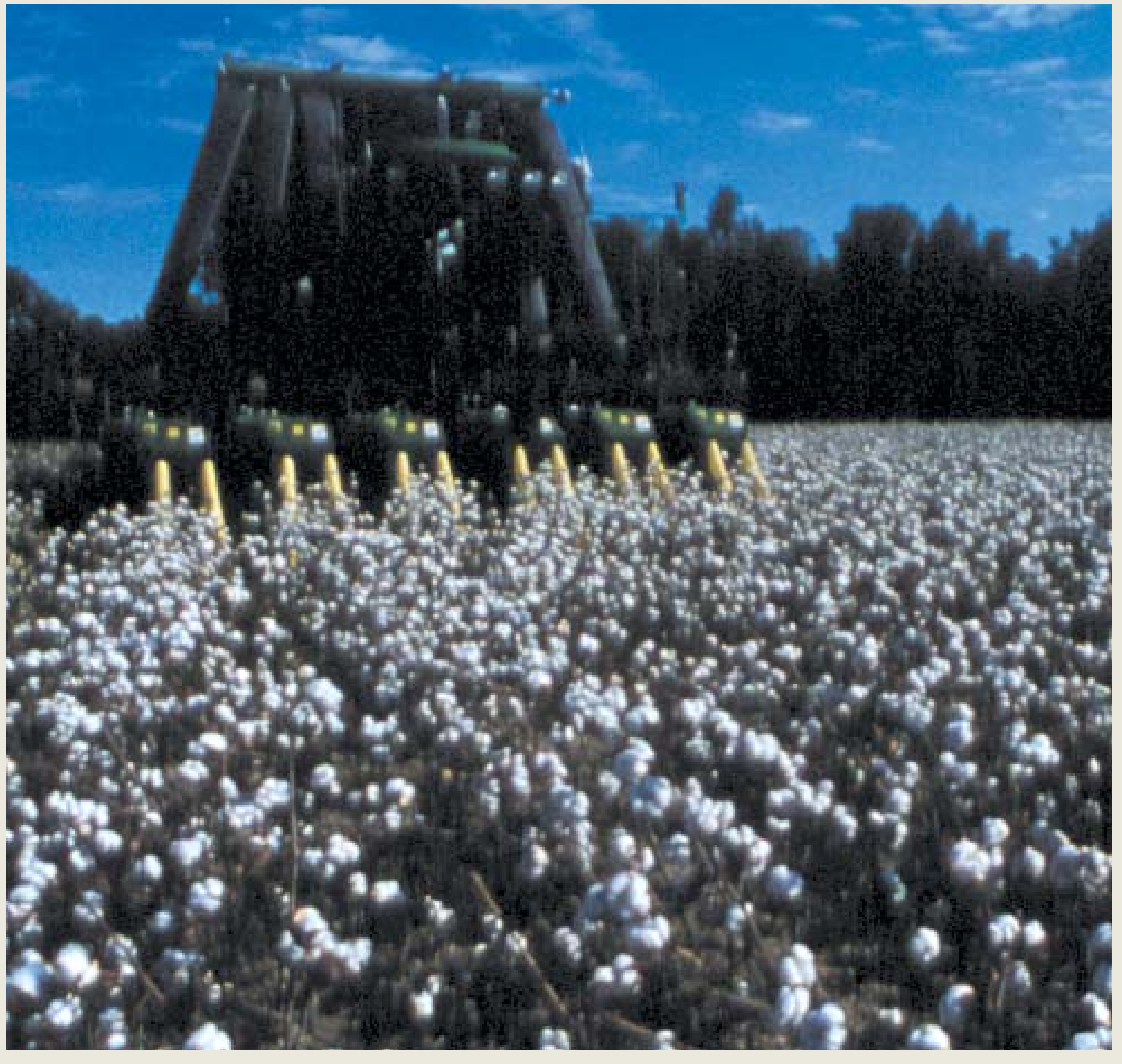
This publication contains important information to improve grower awareness of nematode problems, techniques to detect nematode populations and strategies for managing nematodes before they cause serious yield losses.

Cover photos by J.D. Eisenback (top, middle) and R. Lopez (bottom).

CHEMICAL CONTROL

Most short-term solutions for nematode control involve nematicides. There are two groups of nematicides: fumigants and non-fumigants. Fumigants (Telone™) vaporize when applied in the soil. As gases, they move up through air spaces in the soil, killing nematodes and some other microorganisms. It is critical that the fumigant be applied correctly or it will not be effective. Soil should not be saturated with water or so dry that the fumigant can't be sealed in the soil. Fumigants are not generally effective under noor minimum tillage. After applying most fumigants, a waiting period is required before planting. Non-fumigant nematicides (TEMIK) are applied either in a band or in the seed furrow at planting. This product moves down through the soil killing nematodes directly, or by interfering with feeding and reproduction.

Non-fumigants protect plants early in the growing season allowing them to produce deep, healthy root systems. However, control is temporary and usually by the end of the growing season, nematode populations have increased. The availability and conditions for using these materials vary from state to state. Specific recommendations and guidelines are available from local extension agents or state specialists.



NEMATODES

A BELTWIDE THREAT

Beltwide losses due to nematodes have increased more than 50 percent in the past ten years. Nematodes are a much more insidious problem than most recognize. Even experts say that economic losses have probably been underestimated in the past.

From a historical perspective, nematodes were not thought to be as widespread and damaging as is recognized now. In recent years, the problem has attracted much more attention. Major strides have been made in addressing the situation, but there is still a substantial economic loss every year from nematode infestations across the Cotton Belt.

In the past, losses due to nematodes were erroneously attributed to poor soil fertility, pH or "weak fields." Improvements in properly identifying nematode damage have been made, thus impacting the perceived trend of increased losses due to nematodes. Indirect losses from secondary problems such as seedling disease push the total much higher.

There are many species of plant parasitic nematodes that exist, but only a few have a significant impact on cotton. However, this impact can have severe economic consequences to the grower if managed improperly. Nematodes feed on plant roots, interfering with the uptake of water and nutrients, thus stunting growth. Severe infestations can actually kill cotton plants.

However, it is more often the gradual, frequently unrecognized decline in crop productivity that is the most costly scenario because the grower does not realize how much is being lost.

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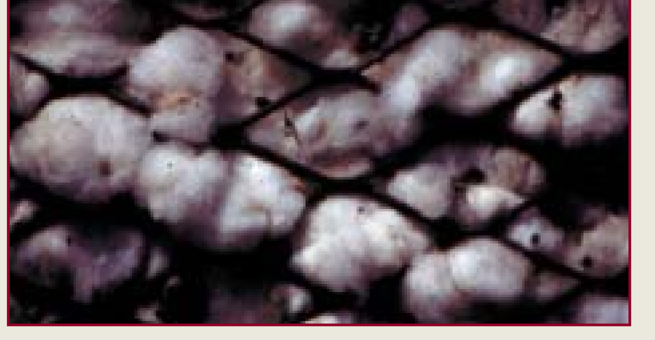


WHAT IS A NEMATODE?

Nematodes are a class of worm-like invertebrates, ranging in size from nearly invisible, microscopic animals to more than 10 feet long. There are more than 10,000 species of nematodes, pre-dating dinosaurs. Only a limited number cause problems to humans and domesticated plants and animals. For instance, nematodes can cause elephantiasis in humans, heartworm in dogs, and root-knot galls in cotton.

Plant parasitic nematodes are often categorized by their life habits. They are obligate plant parasites that require susceptible hosts on which to feed to finish their life cycle. Plant parasitic nematodes can be sedentary (non-moving) or migratory. They can spend their lives inside roots (endo-parasitic) or outside the roots (ecto-parasitic) or a combination of both. Like insects, nematodes must molt to increase their size. They generally go through an egg stage and four juvenile stages (called J1 to J4) before becoming adults. Some species produce eggs by sexual reproduction, while others do not require males to reproduce.

A physical characteristic of plant parasitic nematodes is a hollow tube used for feeding, called a stylet. This hypodermic-like needle punctures root cells and withdraws nutrition from the host plant. Nematode damage is insidious, because it often goes unrecognized. General symptoms include stunted plants, yellowed leaves, wilting and stress. Yield loss usually is not very dramatic and often may be attributed to other causes such as poor nutrition or lack of water.

Life cycle of the reniform nematode (slightly colorized to add emphasis). (right)

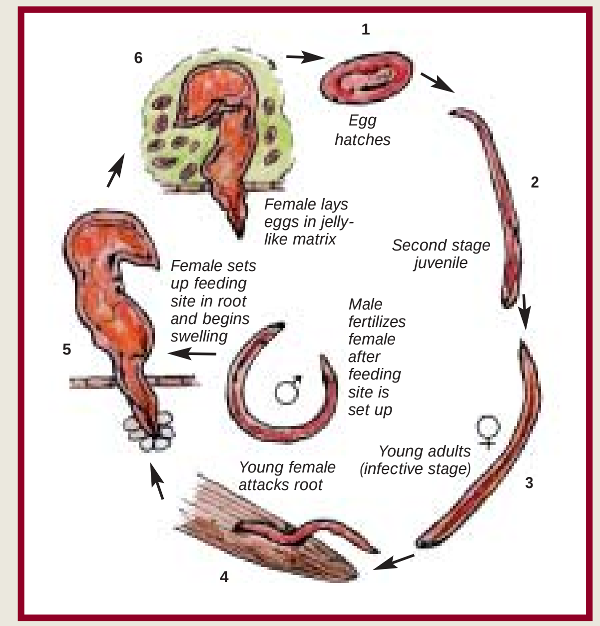
Hot spot in field mid-season caused by extremely high levels of reniform nematode. Photo by C. Overstreet. (left)

NEMATODE DISTRIBUTION AND DENSITY

Plant parasitic nematodes have been found in every state where cotton is grown. Certain genera and species are restricted to particular soil types and climatic conditions. In warmer regions of the Cotton Belt, nematodes are generally more prevalent and reach higher population densities.

NEMATODE SURVEY PROGRAMS INITIATED

In 1986, a county nematode survey program was started in Mississippi. A Beltwide nematode survey program was initiated in 1989 by The Cotton Foundation and the National Cotton Council with the support of Bayer CropScience, the makers of TEMIK® insecticide. The purpose of the program is to determine what nematode species are present, population densities and cotton yield losses. The survey has been completed on more than 60% of the cotton producing counties and parishes in the U.S. Survey results show that nematodes are a very serious Beltwide problem.



SAMPLING FOR NEMATODES

Limited time is available each year to control nematodes. Nematode management decisions must be made prior to planting the crop. If an opportunity is missed to control these pests, action can't be taken until next season. Good soil samples that accurately represent nematode population densities are essential for prudent management decisions.

Correct sampling procedures can greatly improve the "picture" of what is really present in the field. Nematode distribution within a field can be very sporadic – ranging from high levels in one area to perhaps none in other parts of the field. For this reason, several composite soil samples that cover areas of both high and low infestations should be taken to more accurately depict the overall situation. Generally, soil samples should be taken in the fall for the best results. However, recommendations vary in some states.

Unlike counting insects or weeds, which are visible, several procedures are required to accurately estimate nematode population densities. Nematode distribution and population in a field are influenced by several factors including the time of year, previous crop, soil texture and nematode management practices.

IN THE FIELD

Because nematode distribution in a field is generally patchy, predicting loss can be complicated. Nematode populations may be very high in a localized area of a field, and low in the remainder of the field. The accuracy of soil samples to predict nematode populations can usually be improved by increasing the number of samples. Because irregular nematode distribution affects the accuracy of population density estimates, it is necessary to collect several composite samples from a single field.

Collecting a soil sample from a suspected hot spot in a field using a shovel and plastic bag. Photo by C. Overstreet.

VISIBLE INDICATIONS

Because nematodes are not visible without a microscope, it is important to look for visible clues that may be present in the field to be sampled. Previous cropping patterns should be reviewed and assessments should be made of soil texture changes, weak spots and plant symptoms. This information will help determine if it is necessary to subdivide the field to accommodate these conditions.

Dividing a field based upon the severity of symptoms of damage from nematodes may increase cost effectiveness of sampling, because the sampling effort is concentrated in similar areas. Sampling is more valuable in a divided field, because the estimate is more accurate and reliable.

WHEN IS THE BEST TIME TO SAMPLE?

Guidelines vary between states, but generally, it is late summer or fall. Nematode populations usually are low in the spring and build throughout the growing season to reach peak densities at harvest. Nematode populations are easier to detect and estimates are more reliable at harvest than at any other time. Generally, samples should be taken before cultivation when rows are still in place. The population is concentrated around the existing root zone, and weak spots are more easily identified.

Nematode damage severely stunted cotton growth on the untreated cotton in center row. The nematicide-treated cotton on both sides of the row shows healthy growth.

HOW MANY SAMPLES SHOULD I COLLECT?

Generally, a sample should represent about 10 acres of a similar soil type and should consist of at least 20 individual soil cores in that area. The greater the number of samples collected, the more accurate and reliable the estimate will be.

If a population estimate is inaccurate, costly management mistakes can be made. Balancing the number of samples (and related costs) with the value of correct decisions requires experience and knowledge coupled with the understanding of nematode sampling.

COLLECTING AND CARE OF SOIL CORES

Soil probes, which are steel tubes about one inch in diameter, are commonly used to extract soil cores. Each core should be taken to a depth between six to 12 inches. Soil cores are collected in a bucket and thoroughly mixed. About a quart of mixed soil is then placed in a plastic bag and sealed to inhibit drying.

Nematode samples require special care because nematodes are living creatures. A nematode sample should not be handled like a soil fertility sample. For example, if a sample dries, or is placed in the sun, the nematodes will die. The laboratory information on a dried soil sample will not accurately reflect the field situation.

A nematode sample should be handled like a carton of milk. It should be kept cool, but not frozen. During sample collection, it is important to keep the soil sample in a cool location, such as an ice chest in the shade. The sample should be transported in a pre-cooled ice chest to prevent overheating. Samples should be delivered to the diagnostic laboratory as soon as possible. Overnight delivery service should be used if feasible.

A mandatory requirement for good nematode sampling, especially diagnostic sampling, is to provide the laboratory with all pertinent information about the situation. The most useful background details include: current crop, past crop, intended crop, date of sampling, location, grower name, descriptions of all specific problems and nematodes suspected in the area.

EXTRACTING THE NEMATODES FROM SOIL

After the soil has been collected and delivered to the diagnostic laboratory, the analytical work begins. The tiny worms must be removed from the soil and identified with a microscope.

Extraction techniques may vary among laboratories, even for the same nematode species. Some laboratories will report the results by weight (nematodes per gram or kilogram); others will report by volume (nematodes per 100 milliliters or pint of soil). Data must be carefully examined to determine what measurements are used in the reports.

EVALUATION AND INTERPRETATION

The key plant parasitic nematodes in cotton are root-knot, reniform, and Columbia lance. Other plant parasitic nematodes may be present, but they usually are of minor importance. These include ring, spiral and stunt nematodes. After nematodes are identified and counted, these numbers must be interpreted. Multiple species can be present in any field, and each nematode species causes damage at different population densities.

The following are general guidelines for minimum population densities that cause significant crop damage. Guidelines may vary by state.

Root-knot Nematodes

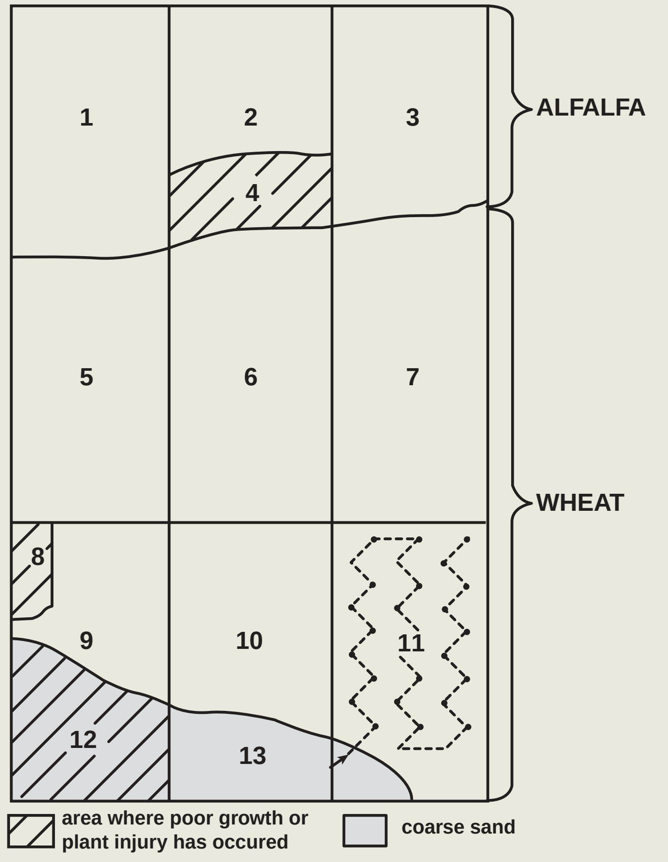
Preplant sample:	50 juveniles per pint
Fall sample:	200-500 juveniles and adults per pint, depending on soil type

Reniform Nematodes

Preplant sample:	1,000 juveniles per pint
Fall sample:	5,000 juveniles and adults per pint

Lance Nematodes

Preplant sample:	250 juveniles and adults per pint
Fall sample:	500 juveniles and adults per pint



Collecting nematode samples based on crop history, soil type, or suspected or previous problems. Pattern shown in block 11 indicates how to collect a good representative sample.

Early season damage by extremely high levels of reniform nematode. Photo by C. Overstreet.

NEMATODE SPECIES IDENTIFICATION

A nematode management program depends on the nematode species. Therefore, an accurate identification of the nematode is essential. Unlike weeds, insects or diseases, plant parasitic nematodes are unseen and require specialized diagnostic procedures to identify them. While nematode problems in the field often can be diagnosed by key plant symptoms, an accurate identification is difficult without a proper soil sample to extract nematodes from the soil. The lack of qualified experts is another reason that crop loss caused by nematodes often goes undiagnosed.

MAJOR NEMATODE SPECIES

The three major species that attack cotton are cotton root-knot, reniform and Columbia lance. Cotton root-knot nematode is found in most cotton growing areas. Reniform nematode is prevalent from North Carolina to Texas, and lance nematode is concentrated in the Southeast. Producers should test their fields before considering a nematode control program.

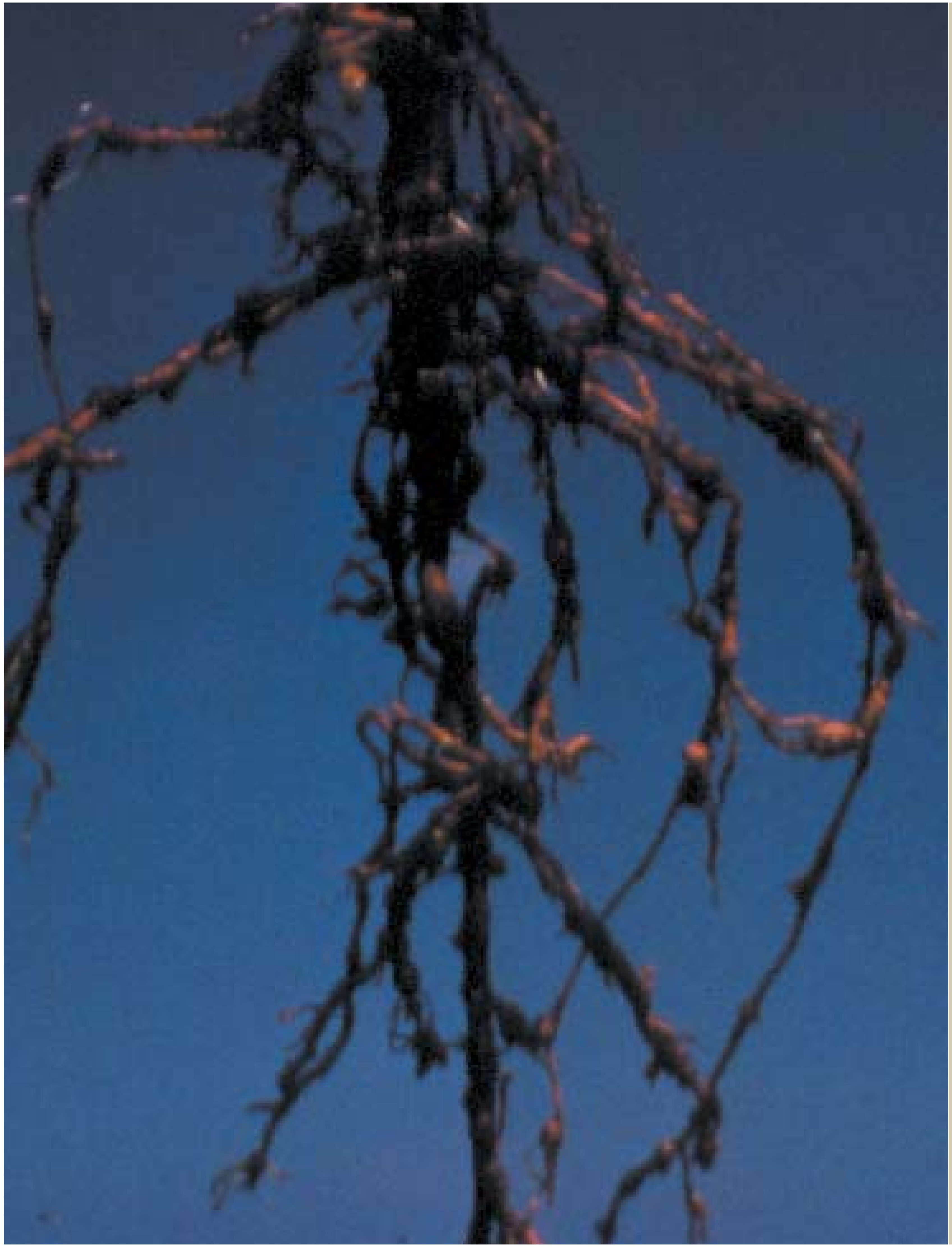
Photos by J.D. Eisenback (top, middle) and R. Lopez (bottom).

Root-knot Nematode

Columbia Lance Nematode

Reniform Nematode

Photo on left: Lance nematodes feeding ecto-parasitically on a root. Photo by F.H. Smith.



ROOT-KNOT NEMATODE

(Meloidogyne spp.*)*

Root-knot nematodes (*Meloidogyne* spp.) were first recorded as parasites on vegetables in 1885. Five years later, they were observed attacking cotton in the southern United States. Root-knot nematodes, which include more than 60 species, attack nearly all crop and weed species.

The four most common species of root-knot nematodes are *Meloidgyne incognita*, *M. arenaria*, *M. hapla*, and *M. javanica.* They are generally considered to be among the 10 most important plant pathogens in the world and are responsible for hundreds of millions of dollars in crop losses annually. All four species occur in the U.S. Cotton Belt, but only some populations of the species *M. incognita* (also known as the southern root-knot nematode) attack cotton. Recent survey data shows populations of southern root-knot nematodes are widespread throughout the Cotton Belt. More than 75% of the cotton fields in some areas are infested with this nematode.

BIOLOGY OF ROOT-KNOT NEMATODES

Like all other plant parasitic nematodes, root-knot nematodes must feed upon a host plant to complete their life cycle. The simple life cycle has four juvenile stages in addition to the egg-laying adult female. Egg production occurs without sexual cross-fertilization of eggs. Even though adult males may be present, they are not required for reproduction. The time required for an individual to develop from the egg through the four juvenile stages, to the adult female with egg production capability depends primarily on soil temperature. One generation can complete a life cycle in four weeks when the soil temperature is 80°F. However, little or no development occurs at soil temperatures below 50°F or over 100°F.

Severe root galling caused by root-knot nematodes. Plants this severely galled rarely survive long enough to produce mature bolls. Photo by J.D. Mueller.

Root-knot nematodes are sedentary endo-parasites. While feeding on cotton roots, they are completely embedded within root tissues. After feeding begins, they lose the ability to move. The first juvenile stage, which is inside the egg, is not plant parasitic. The second juvenile stage hatches from the egg and migrates through the soil in search of a cotton root. Most control practices are aimed at reducing populations of these juveniles.

The second stage juvenile enters a root near the tip and migrates to the area behind the tip where the xylem and phloem of the vascular tissue develop. Because the nematode is much smaller than the root tip, it completely embeds itself within the root. As many as 20 juveniles may invade a single root tip. Second stage juveniles cause little physical damage to the roots during the penetration process. Most damage to the cotton plant results from physiological changes caused by nematodes feeding on root tissues.

The second stage juvenile develops from its tubular stage and becomes enlarged and sausage-shaped before molting to become the third stage and subsequently a fourth stage juvenile. Approximately three weeks after root penetration, the nematode develops into a swollen, pear-shaped adult female. The male develops at the same time, but reverts to its previous worm-shape. The male exits the root without feeding.

The adult female deposits eggs in a gelatinous matrix produced by glands located near its anus. An egg mass contains from 300 to 1,000 eggs. A new generation of juveniles, which can cause a second round of infection in the root tissues, begins hatching after 10 days. Root-knot nematode causes the plant to develop several large "giant cells" near its head region that become the source of food for the nematode. These changes in the roots by the nematode results in the galls that are a distinctive symptom of root-knot nematode. Galls caused by a single nematode may be small and hard to distinguish. Multiple infections result in large galls.

POPULATIONS

The numbers of nematodes in a field vary throughout the year. Populations usually are lowest at planting and highest at crop maturity. Root-knot nematodes have limited ability to survive in frozen soil. Populations decline in the winter when soil freezes and there are fewer host plant roots to feed upon. As many as 99% of the nematodes in a field may die between harvesting one crop and planting the next one. However, population densities can increase rapidly, because each female lays as many as 1,000 eggs and the life cycle time is relatively short from the juvenile to egg-laying female adult. It is not unusual for population densities to increase more than 100 times between planting and harvest. Because population densities can fluctuate greatly, and detection procedures are less than 100% efficient, it is important to sample fields when the population densities are expected to be the highest – prior to, or immediately after crop maturity.

INTERACTIONS WITH OTHER PATHOGENS

Cotton is susceptible to several different pathogens. When a crop is attacked simultaneously by more than one pathogen, the effects of each pathogen can be different than when each pathogen attacks individually. Root-knot nematodes are noted for interacting with other pathogens to cause disease complexes. In most instances, disease complexes result when soilborne fungal pathogens are present with the root-knot nematode. A common disease complex is the Fusarium wilt/root-knot nematode complex, in which the nematodes increase the incidence of the fungal disease and the severity of the disease symptoms. It usually requires 100 times more of the individual Fusarium wilt pathogen to cause the same amount of damage to cotton as the Fusarium wilt/root-knot nematode complex. Cotton root rots caused by several different fungi are affected similarly by the root-knot nematode, including Verticillium. It is important to remember that root-knot nematodes are aggressive pathogens capable of creating large crop losses by themselves. The absence of Fusarium wilt symptoms does not indicate an absence of nematode problems.

SYMPTOMS

Plant pathogenic nematodes differ from many other pathogens and insect pests because there are no unique symptoms on the above-ground portions of the plant. Unlike many pests, the root-knot nematode is microscopic in size. Because nematodes are not uniformly distributed in the soil, the damage they cause occurs in irregular patches. These damaged patches may be small and limited in number, or they may be large and widely distributed. Depending on the level of infestation, damaged plants may exhibit symptoms ranging from mild to severe stunting with a reduced rate of development. In the most severe cases, premature death of the plants may occur. Wilting leaves are frequent symptoms, because of the common nematode interaction with the Fusarium wilt pathogen. The wilt pathogen also causes a brown discoloration (necrosis) of the vascular tissue of the lower stem. There is no brown discoloration in the absence of the wilt pathogen.

Symptoms of root damage by the root-knot nematode are visible galls or knots from which the nematode gets its name. Swellings of the infected root tissue can be found on the cotton tap root and the lateral roots. Galls that form on the woody roots of cotton are relatively small and may be difficult to see compared to root galls on garden vegetables such as tomatoes or okra. The galls are easier to detect if cotton plants are carefully dug (not pulled) from the soil. The fine lateral roots require meticulous handling when rinsed with water to remove soil. Of vital importance to the cotton plant is the tap root and its relatively few lateral roots. A few galls on these roots will disrupt the normal flow of water and nutrients to the leaves and developing bolls, which will significantly reduce the cotton plant's yield.

MANAGEMENT AND CONTROL OF ROOT-KNOT NEMATODES

There are several races of the cotton root-knot nematodes (*M. incognita*). Two are cotton races and the others are non-cotton races. The cotton races of *M. incognita* attacks cotton, soybeans, tobacco, corn and many vegetable crops, but not peanuts. The non-cotton races of *M. incognita* and other types of root-knot nematodes *(M. arenaria, M. javanica)* are also found in the Cotton Belt. They attack many crops, but not cotton.

Because there are several species of root-knot nematodes in the Cotton Belt, it is very important to know which species is present when planning a management strategy. Several control tactics are available that are based on specific characteristics of individual species of root-knot nematodes.

The development of an optimal management system can be a highly individualized process. There are several approaches that involve different control tactics. The potential yield loss and the number of acres involved will determine how much additional cost for nematode control can be justified. Approaches that may be practical for one grower many not be feasible for another. When crop rotation is part of the normal production system, nematode population densities can be reduced by selecting rotation crops that are not attacked by root-knot nematodes, or by planting resistant cultivars such as soybeans or tobacco. When selecting rotation crops, it is important not to create, or aggravate other disease or pest problems. Two effective rotation systems for controlling the cotton race of root-knot nematodes are: (1) a peanut/cotton rotation that controls root-knot nematodes on both crops; and (2) cowpeas or alfalfa rotated with cotton in the far west.

Maintaining a clean fallow field will also reduce nematode populations. However, this practice may be impractical, because of the loss of revenue during the fallow period, the cost of weed control and potential soil erosion problems. No biological control systems that are reliable on a large scale are currently available, although they have attracted widespread interest.

Many disease and pest problems can be managed effectively with resistant host plants. Several cotton cultivars are available that are reported to be resistant to the Fusarium wilt/root-knot nematode disease complex. These cultivars that resist Fusarium wilt produce greater yields in fields infested with the wilt pathogen. Cotton cultivars with resistance to the Fusarium wilt/root-knot nematode complex do not show any significant resistance to the nematodes. Although some cultivars are resistant to Fusarium wilt, it is important to understand that root-knot nematodes alone can, and do, cause substantial yield losses to such cotton cultivars. Fortunately, cotton breeding programs are making progress developing plants with improved resistance to root-knot nematodes.

Chemical nematicides are widely used to control root-knot nematodes. Numerous studies show that when nematicides are used to control nematode population densities causing significant yield loss, population densities are reduced and yields are increased. Yield increases of more than 50% are common in severely infested fields. The objective for using chemical nematicides is to provide a zone of protected soil in which cotton roots can develop for four to six weeks. By protecting the crop during its early development, yield losses will be reduced substantially even though nematodes may penetrate the roots during the latter part of the season.

Several nematicides labeled for use on cotton include soil fumigants and contact non-fumigant products. Before using any nematicide, state Extension Service recommendations should be carefully reviewed. All pesticides should be used only in accordance with label instructions.

Cotton yield response to soil fumigation in a field in Georgia infested with root-knot nematodes. Note the poor yield of the four center rows that were left untreated. Photo by W. Powell.

RENIFORM NEMATODE

(Rotylenchulus reniformis)

Reniform nematodes *(Rotylenchulus reniformis)* ranks second to the root-knot nematode for damaging cotton in the United States. It will become the most serious nematode threat to cotton in the country by the turn of the century, if it continues to spread at its present rate.

According to 2000 loss estimates, $122 million was lost to reniform nematodes. It is now considered the most damaging cotton nematode in Alabama, Mississippi and Louisiana. More than half the counties and parishes in these states are infested with reniform nematodes.

HISTORY AND DISTRIBUTION

The spread of the reniform nematode has been relatively rapid compared to other cotton parasitic nematodes. It was first reported on cotton in Georgia in 1940. A year later it was identified on cotton in Louisiana, and by 1959, it had invaded cotton in east Alabama. Since that time, reniform nematode has been detected in every southern state producing cotton from North Carolina in the East, to Texas in the West, and to Missouri in the North. Reniform has not been reported on cotton in the western states.

LOSSES

The reniform nematode is found in any soil type capable of growing cotton. Because it is easily spread by cultivation and thrives in a variety of soils, damage is usually uniform over the entire field. The amount of damage in a field depends largely on nematode population densities, prevailing climatic conditions, and soil types. Under ideal growing conditions yield losses may range up to 10% in moderately infested fields without reniform nematodes being detected. Under these same growing conditions, losses in fields with high nematode population densities will range from 20 to 50%. With unfavorable growing conditions in fields with high population densities, losses may surpass 70%.

Reniform nematode protruding from root. Egg mass has been teased away from nematode. Photo by C. Overstreet.

SYMPTOMS

The presence of reniform nematodes can't be confirmed by field symptoms alone. Cotton damage by reniform nematodes can have symptoms similar to those associated with nutritional deficiencies, hardpans and other plant parasitic nematodes. Stunting, reduced yields and delayed maturity are common symptoms of damage caused by reniform nematodes. These symptoms can indicate potential reniform nematode problems, but a soil analysis is the only positive means to identify reniform nematodes in a field.

The degree and intensity of symptoms vary with growing conditions, reniform nematode population densities and distribution within the field. Under favorable conditions, damaged cotton may exhibit only slight stunting with fewer bolls. If heavily stressed, however, plants can be badly stunted and show symptoms of severe potassium deficiency.

Symptoms also differ according to the length of time the cotton field has been infested with reniform nematodes. In newly infested fields where populations are spotty, stunted cotton will appear in areas that vary in diameter from a few feet to several hundred feet. These localized areas eventually will increase in size until they merge and cover the entire field. When reniform nematode populations are well established, symptoms of nematode damage will be distributed throughout the field.

The first symptom of injury can appear early in the season when cotton is still in the seedling stage. Nematode damage is often confused with seedling disease at this stage. Affected seedlings and young plants up to the third to fourth leaf stages turn a dull, light green color. Roots are often stunted and necrotic. If infection is severe, many young plants stop growing and die. Plants that survive continue to grow slowly, but never completely recover. At maturity, affected plants are often badly stunted with very few, undersized bolls.

In certain areas of the Southeast, specifically south Alabama, reniform nematodes are associated with symptoms on the foliage similar to potassium deficiency. Older leaves first exhibit light green to yellow mottling between the leaf veins. As the disease progresses, leaves become necrotic and "scorched," until only the leaf tissue adjacent to the major veins remains green.

If cotton plants are dug up and the soil is carefully removed from the roots, soil particles will adhere to the egg masses deposited by the female. However, they are not easily visible to the unaided eye.

BIOLOGY

The reniform nematode thrives and reproduces best under soil temperatures between 77°F and 86°F. It survives well in dry soils for periods up to six months or longer. This unique trait may explain its ability to spread from field to field in soil particles or clods clinging to farm equipment.

LIFE CYCLE

The reniform nematode's life cycle is from 25 to 35 days at temperatures between 77°F and 86°F. Because it produces several generations per season, populations become extremely large by the end of the growing season. Reniform nematodes commonly reproduce by sexual reproduction.

The immature adult female, while in the vermiform shape (worm-like), penetrates the cotton root. Approximately one-third of the anterior (head) portion of her body is embedded in the root tissue, while her posterior remains outside. Two days after she enters the root, the female's posterior begins to swell. Three days later she assumes a reniform (kidney) shape. The kidney shape of the female gives the reniform nematode its name. Approximately nine days after penetrating the root, the female lays 40 to 70 eggs in a gelatinous mass surrounding her posterior on the outside of the root.

Adult males, which do not feed, coil around and inseminate the female. The female will then produce the gelatinous egg mass and begin to lay eggs. The first stage juvenile remains in the egg and molts. Six to seven days later, the second stage juvenile emerges from the egg and becomes active. After a few days, the juvenile becomes inactive and undergoes two more molts before becoming an adult. During molting, which lasts from eight to 18 days, the second-, third- and fourth-stage juveniles do not feed. Males and females are produced in approximately equal numbers.

MODE OF INFECTION

The adult female is the only stage of the reniform nematode that feeds. Like other sedentary nematodes, the reniform nematode stimulates the host plant to channel plant food to the root tissue where the nematode is feeding. As the young female penetrates the cortex, she destroys epidermal root cells causing a necrosis of the surrounding tissue. During this feeding process, damaged root cells increase their metabolic activity. The affected cells enlarge, lose part of their cell walls, and then fuse to form a large multi-celled feeding mass called a "syncytium." When a cotton plant's root system is attacked by a large number of reniform nematodes, much of the root system is destroyed, impairing the plant's ability to take up moisture and nutrients from the soil.

INTERACTION WITH OTHER DISEASES

Reniform nematodes can increase the incidence of cotton seedling diseases. When reniform nematodes feed on seedling roots, plant growth slows or stops. Damaged seedlings are predisposed to invasion by *Thielaviopsis basicola*, *Rhizoctonia solani*, *Pythium* spp. and other seedling disease fungi. Unable to overcome seedling disease fungi, weakened plants die or fail to develop into healthy cotton.

Reniform nematodes, like root-knot nematodes, may increase the incidence of Fusarium wilt as nematode population density increases.

HOSTS

Reniform nematodes cause economic injury to a wide range of crops in the United States and throughout the tropical and subtropical regions of the world. Crops in southern cotton producing states that are particularly susceptible to reniform nematodes include: cowpeas, tomatoes, okra, cantaloupe, tobacco and most varieties of soybeans. Several crops resistant to reniform nematodes are peanuts, wheat, corn, grain sorghum, rice, peas, cabbage, cauliflower and a few varieties of soybeans.

GENERAL CONTROL MEASURES

Preventing reniform nematodes from spreading is the most effective control measure. After fields become infested with reniform nematodes, they cannot be eradicated. Controlling them can be expensive and, in many cases, impractical. Cotton growers should make every effort to keep their fields free of reniform nematodes. They should first sample all of their fields to determine if reniform nematodes are present. The best time to sample is just prior to harvest or immediately after harvest. Records should be maintained indicating infested fields and those free of nematodes. Reniform nematodes can be spread from an infested field to a clean field with equipment, tools and implements. Prior to entering a clean field, soil should be removed from machinery and equipment previously used in fields infested with reniform nematodes.

Use of nematicides, rotation with crops not attacked by nematodes, or a combination of the two is recommended in fields with high reniform nematode population densities. Nematicide treatments hold reniform nematode populations at a manageable level for approximately six weeks. This provides cotton plants sufficient time to develop healthy root systems. After six weeks, reniform nematode population levels increase rapidly, and by the end of the growing season, they reach population levels equal to, or even greater than population levels in untreated cotton. Apparently, six weeks of protection from reniform nematodes is adequate, since nematicide sidedress treatments later in the season do not consistently improve cotton yields. Nematicide treatments are, therefore, effective for only one year and must be applied at the beginning of the season in fields where cotton is continuously grown.

Rotating cotton with crops not attacked by nematodes is effective and should be practiced where sufficient land is available. A one- or two-year rotation with grain sorghum, corn, peanuts and other non-host crops is as effective as using nematicides. Rotation provides effective control for only one year because reniform nematode populations increase to damaging levels after just one growing season of cotton.

Adult reniform female begins to feed on the root system during the seedling stage. Photo by G. Lawrence.

Egg masses of the embedded reniform female can be seen with a magnifying glass. Photo by G. Lawrence.

LANCE NEMATODE
(Hoplolaimus spp.)

Lance nematodes (*Hoplolaimus* spp.) include at least eight species found in the southern United States. Only *Hoplolaimus columbus*, *H. galeatus* and *H. magnistylus* cause significant yield losses on cotton. The Columbia lance nematode *(Hoplolaimus columbus)* causes the greatest damage, but its geographical distribution is the most limited. These three species vary in their life cycles, distribution and degree of damage they cause to cotton. Information on *H. galeatus* and *H. magnistylus* is limited. Most of the following information refers to *H. columbus*.

HISTORY AND DISTRIBUTION

The distribution of *H. columbus*, *H. galeatus* and *H. magnistylus* vary extensively. *H. columbus* occurs primarily in the coastal plains of Georgia, North Carolina and South Carolina. It has also been found in soybeans and cotton in Louisiana and cotton in Alabama. Fifty percent of all cotton fields in South Carolina are infested and 35% of these infested fields have population densities above the damage threshold. *H. columbus* is considered the primary cotton nematode in South Carolina. Columbia lance nematode is primarily a problem on sandy loam and sandy soils.

H. magnistylus is found primarily in Arkansas, Louisiana and Mississippi. Distribution is not widespread and it is not as big a threat to cotton as root-knot or reniform nematodes in any state.

H. galeatus occurs from Florida to Virginia, and from the east coast of the Carolinas to the Mississippi River. It is rarely found in cotton in these areas, but it is common on turf grasses and corn. In 1968, the Columbia lance nematode was identified in cotton in South Carolina. In 1955, *H. galeatus* was found in cotton in North Carolina, and *H. magnistylus* appeared in Arkansas on cotton in 1982. The fumigant nematicides that were used extensively in the 1960s and 1970s were very effective in controlling lance nematodes. The effectiveness of fumigant nematicides and the extensive damage to cotton caused by root-knot nematodes may have overshadowed the damage inflicted by lance nematodes at this time.

Columbia lance nematodes feeding and causing a lesion on cotton roots. Photo by S.A. Lewis.

YIELD LOSSES, SYMPTOMS

Symptoms of lance nematode damage on cotton depend on nematode density and environmental conditions. Lance nematodes feed on root tips of young cotton plants altering root growth patterns. The plant's taproot may be stunted and secondary branching may increase in the upper four inches of soil. This obstructs the uptake of water and nutrients causing stunting and mild chlorosis (yellowing of leaves) of the plant above ground. Continued feeding and root damage increase the stress caused by the reduction of moisture and nutrient uptake. However, these symptoms on cotton are not as apparent as on soybeans where severe chlorosis may occur. The clustered or spotty distribution of lance nematodes in a field is typical of other nematode species. Symptoms of root damage frequently appear above ground in oval patterns elongated in the direction of tillage practices.

Cotton yield losses of 5 to 10% may occur in fields where Columbia lance nematode symptoms are not pronounced. In fields with severe infestations, yield losses may reach 50 to 60%. The uneven maturity of plants in infested fields also may cause yield losses. In most states, the threshold level for Columbia lance nematodes is approximately 500 per pint of soil taken at harvest. Fall samples are best for determining if Columbia lance nematode is above the damage threshold. However, soil samples can detect the nematode at any time of the year. Threshold levels for *H. magnistylus* and *H. galeatus* have not been reported.

BIOLOGY

Lance nematodes are relatively large with adults ranging in length from .036 inch to .076 inch. Males and females are usually present in populations of *H. galeatus* and *H. magnistylus*. Both sexes are required for reproduction of both species. The male is not required for reproduction of *H. columbus*. In field populations of *H. columbus*, males are rarely seen, but have been identified in laboratory cultures.

Hoplolaimus spp. are migratory ecto-endo-parasites, which are unlike root-knot and reniform nematodes that are sedentary endo-parasites. *Hoplolaimus* spp. feed and migrate through the outer tissues of the cotton root, and to a lesser degree, the inner tissues. During their entire life cycle, they remain worm-like in shape while exiting and re-entering plant roots. All juvenile stages of *H. columbus* are infective.

A female *Hoplolaimus* deposits individual eggs. No egg mass is created. The estimated life span of a female is from several months to more than a year. The egg-laying ability of the female lance nematode is relatively low. She lays 20 to 50 eggs at a time, but the number of times in her life she lays eggs is unknown. Although the female produces relatively few eggs, the offspring tolerate high levels of desiccation and changes in soil conditions during the winter, resulting in high survival rate. There is undocumented evidence that lance nematode eggs can also overwinter. Juvenile and adult Columbia lance nematodes have been recovered in soil to a depth of more than 16 inches. The ability of juvenile and adult lance nematodes to migrate vertically in the soil may contribute to their high overwintering survival rates.

HOSTS

Lance nematodes have very wide host ranges. Columbia lance nematodes damage cotton, corn, soybeans, wheat and bermudagrass. Greenhouse tests have shown that some winter annuals, such as wheat, support high levels of Columbia lance nematodes. However, low winter soil temperatures may limit nematode reproduction, plant infection and yield losses in the field. Peanuts, sweet potatoes, tomatoes, peppers, rye grass and bahiagrass are not parasitized by Columbia lance nematodes. Crops that are poor hosts for Columbia lance nematodes are watermelons, cucumbers, okra and cantaloupe. When parasitized by Columbia lance nematodes, these crops do not show a yield loss, but nematodes can survive and reproduce in their roots. Common weeds that are hosts for Columbia lance nematodes include henbit, nutsedges, cowpeas, crimson clover, pigweed, sicklepod and showy crotalaria.

INTERACTIONS WITH OTHER DISEASES

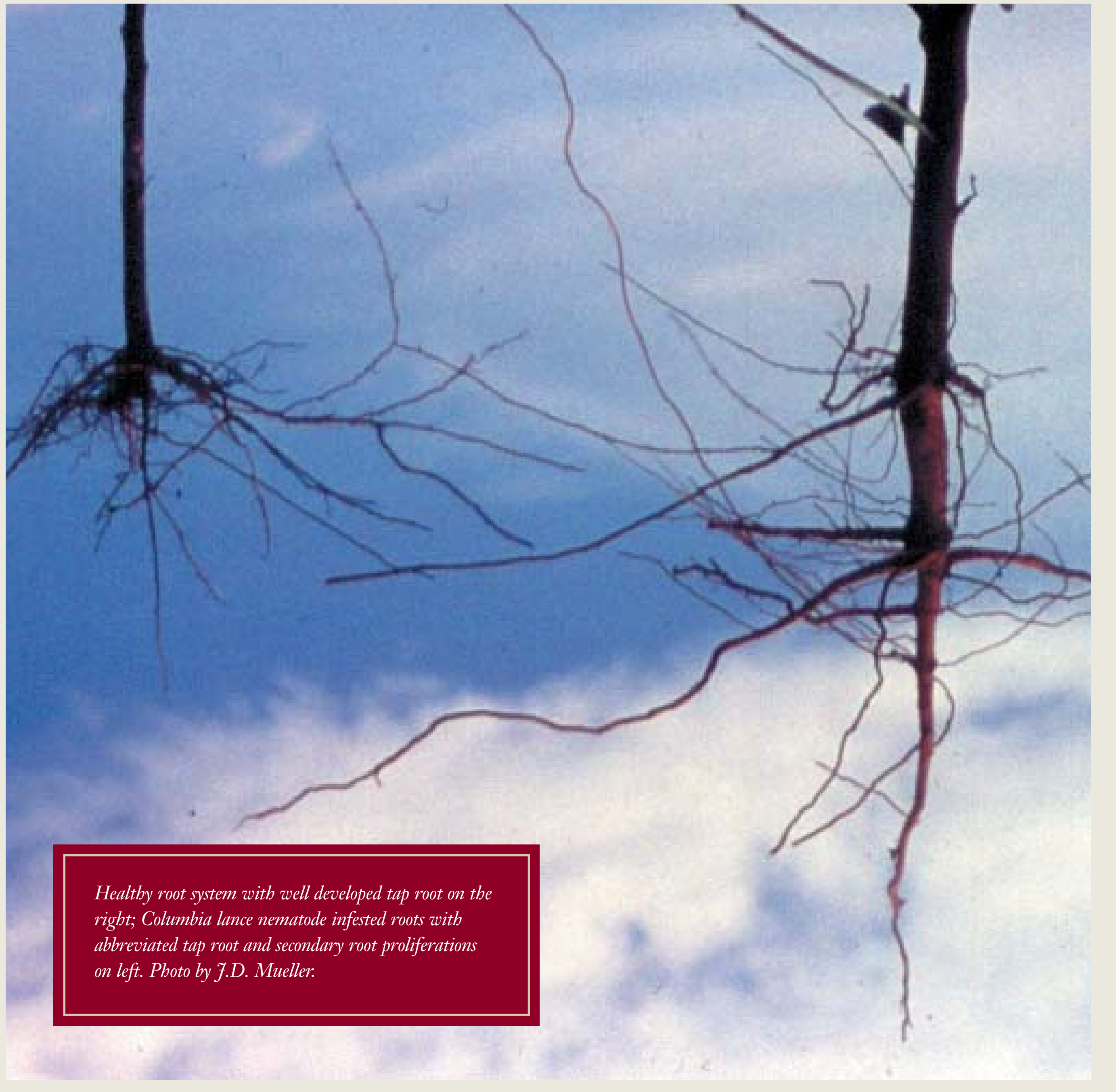
Lance nematodes are not known to form or enhance a disease complex with the Fusarium wilt fungus. Because of their migratory behavior while feeding on plant roots, they create many wounds where fungal infections can increase seedling disease caused by *Rhizoctonia solani*. Seedling diseases due to *Pythium* spp. are not enhanced by the feeding of lance nematodes.

CONTROL

Crop rotation. Because lance nematodes parasitize a wide range of crops, rotating cotton with other crops has limited value as a control practice. In some areas where peanut acreage is relatively large, cotton can be rotated with peanuts, which is a non-host crop to lance nematodes. However, this rotation has limited value as a control measure in many areas such as South Carolina where only 15,000 acres of peanuts are available for rotation with 200,000 acres of cotton. Corn and soybeans are not effective rotation crops. Because many weed species are hosts for the lance nematode, fallowing fields has limited value as a control measure.

Host plant resistance. No cotton genotypes have been found that exhibit resistance to lance nematodes. Resistance in root-knot and reniform nematodes is due to the lack of formation of a specialized feeding site. The migratory nature of lance nematode feeding greatly reduces the likelihood of finding resistance because no specialized feeding site is present. Some cotton cultivars appear to be more sensitive to lance nematodes than others, but no consistently high levels of resistance have been identified.

Cultural practices. Lance nematode damage to cotton roots results in yield losses due to nutrient and moisture stresses. These stresses cannot be alleviated by applying higher rates of fertilizer or more frequent irrigation. In-row subsoiling is partially effective in reducing yield losses caused by lance nematodes. Subsoiling does not affect nematode infestation levels. However, it does reduce symptom development and subsequent yield losses by allowing healthier root development. Subsoiling is less effective under heavy nematode pressure and drought stress. Subsoiling also will not reduce nematode population densities in the long term.



Healthy root system with well developed tap root on the right; Columbia lance nematode infested roots with abbreviated tap root and secondary root proliferations on left. Photo by J.D. Mueller.

Nematicides are effective in reducing yield losses due to lance nematodes. Local guidelines are available for rates and types that are effective for specific soil types and environmental conditions. Nematicide treatments generally suppress nematode populations for only the first portion of the growing season. At harvest, population densities may be as great or greater than at planting, requiring the use of control measures at the start of each growing season.

COTTON NEMATODE MANAGEMENT

The goal of a cotton nematode management program is to keep nematode population densities at a low level during the early growing season. This allows cotton plants to establish healthy root systems. However, where a single susceptible crop is used, nematodes can increase to a level that can cause great economic loss. Nematode management integrates several production practices to keep population densities below damaging levels.

Effective management practices require knowing which fields are infested, the genera that are present, and their population densities. The first most important step is to sample all fields to determine if nematodes are present; and if so, to establish population density levels. If no species are detected, then the strategy is to make sure that none are introduced. If nematodes are present, then the strategy is to keep them from spreading to non-infested fields and to reduce population densities. Root-knot and lance nematodes should be identified by specific species. Management practices may include the use of tolerant varieties of cotton, cultural practices and/or chemical controls.

RESISTANT CULTIVARS

Progress is being made in developing varieties of cotton tolerant or resistant to cotton nematodes.

CULTURAL PRACTICES

Research shows that three cultural practices are effective in reducing nematode damage.

1. Water management – In fields with high nematode populations, irrigation reduces crop moisture stress. Irrigation water or flood water should not be allowed to move from infested to non-infested fields.

2. Clean equipment – Implements, tools and equipment should be cleaned of soil and root debris before moving from infested to non-infested fields.

3. Rotation – Rotation is an effective management practice for reducing cotton nematode populations. Rotation of a non-host crop with cotton for one or more years reduces nematode populations by starving the pests. A one-year rotation from cotton to grain sorghum or corn will greatly reduce the populations of the reniform nematode for the following year. Peanuts will reduce the population density of root-knot and lance nematodes. Tobacco will also reduce densities of lance nematodes. Some nematodes are more persistent and require longer rotation sequences. Major rotation problems occur if land is not available for rotation, or if a rotation crop with suitable economic value is not available.

Early season cotton growth response to TEMIK®, a contact nematicide (10 lbs/A) in a Texas field with a high population density of root-knot nematodes. Treated plants are on the left.