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College of Agricultural, Consumer and Environmental Sciences

report on
PLANT
DISEASE

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ROOT-KNOT NEMATODES

Figure 1. Root knot on tomato.

Root-knot disease is caused by various species of *Meloidogyne.* It has long been considered "the nematode" disease by farmers and other plant growers because of the severe yield reduction and obvious root-galling symptoms that are caused by these pests. There are several species of root-knot nematodes found in Illinois, including *M. hapla, M. incognita, M. arenaria, M. javanica,* and *M. naasi.* Collectively, these species attack more than 2,000 different kinds of plants, including most vegetable, fruit, and field crops; many ornamentals; and numerous common weeds. No species attack all 2,000 host plants; thus, knowledge of the host range of each nematode and accurate identification of the species of *Meloidogyne* involved in a particular problem are important when crop rotation is used as a control measure. The most important species in Illinois are *M. hapla* and *M. incognita*, which have the widest host ranges of any of the root-knot nematodes.

SYMPTOMS

Root knot nematodes usually are detected first in localized areas within a field, nursery planting, or home garden. Obviously affected spots most often are circular to oval in shape and vary from a few feet across to several acres in size. Plants within these areas are stunted and frequently chlorotic. They tend to wilt excessively during the heat of the day and recover at night. The damage is most conspicuous in the center of an infested area and diminishes toward the edges. Occasionally, entire fields are involved. Such extensive damage is usually the result of planting a highly susceptible crop for many consecutive years or transplanting infected plants. Infected perennials show a general lack of vigor or poor growth. Woody perennials may also exhibit early color change and defoliation, increased winter injury, and twig and branch dieback. Crop yields can be reduced up to 90% or more, depending on the nematode level and other biotic and abiotic factors.

Unfortunately, the presence of root-knot nematodes cannot be diagnosed by aboveground symptoms alone. Such factors as poor drainage, low soil fertility, and other disease-causing organisms can produce similar above-ground symptoms. However, the characteristic galls produced on infected roots and other underground plant parts distinguish root-knot nematode damage from that caused by any other factor in Illinois fields (Figures 1, 2, and 3). By carefully **digging** affected plants and shaking the soil from the root systems, one can see the abnormal swellings on the roots. Individual swellings vary from barely visible, spindle-shaped swellings about 1/8 inch in diameter to ones up to an inch in diameter depending on the species of *Meloidogyne*, type of plant, and level of infection. On heavily infected plants, galls tend to fuse together so that a large part or all of the root may be swollen (Figure 1). Other less obvious symptoms produced on roots include discoloration and decay, curling of root tips, and abnormal proliferation of lateral roots. Proliferation is particularly obvious on root crops, such as carrot. On these crops the nematodes cause formation of multiple storage roots and the symptom known as "hairy root" (Figure 2).

Figure 2. Root-knot nematode damage to carrot roots (left two), showing typical galling and hairy root; normal root (right)

If a grower finds plants with these symptoms, he should notify his nearest Extension adviser at once. For final diagnosis, the adviser may need to collect plants showing the symptoms and send samples to the Plant Clinic, 1401 W. St. Mary's Road, Urbana, IL 61802 without delay (see RPD 1100, "Collecting and Submitting Soil Samples for Nematode Analysis").

Root knot nematode galls can be confused with *Rhizobium* nodules on roots of leguminous plants. On close examination, however, the nematode gall can be seen to occupy the entire circumference of the root, whereas the nodule is located on the side of a root. Several other types of nematodes form root galls similar to those of *Meloidogyne*. These nematodes are not known to occur out-of-doors in Illinois. They are encountered only rarely on plants, in homes or greenhouses, that have been imported from other areas of the country.

The degree of root-knot nematode damage expressed on tops of plants is dependent upon a number of environmental conditions. Injury is most severe in light-textured soils that are low in nutrients and organic matter. Plants grown in good, loamy, fertile soils often can withstand low-to-moderate nematode populations without showing obvious aboveground symptoms. Periods of drought and very hot weather enhance damage, as does planting the crop later than normal in the field. The grower, however, can reduce the amount of damage from these pests by improving the growing conditions for the plant.

Figure 3. Root-knot nematode injury to potato tubers.

LIFE HISTORY

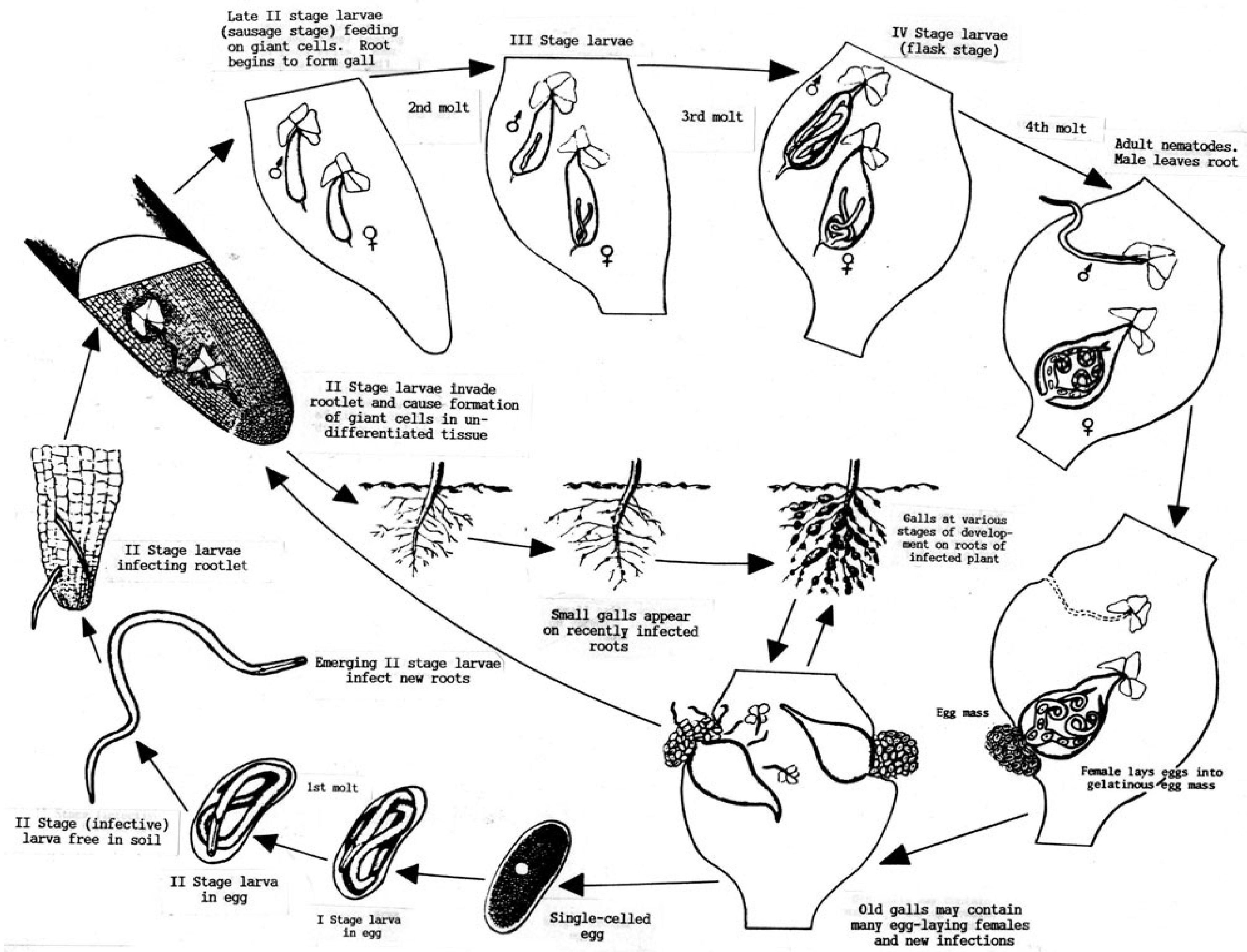
Root-knot nematodes are sedentary endoparasites in that the female no longer is motile once she has established a feeding site in the root (Figure 4). The female deposits single-celled eggs in a gelatinous mass at or near the root surface. Embryonation of the egg begins immediately and continues until a worm-shaped larvae hatches. This larvae is about 1/60 of an inch long and is in the second stage, having passed through one molt within the egg. It then migrates either into the soil or to a different location in the root.

The larva in the soil penetrates a suitable root by repeatedly thrusting its feeding structure, the stylet, into cells at the surface. After forcing its way into the root, the larva moves between and through cells to the still-undifferentiated conductive tissues. Within two or three days, the larva becomes settled, with its head embedded in the developing vascula cylinder, and begins feeding. The nematode then begins to grow in diameter, loses its ability to move, and matures.

While the nematode is maturing, it goes through two additional larval stages interspersed by molts. The only significant growth is in diameter, so the mature female is not much longer than the second-stage larva. Her body is now spherical or pear-shaped, with a diameter of about 1/40 inch and a narrow neck. The male develops in the same way as the female, except that he reverts to the worm shape at the last molt. Males are not always required for reproduction and usually appear in high numbers only under adverse conditions. The cycle is completed when the female begins laying eggs. Her egg masses normally contain 300 to 500 eggs but may range from almost none under unfavorable conditions to as many as 2,000 under highly favorable conditions.

Roots begin to swell within a day after infection. Cells around the nematode are stimulated to multiply and enlarge abnormally in response to its salivary secretions. Important microscopic changes begin to occur in the conductive tissues. Walls of cells around the head of the nematode dissolve and cell contents are incorporated into an ever-enlarging multinucleate syncytium, or giant cell. The nematode feeds upon the giant cells throughout the rest of its life. Continued enlargement of these cells, rapid multiplication of other cells, and growth of the nematode contribute to the developing root gall, which protects the maturing nematode from the outside environment. The conductive tissues no longer function properly. Translocation of water and nutrients is impeded and, as a result, top growth is affected adversely. The heavier the infection burden, the more stunting and chlorosis occur aboveground.

The length of the life cycle and rate of population increase depend upon several factors, most important of which are soil temperature, host suitability, and soil type. At 80°F (27°C), which is about optimum for most *Meloidogyne* species, one generation on a good host requires approximately 21 to 25 days, whereas at 67°F (19°C) at least 87 days are necessary. Thus, three to six generations are possible out-of-doors in Illinois, depending on location. Many more generations can occur indoors. The life cycle is lengthened on a less-suitable host. Sandy, organic muck, and peat soils are more favorable for population build-up than are heavier clay soils.


Late II stage larvae (sausage stage) feeding on giant cells. Root begins to form gall
2nd molt
III Stage larvae
3rd molt
IV Stage larvae (flask stage)
4th molt
Adult nematodes. Male leaves root
II Stage larvae invade rootlet and cause formation of giant cells in undifferentiated tissue
Galls at various stages of development on roots of infected plant
II Stage larvae infecting rootlet
Small galls appear on recently infected roots
Emerging II stage larvae infect new roots
Egg mass
Female lays eggs into gelatinous egg mass
1st molt
II Stage (infective) larva free in soil
II Stage larva in egg
I Stage larva in egg
Single-celled egg
Old galls may contain many egg-laying females and new infections

DISEASE COMPLEXES

Root-knot nematodes often interact with other soil-inhabiting plant pathogens to form disease complexes in which the resulting disease is much more severe than components of the complex would cause alone. *Meloidogyne* species are known to interact with both *Verticillium* and *Fusarium* fungi, which cause wilt diseases of pepper, tomatoes, potatoes, and other plants. In certain situations, the nematode has been responsible for breaking disease resistance to Fusarium wilt. Disease complexes often kill plants, particularly when young, whereas the nematodes alone seldom cause such a severe reaction.

MEANS OF SPREAD

Only males and second-stage larvae of root-knot nematodes are able to move through the soil. This movement, however, is limited to several inches a year and is unimportant when compared with other ways in which the nematodes can be disseminated. Natural means of spread include water, wind, and wildlife. Water transport of eggs and larvae during downpours and floods may involve long distances. Wildlife moving through infested fields carry these stages in moist soil clinging to their bodies or feet. Wind is probably important only after plowing when infected roots are brought to the soil surface. Man is unquestionably most important in spreading the disease. Nematodes are transported in infested soil clinging to vehicles, tools, equipment, and shoes and in infected plants. They can be carried from one end of the country to the other in roots of infected plants. Southern species frequently are carried northward into Illinois in fruit and vegetable transplants, ornamentals, and houseplants. If no measures are undertaken to control the nematodes in infested soil, on vehicles, and on cultivation and tillage equipment, water and wind will move soil containing eggs and larvae over larger areas of a field.

SPECIES OF ROOT-KNOT NEMATODES

Meloidogyne hapla — Northern root-knot nematode

This is the most common root-knot nematode found in Illinois and other northern soils. Unlike most other root-knot nematode species, *M. hapla* withstands freezing temperatures, thereby allowing it to survive cold northern winters outdoors. *M. hapla* forms smaller galls on host plants and is somewhat less pathogenic than most other root-knot nematode species. It typically causes excessive root branching by continually attacking just behind the growing point of the root, thus stopping growth of the root.

Common hosts include African violet, alfalfa, asters, barberry, beans, beet (garden and sugar), blueberry, boxwood, broccoli, cabbage, cantaloupe, carrot, cauliflower, celery, cherry, Chinese cabbage, clovers, coleus, cress, daylily, delphinium, eggplant, endive, escarole, forsythia, geranium, germander, gladiolus, grape, grape-hyacinth, gourds, horseradish, iris, kale, lespedezas, lettuce, lentil, lupine, marigold, mock orange, morning-glory, mulberry, mustard, myrtle, onion (shallot, leek, Welsh onion), okra, pansy, parsley, parsnip, pea, peach, peanut, peony, pepper, periwinkle, potato, privet, radish, rose, rutabaga, snapdragon, soybean, spirea, strawberry, sunflower, sweet potato, tomato, vetches, viburnum, and weigelia.

Resistant plants include asparagus, bush red peppers, most varieties of watermelon, several varieties of cucumber, squash (Butternut, Black Zucchini, Caserta, Early prolific, Straight Neck), several varieties of cantaloupe (Rio Sweet, Weslaco, Hales Best, Rocky Ford), and melons (Honeyball Pink Flesh, Honeydew, Golden Rind, Kenshaw, Casaba, wintermelons). Most varieties of pumpkin and sweet corn are thought to be immune or highly resistant. Untested tomato varieties resistant to *M. incognita* may have some resistance to *M. hapla* as well. Dwarf French marigolds are resistant but American marigolds are not. Three-year rotations with bluegrass, small grains, or field corn, which are immune, provide excellent control provided plantings are kept free of weeds on which the northern root-knot nematode might reproduce.

Meloidogyne incognita — Southern root-knot nematode

This species of root-knot nematode cannot withstand freezing and so is limited to soils that do not freeze. It often occurs on plants in the home, in greenhouses, and close to cellar foundations, where freezing conditions do not occur. The southern root-knot nematode is capable of overwintering in the field in parts of southern Illinois, particularly in sandy soils. It is the most frequently introduced species on transplants from the south. Although it may damage infected transplants and neighboring plants severely during the ensuing season, populations usually die out during the first winter in all but southern Illinois. Stunting, yellowing, and wilting are much more severe and death of young plants more common than with *M. hapla*. Root galls usually are much larger than those of the northern root-knot nematode.

M. incognita causes damage to a number of crops including alfalfa, asparagus, beans, cabbage, cantaloupe, carrot, celery, chard, clovers, corn, cotton, cucumber, eggplant, grape, lespedezas, lettuce, okra, onion, peach, pepper, potato, radish, rhubarb, soybeans, spinach, squash, sweet potato, tobacco, tomato, turnip, vetches, and watermelon. Ornamentals commonly affected are abelia, African violet, azalea, begonia, boxwood, camellia, caltha, coleus, collinsia, daylily, dahlia, gardenia, geranium, hibiscus, hollyhock, iris, peperomia, petunia, prayer plant, rose, schefflera, and willow.

Resistance to *M. incognita* is available in the following plant varieties: garden bean - Nemasnap, Coffee Wonder, Manoa Wonder, Wingard Wonder, and Springwater Hal Runner; lima bean - Nemagreen and Hopi; peach (rootstocks) - Nemaguard, Okinawa, and Yuma; soybean - Dyer and Forrest; sweet potato - Nemagold and Hearogold; tomato - Beefmaster, Better Boy, Bonus, Nemared, Nematex, Terrific, and Vineripe. Resistant plants that can be used in two- or three-year rotations are asparagus, strawberry, and small grains. Both French and American marigolds, as well as castor bean and chrysanthemum, are resistant.

Meloidogyne arenaria, M. javanica - Peanut and javanese root-knot nematodes

These species occasionally are found in greenhouses but do not occur outdoors in Illinois since they cannot withstand cold temperatures. They have similar preferences in hosts, among which are alfalfa, azalea, beans, beet, cabbage, calendula, carnation, carrot, corn, cucurbits such as cucumber and squash, eggplant, grape, impatiens, peach, potato, radish, snapdragon, soybean, tomato, and zinnia. Peanuts, pepper, gherkin, strawberry, and sweet potato are said to be immune or highly resistant to *M. javanica*, but peanuts are very susceptible to *M. incognita.* Most of the varieties of peach rootstock and tomato resistant to *M. incognita* are also resistant to these species.

Meloidogyne naasi - Barley root-knot nematode

This species is not common in Illinois but is a potential threat to all small grains and many grasses. Probably an introduced species, it is present on creeping bentgrass in a few isolated locations in the northern part of the state. On this host, it causes stunting, chlorosis, and stand decline. Like *M. hapla*, the barley root-knot nematode produces small root galls, which on turfgrasses are so tiny as to be easily overlooked. It can cause severe yield losses in small grains as a result of stunted plants, reduced tillering, and small heads and seed. Like the northern root-knot nematode, it easily overwinters in Illinois.

Unlike other species of root-knot nematodes, *M. naasi* prefers members of the grass family. In addition to barley and creeping bentgrass, hosts include colonial and creeping bentgrasses, fescues, Kentucky bluegrass, oats, orchardgrass, redtop, rice, rye, rye-grasses, wheat, and a number of weed grasses. The only important crop hosts outside of the grass family are soybean and sugarbeet.

M. naasi is easily controlled through crop rotation, when small grains and grasses are avoided. Kentucky bluegrass and soybean are somewhat resistant and probably do not suffer significant damage. They may, however, carry over enough nematodes to cause damage on a subsequent highly susceptible crop. Corn and sorghum appear to be immune to our population of the barley root-knot nematode.

CONTROL

Crop Rotation. Rotation with resistant or nonhost crops for two to three years generally provides excellent control of root-knot nematodes. Suggested rotation crops are found in the discussion of each *Maloidogyne* species. It is important, however, to keep these crops free of weeds or volunteer plants susceptible to the species involved, since their presence nullifies the use of rotation.

Resistant Varieties. Use of resistant varieties is perhaps the best method of controlling root-knot nematodes. However, these varieties are usually resistant to only one or two species of *Meloidogyne*. Therefore, this method is limited to situations in which one or perhaps two *Meloidogyne* species are present. Resistance may not provide protection against even one species, since numerous intraspecific races and biotypes are known to exist in nature. (See text on each root-knot species for information on resistance).

Incorporation of Organic Matter. Although not a reliable control measure, incorporation of large amounts of slightly decayed plant material into the soil tends to suppress the development of root-knot nematode populations. It is thought that this material stimulates populations of bacteria, fungi, and other soil inhabitants that are antagonistic to nematodes. Unless additional fertilizer is added to soil, this method may cause nutrient imbalances that reduce plant growth.

Early Planting. Certain crops such as radishes and lettuce can develop at temperatures as low as 55°F (13°C). As previously mentioned, root-knot nematodes reproduce slowly if at all at such temperatures. Thus, these crops can be grown at low temperatures through most of their cycle without suffering nematode infection. Many other annual crops can be planted before soil temperatures reach a level where nematode activity begins. By planting as early as possible, infection is delayed and severe early season damage can be avoided.

Temperature Control. Allowing the soil to freeze in the greenhouse will kill the eggs and larvae of all but the northern and barley root-knot nematodes. The soil should be worked periodically during the freezing process to assure all the infested soil freezes. Exposing greenhouse soil to relatively high temperatures and thorough drying will greatly reduce the number of nematodes in the soil. Many greenhouse crops also can be grown at temperatures as low as 55° to 60°F (13° to 16°C), which limits nematode activity.

Heat Treatment of Propagation Material. Plant parts infected with root-knot nematodes can be disinfected by placing them in hot water. The temperature and period of exposure involved depends on the plant being treated. The temperature must be controlled critically and is usually just below that which injures plant tissues. Temperatures of 112° to 115°F (44° to 46°C) and times varying from 10 to 30 minutes are used most commonly. Before large-scale treating, it is best to test a few plants to determine the temperature and time limits that the host can withstand without sustaining injury.

Heat Treatment of Soil. Soil disinfestation by heat in one form or another is the most commonly used method of nematode control in greenhouses and the home. This is because it is both highly effective and may be the only practical control option available to the grower. Since it is difficult to treat large volumes of soil with heat, its usefulness is limited to relatively small quantities. Nematodes are killed by exposure to temperatures of 104° to 130°F (40° to 54°C), depending on the species. Any method that will thoroughly heat soil and plant residues above these temperatures will kill nematodes. Moist heat in the form of steam is most efficient, although baking small quantities in an oven is also effective. The temperature should reach at least 180°F (82°C) for 30 minutes (or 160°F, 70°C, for an hour) to kill all nematodes residing in the soil.

Plant Care. Since root-knot nematodes interfere with the proper absorption and translocation of moisture and nutrients in the infected plant, damage to many crops can be offset to some degree by maintaining proper soil moisture and nutrient levels. Protection from other stress factors such as cold, disease, and insect attack also lessens damage.

Chemical Control. Control of root-knot nematodes through the use of chemicals is highly effective and practical, particularly on a field basis and where crops of relatively high value are involved. It may be the only alternative where crop rotation cannot be practiced or resistant varieties are unavailable. Both fumigant and nonfumigant chemicals are available for nematode control. The Illinois Pest Control Handbook (revised annually) lists the chemicals registered for use in Illinois.