Alternative Nematode Control

Pest Management Technical Note

Abstract: This publication provides general information on these tiny worm-like organisms. A more detailed description of the genera of nematodes that attack plants is provided as well as various methods to diagnose, discourage and treat against plant parasitic nematodes in a least toxic, sustainable manner.

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Introduction

Nematodes are tiny, worm-like, multicellular animals adapted to living in water. The number of nematode species is estimated at half a million, many of which are "free-living" types found in the oceans, in freshwater habitats, and in soils. Parasitic species form a smaller group. Nematodes are common in soils all over the world (1, 2). As a commentator in the early twentieth century wrote:

> If all the matter in the universe except the nematodes were swept away, our world would still be dimly recognizable, and if, as disembodied spirits, we could investigate it, we should find its mountains, hills, vales, rivers, lakes and oceans represented by a thin film of nematodes. (3)

An important part of the soil fauna, nematodes live in the maze of interconnected channels—called pores—that are formed by soil processes. They move in the films of water that cling to soil particles. Many genera and species have particular soil and climatic requirements. For example, certain species do best in sandy soils, while others favor clay soils. Nematode populations are generally denser and more prevalent in the world's warmer regions, where longer growing seasons extend feeding periods and increase reproductive rates (1). In the southern United States, as many as ten generations are produced in one season (2).

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Light, sandy soils generally harbor larger populations of plant-parasitic nematodes than clay soils. This is attributable to the more efficient aeration of sandy soil, the presence of fewer organisms that compete with and prey on nematodes, and the ease with which nematodes can move through the root zone. Also, plants growing in readily drained soils are more likely to suffer from intermittent drought, and are thus more vulnerable to damage by parasitic nematodes. Desert valleys and tropical sandy soils are particularly challenged by nematode overpopulation (1).

Plant-parasitic nematodes—the majority of which are root feeders, completing their lifcycles in the root zone—are found in association with most plants. Some are endoparasitic, living and feeding within the tissue of roots, tubers, buds, seeds, etc (3). Others are ectoparasitic, feeding externally through plant walls. A single endoparasitic nematode can kill a plant or reduce its productivity, while several hundred ectoparasitic nematodes might feed on a plant without seriously affecting production (4). A few species are highly host-specific, such as *Heterodera glycines* on soybeans and *Globodera rostochiensis* on potatoes (3). But in general, nematodes have a wide host range.

Endoparasitic root feeders include such economically important pests as the root-knot nematodes (*Meloidogyne* species), the cyst nematodes (*Heterodera* species), and the root-lesion nematodes (*Pratylenchus* species) (3). Direct feeding by nematodes can drastically decrease a plant's uptake of nutrients and water. Nematodes have the greatest impact on crop productivity when they attack the roots of seedlings immediately after seed germination (5). Nematode feeding also creates open wounds that provide entry to a wide variety of plant-pathogenic fungi and bacteria. These microbial infections are often more economically damaging than the direct effects of nematode feeding.

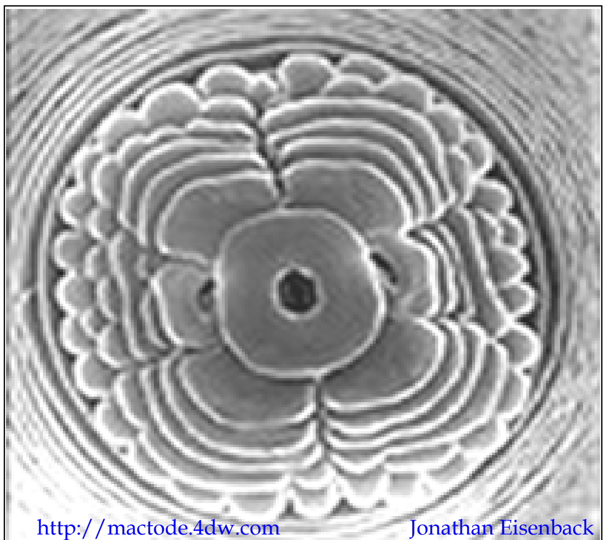
Nematode control is essentially *prevention*, because once a plant is parasitized it is impossible to kill the nematode without also destroying the host. The most sustainable approach to nematode control will integrate several tools and strategies, including cover crops, crop rotation, soil solarization, least-toxic pesticides, and plant varieties resistant to nematode damage. These methods work best in the context of a healthy soil environment with sufficient organic matter to support diverse populations of microorganisms. A balanced soil ecosystem will support a wide variety of "biological control" organisms that will help keep nematode pest populations in check.

Major Plant-parasitic Nematode Genera in the U.S. & Associated Damage to Plants

- **Root-knot** nematodes form galls on injured plant tissue. The galls block water and nutrient flow to the plant, stunting growth, impairing fruit production, and causing foliage to yellow and wilt. Roots become rough and pimpled and susceptible to cracking.
- **Cyst** nematodes give plants an unthrifty or malnourished appearance, and cause them to produce smaller-than-normal tops. Foliage is liable to wilt and curl, while roots become thick and tough and take on a red or brown coloring.
- **Sting** nematodes are found mainly in the South, especially in sandy soils with meager organic-matter content. Areas of stunted plants are an early indicator. As these areas grow larger and finally meet, the plants that were first affected will start to die at the margins of older leaves.
- **Root-lesion or meadow** nematodes cause internal browning in potato tubers and in the roots of corn, lettuce, peas, carrots, tomatoes, and brassicas (2).

Spiral nematode, Helicotylenchus sp.

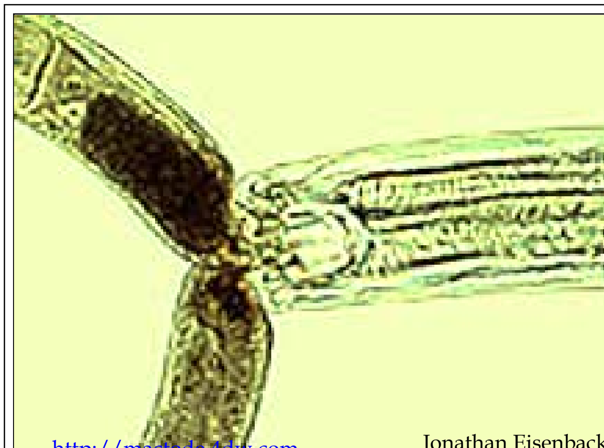
Pratylenchus sp. larva and egg.



Face view of lance nematode, Hoplolaimus sp.

Sugarbeet cyst nematode juvenile.

Lesion nematodes penetrating a root.



Mononchoid nematode feeding on another nematode.

Symptoms and Sampling

Usually, sampling is done because the grower observes a section of field with unhealthy plants, or notices an unexplained yield reduction. Because nematodes damage roots, any condition that stresses the plant—such as drought (or even hot spells), flooding, nutrient deficiencies, or soil compaction—will tend to amplify the damage symptoms noted above. Failure to respond normally to fertilizers and slower-than-normal recovery from wilting are signs of nematode infestation. In the undisturbed soil of groves, turf, and pastures, visible symptoms of nematode injury normally appear as round, oval, or irregular areas that gradually increase in size year by year. In cultivated land, nematode-injured spots are often elongated in the direction of cultivation, because nematodes are moved by machinery (6).

It is important to note that species of nematode are present in all soils; their mere presence does not necessarily mean that they are damaging plants. Harmless or even beneficial species are found in proximity to plants, right along with the parasitic species. Beneficial nematodes feed on such pests as Japanese beetle grubs and plant-parasitic nematodes, and release nutrients into the soil by eating bacteria and fungi (4, 7). Identification of species, and determination of which species, if any, are responsible for the observed damage, is the work of an experienced nematologist.

There are many variations of nematode sampling technique depending on the crop, the root depth, the type of nematode causing the damage, and the time of the season. The procedure presented here is a generic sampling technique for annual crops. When testing for the presence of nematodes it is best to take soil samples in the late summer. Root-zone soil samples are best taken immediately after harvest, or just prior to harvest if the crop showed signs of damage. First, fields should be divided into 20-acre blocks that have similar damage, soil texture, or cropping history. Then from each block take several sub-samples, mixing them well to create a single one-quart sample for each block. Soil samples should be kept cool, but not frozen.

Samples for established perennial crops are best taken from the feeder root zone, which is usually located around the canopy drip line (1). Your county or state Cooperative Extension Service can provide names of commercial labs that have nematode-identification services.

Preventing Further Spread of Nematodes

Preventing nematodes from entering uninfested areas is important; under their own steam they can spread across a field at a rate of 3 feet per year. The following measures will help prevent human-assisted spread of nematodes to uninfested fields:

- Using certified planting material
- Using soilless growing media in greenhouses
- Cleaning soil from equipment before moving between fields
- Keeping excess irrigation water in a holding pond so that any nematodes present can settle out, pumping water from near the surface of the pond, and planning irrigation to minimize the amount of excess water
- Preventing or reducing animal movement from infested to uninfested fields
- Composting manure to kill any nematodes that might be present, before applying it to fields (8)
- Eliminating important weed hosts such as crabgrass, ragweed, and cocklebur (2)

Managing Soil Biology

The basis of sustainable nematode control is the maintenance of a healthy soil food-web. This begins with routine application of organic matter. There is substantial evidence that the addition of organic matter in the form of compost or manure will decrease nematode pest populations and associated damage to crops (9, 10). This could be a result of improved soil structure and fertility, alteration of the level of plant resistance, release of nemato-toxins, or increased populations of fungal and bacterial parasites and other nematode-antagonistic agents (11). Higher organic-matter content increases soil's water-holding capacity, and supports thriving communities of the decomposers and predators that make up the soil's "digestive system."

Nematodes are important participants in this underground energy-transfer system. They consume living plant material, fungi, bacteria, mites, insects, and each other, and are themselves consumed in turn. Some fungi, for example, capture nematodes with traps, sticky knobs, and other specialized structures (1). Nematodes and protozoa regulate mineralization processes. Evidence suggests that between 30 and 50 percent of the nitrogen present in crop plants was made available by the activity of bacteria-consuming nematodes (4). Research in Denmark has indicated that nematodes convert about as much energy as earthworms in certain forest soils (1). Don't forget, the vast majority of nematodes found in the soil are not plant parasites.

The food-web's stability is challenged by the yearly turning of the soil, which reduces the numbers of organisms that displace or prey on plant-parasitic nematodes, while bringing more nematodes to the surface from deeper soil. If the same host crop is planted year after year, plant-parasitic nematodes may increase to damaging levels. Root-feeding nematodes are very opportunistic, and are among the first organisms to invade after a disturbance (1, 4). Keeping these facts in mind, it is important to actively manage soil biology using minimum-tillage practices, compost, animal manures, green manures, cover crops, and crop rotations. These practices help promote the growth of beneficial organisms while suppressing plant parasites. Certain organisms that are associated with well-managed crop soils—e.g., *Rhizobacteria* and mycorrhizae—may induce systemic host resistance to nematodes and to some foliar diseases (12) . For further information see the ATTRA publication *Sustainable Management of Soil-borne Plant Diseases*.

Soil amendments for nematode control. Some sources of organic matter known to be nematode-suppressive include oilcakes, sawdust, sugarcane bagasse, bone meal, horn meal, compost, and certain green manures.

Most nematode species can be significantly reduced by tilling in chitinous materials such as crushed shells of crustaceans (shrimp, crab, etc.). This is effective because several species of fungi that "feed" on chitin also attack chitin-containing nematode eggs and nematodes. Increasing the amount of chitin in the soil will also increase the population of these fungi. A shrimp-shell-based fertilizer called Eco Poly 21™ Micro shrimp fertilizer is available from Peaceful Valley Farm Supply (13). At 2002 catalog prices, it would cost between $87 and $216 to treat an acre with this product (the suggested application rate is 20 to 50 lbs. per acre). Clandosan™, a nematicide made of crab shells and agricultural-grade urea, can be used as a *pre-plant* treatment (it should not be used *on plants* because the amount of urea in it can "burn" or kill them) (14).

Crop Rotations and Cover Crops

Crop rotation to a non-host crop is often adequate by itself to prevent nematode populations from reaching economically damaging levels. However, it is necessary to positively identify the species of nematode in order to know what plants are its host(s) and non-hosts. A general rule of thumb is to rotate to crops that are not related to each other. For example, rotating from pumpkin to cucumbers would probably not be effective for keeping nematode populations down, as these plants are closely related. A pumpkin/bell pepper rotation might be more effective. Even better is a rotation from a broadleaf to a grass. Asparagus, corn, onions, garlic, small grains, Cahaba white vetch, and Nova vetch are good rotation crops for reducing root-knot nematode populations. Crotalaria, velvet bean, and grasses like rye are usually resistant to root-knot nematodes (2, 15). Rotations like these will not only help prevent nematode populations from reaching economic levels, they will also help control plant diseases and insect pests.

Allelochemicals are plant-produced compounds (other than food compounds) that affect the behavior of other organisms in the plant's environment. For example, sudangrass (and sorghum) contain a chemical, dhurrin, that degrades into hydrogen cyanide, which is a powerful nematicide (16, 17, 18) . Some cover crops have exhibited nematode-suppressive characteristics equivalent to aldicarb, a synthetic chemical pesticide (19).

Nematodes and pH. Cyst nematodes do not hatch well in very acid soils (pH 4) or alkaline soils (pH 8). They do best in soil with a near-neutral pH of 6. This can be used to some advantage. For example, potatoes may be safest from nematode damage in an acid soil, while cabbage and beets can be planted in alkaline soil. But most plants do best at the pH that favors nematodes (2).

Researchers have observed that brassicas (e.g., rapeseed, mustard) have a nematode-supressive effect that benefits the following crop in a rotation. This "mustard effect" seems to be triggered by nematicidal compounds released from the decomposing brassica residues. Dr. Jack Brown (20), a plant breeder at the University of Idaho, identified several such compounds in brassicas, including a class of chemicals called *glucosinolates*. Toxicity is attributed not to the intact glucosinolates, but to by-products released by enzymatic degradation; they don't directly kill nematodes, but rather interfere with their reproductive cycles. These breakdown products are similar to the synthetic chemical fumigant VAPAM®. They also include the compounds responsible for the pungent flavors and odors of brassica crops such as mustard and horseradish (21). Dr. Brown has been breeding brassica lines that contain high levels of glucosinolates. One rapeseed variety from this breeding program, called 'Humus,' is now commercially available from Peaceful Valley Farm Supply (13).

Allelopathic cover crops. Other plants that suppress nematodes through chemical residues, especially when grown as cover crops and tilled into the soil, include castor beans, chrysanthemums, and sesame(22, 23, 24, 25, 26, 27).

Here are some examples of how other brassica crops are being used to manage nematodes:

- The use of oil radish as a green manure has dramatically reduced stubby root nematode (*Trichodorus*) and root lesion nematode (*Pratylenchus*) in Idaho potato fields (28).
- When oil radish is used as a "trap crop" for the sugarbeet cyst nematode, its roots exude chemicals that stimulate hatching of nematode eggs. The larvae that emerge are unable to develop into reproductive females—reducing the population densities for the following crop (29).
- Plantings of rape or mustard in rotation with strawberries have checked the increase of some nematodes (21).
- Rapeseed and sudangrass green manures grown prior to potatoes at Prosser, Washington, provided 72 and 86% control of the root-knot nematode in potatoes (30). In the same study, on-farm research in western Idaho showed that rapeseed green manures decreased soil populations of root-lesion nematodes to a greater extent than did sudangrass green manures. Fall sudangrass should be plowed down after it is stressed (i.e., the first frost, stopping irrigation). Winter rapeseed and canola should be incorporated in very early spring (31).

The best rotation for controlling the Columbia root-knot nematode in potatoes involves planting a summer non-host crop, followed by a winter cover crop (rapeseed) incorporated as a green manure. Non-host crops include supersweet corn (Crisp and Sweet 710/711), pepper, lima bean, turnip, cowpea, muskmelon, watermelon, squash, rapeseed, canola, mustard, and sudangrass (Trudan 8, Sordan 79) (32).

Marigold is another (non-brassica) crop that acts as a nematicide. Apparently, nematodes are attracted to marigold roots, but when the nematode attacks, the root releases ozone, killing the nematode. Planting just a few marigolds will not be effective. To get the full benefit, a cover crop of marigolds, free of weeds, must be planted for a full season (33).

Tomatoes planted two weeks after African marigolds (*Tagetes minuta*) were disked into the soil showed a 99% reduction in root-lesion nematode damage compared to a tomato–tomato or fallow–tomato rotation (34). French marigold (*Tagetes patula*) is reportedly the most effective type in lowering *root-knot* nematode populations. The most effective cultivars are those that germinate quickly, grow vigorously, and have deep root penetration. The cultivar Single Gold provided 99% control in Dutch tests (33). This variety is sold by Burpee (35) under the name 'Nema-gone,' and ½ ounce of seed (enough for 1,000 square feet) costs $8.

Seed companies are researching open-pollinated varieties that can be grown as a short-rotation (40–50 days) cover crop for nematode suppression. A few seed companies sell limited quantities of marigold seeds at wholesale prices. However, sorghum, sudangrass, rape, and mustard seed are commonly available from agricultural seed dealers at considerably cheaper prices, and are perhaps just as effective.

Allies from the prairie. In Ontario, certain prairie species have been found to provide excellent nematode control when used as a cover crop, including black-eyed susan, gaillardia, and switchgrass, according to Dr. Marvin Pritts of Cornell University (36).

There is tremendous variability among cover-crop species in their susceptibility to or suppression of the four major races of plant-parasitic nematodes. Cover crops that suppress root-knot nematodes may be susceptible to sting nematodes, for example. It is important to identify the nematode species in the field—and know what their plant hosts and antagonists are—before planning a cover-cropping strategy.

Fields that are left fallow but kept weed-free for one to two years usually have an 80 to 90% per-year reduction in root-knot populations (3). This host-free period can be achieved in one season, rather than two years, by disking every ten days all summer. Such disking, however, while having the added advantage of reducing perennial weeds, is expensive in terms of fuel costs, possible erosion, and loss of organic matter through oxidation (4).

Botanical Nematicides

Certain plants are able to kill or repel pests, disrupt their lifecycle, or discourage them from feeding. Some of these—marigolds, sesame, castorbean, and various brassicas—have just been discussed as nematode-suppressive cover crops. In this section we will look at plants whose extracts or essential oils can be applied as nematicides.

For hundreds of years, Indian farmers have used the neem tree (*Azadirachta indica*) for its pesticidal, antifungal, and antifeedant properties. In research trials, potting soil amended with plant parts from the neem tree and Chinaberry tree (*Melia azadirach*) inhibited root-knot nematode development on tomatoes (37). There are, however, no neem products registered in the U.S. for use against nematodes. Margosan-O™, Azatin™, Superneem 4.5™, Neemix™, and Triact™ are neem products registered as insecticides, fungicides, and miticides. Neem cake, made from crushed neem seeds, provides nitrogen in a slow-release form in addition to protecting plants against parasitic nematodes. It can be mixed with fertilizers such as composted manures, seaweed, and kelp. Recommended rates are 180–360 lbs./acre or 2 lbs./100–160 sq. ft. (38). Neem cake is toxic to plant-parasitic nematodes and not as detrimental to beneficial free-living soil organisms (39).

Essential oils from various plants have shown promise as potential sources for new nematicides. Most of these plants are aromatic and culinary herbs that contain the nematicidal compounds carvacrol and thymol. At very low concentrations (1000 micrograms/liter, or .001 gm/liter) several oils immobilized juvenile root-knot nematodes and some also reduced hatching of eggs. The essential oils from the following plants ranked the highest for nematicidal activity: caraway, fennel, applemint, spearmint, Syrian oregano, and oregano(40).

A Mediterranean plant known as rock fleabane (*Inula viscose*) has also exhibited nematicidal properties. Leaf powder at a concentration of 0.1% in sand reduced second-stage juveniles of root-knot nematode (*Meloidogyne javanica*), which, along with the citrus nematode (*Tylenchulus semipenetrans*) was most affected by the treatment. Other species tested, such as the stem-bulb nematode (*Ditylenchus dipsaci*) , were unaffected (41).

Biocontrols

Several microbial pathogens are effective against nematodes. These include the bacteria *Pasteuria penetrans* (formerly known as *Bacillus penetrans*), *Bacillus thuringiensis* (available in insecticidal formulations) and *Burkholderia cepacia.* Nematicidal fungi include *Trichoderma harzianum, Hirsutella rhossiliensis, Hirsutella minnesotensis, Verticillium chlamydosporum, Arthrobotrys dactyloides* and *Paceilomyces lilacinus*). Another fungus, *Myrothecium verrucaria*, found to be highly effective in the control of nematodes (42), is available in a commercial formulation, DiTera™, from Abbott Laboratories (43). Circle One, Inc. offers a combination of several beneficial fungi in a nematode-control product called Prosper-Nema™ (44). Market VI offers the bacterium *Burkholderia cepacia* in a product called Deny™. Rincon-Vitova has a product called Activate™ whose active ingredient is the bacterium *Bacillus chitinosporus* (45).

The insect-attacking nematode *Steinernema riobravis* can provide root-knot nematode control comparable to that achieved with chemical nematicides (46). Although the exact mechanisms of control are not known, researchers hypothesize that there is an allelochemical involved (perhaps manufactured by symbiotic bacteria that live within *S. riobravis*) that repels plant-parasitic nematodes. Those interested in using this biocontrol will need to experiment with application rates and techniques to develop methods best suited to their operations.

A soil-dwelling predatory mite, *Hypoaspis miles,* preys primarily on fungus-gnat larvae but will also attack spring tails, thrips, and nematodes (47). These mites are available commercially for the control of fungus gnats in greenhouse production of tomatoes, peppers, cucumbers, flowers, and foliage plants. The mites are applied to the planting media.

It is clear that there is a wide range of organisms that feed on, kill, or repel nematodes. These organisms are most effective, and are found most commonly, in healthy, well-managed soils.

Plant Resistance

Generally speaking, growing resistant cultivars is more effective against sedentary endoparasitic species such as root-knot and cyst nematodes than against "grazing" ectoparasitic species. Root-knot and cyst nematodes spend most of their lifecycle within the root, relying on specialized cells for feeding. After entering the roots of resistant cultivars, these nematodes become trapped when the feeding cells necessary for their survival fail to develop.

Many crop cultivars—tomatoes and soybeans in particular—have been specificallybred for nematode resistance. The "N" designation on tomato seed packages (usually as part of "VFN") refers to nematode resistance. A few cultivars of potatoes are resistant to the golden nematode, which is a pest only in a small area of the northeastern U.S. Although most cultivars of potatoes are susceptible to infection by nematodes, some varieties tolerate infection better than others. For example, population densities of root-lesion nematodes (*Pratylenchus penetrans*) that would affect yield in 'Superior' are tolerated with little effect by 'Russet Burbank' (48). Dr. Richard L. Fery, a geneticist at USDA's Agricultural Research Service in Charleston, South Carolina, developed two nematode-resistant varieties of bell pepper, 'Charleston Belle' and 'Carolina Wonder,' available from commercial seed companies (49). Nematode-tolerant cultivars of beans and sweet potatoes also exist.

The choice of nematode-resistant rootstock for perennial fruit production is important to ensure protection of your trees and vines against these unseen pests. Make sure to consult with the local farm advisor to confirm that the rootstock you choose is appropriate for the area.

Breeding for nematode resistance in most crops is complicated by the ability of the nematode species (primarily cyst nematodes and root- knot nematodes) to develop races or biotypes that overcome the resistance factors of the crop. In order to maintain resistant crop cultivars on farms, researchers suggest that susceptible and resistant cultivars be planted in rotation. When a nematode-resistant cultivar is planted, nematode populations generally decrease, but over the course of the growing season the few nematodes in a particular population capable of overcoming this resistance begin to increase. If in the following season the farmer plants a susceptible cultivar, overall nematode numbers will still be low enough to avoid significant yield reduction, but more importantly, the selective pressure favoring the increase of the "counter-resistant" biotypes is removed. As long as the farmer continues to alternate susceptible and resistant cultivars (and, better yet, incorporate non-host crops into the rotation), the nematodes can be kept at non-damaging levels.

Table 1
Nematode-resistant rootstock for perennial fruit

Fruit	Rootstock
Apple	No commonly used rootstock is completely resistant (50)
Pears	Bartlett, Quince (slight resistance) (50)
Asian Pear	Calleryana (51)
Citrus	*Poncirus trifoliate*, lime, rough lemon, sour orange (52)
Grapes	Freedom, Harmony, Dog Ridge, Ramsey (53)
Peach & Nectarines	Nemaguard, Nemared, Citation, Hansen 536 (54)
Plums	Myrobalan 29-C, Marianna 2624 (54)
Apricots & Almonds	Nemaguard, Nemared, Myrobalan, Marianna 2624 (54)
Cherries	Mazzard, Mahaleb (54)

Transgenic crop resistance to nematodes and other pests is being developed for numerous crops by various companies worldwide. The use of genetically modified organisms is not accepted in organic production systems. For more information on this subject see the ATTRA publication *Genetic Engineering of Crop Plants*.

Red Plastic Mulch

Springtime field tests at the Agricultural Research Service in Florence, South Carolina indicated that red plastic mulch suppresses root-knot nematode damage in tomatoes. According to Michael Kasperbauer (55), one of the researchers, "The red mulch reflects wavelengths of light that cause the plant to keep more growth above ground, which results in greater yield. Meanwhile, the plant is putting less energy into its root system—the very food the nematodes feed on. So reflection from the red mulch, in effect, tugs food away from the nematodes that are trying to draw nutrients from the roots." The research team planted tomatoes in sterilized soil, mulched them with red or black plastic, and inoculated the roots with nematodes. Plants that were inoculated with 200,000 nematode eggs and mulched with black plastic produced 8 pounds of tomatoes, while those mulched with red plastic produced 17 pounds (56). The red mulch is available commercially from Ken-Bar, Inc., of Reading, Massachusetts (57).

Solarization

Soil solarization, a method of pasteurization, can effectively suppress most species of nematode. However, it is consistently effective only where summers are predictably sunny and warm. The basic technique entails laying clear plastic over tilled, moistened soil for approximately six to eight weeks. Solar heat is trapped by the plastic, raising the soil temperature. The incorporation of poultry litter prior to solarization, or use of a second layer of clear plastic, can reduce effective solarization time to 30 days (58, 59). Brassica residues are also known to increase the solarization effect, in a process known as biofumigation. The plastic holds in the gaseous breakdown products of the brassica crop (or food processing wastes), thereby increasing the fumigation-like effect (60). Large-scale field experiments using cabbage residues with solarization obtained results comparable to solarization combined with methyl bromide (61).

Solarization is well documented as an appropriate technology for control of soil-borne pathogens and nematodes, but the economics of purchasing and applying plastic restrict its use to high-value crops. Further information on solarization is available from ATTRA on request.

Steaming the soil suppresses nematodes in a manner similar to solarization. There are prototype steam machines capable of performing field applications, but steaming is probably economical only for greenhouse operations or small plantings of high-value crops (62). For more information on steaming, contact ATTRA.

Flooding

In certain parts of the country (e.g., Tule Lake in California) where water is usually available and water pumping equipment and dikes already exist, and for certain large-scale monocultures (e.g., potatoes), flooding is sometimes used as a management tool for nematode control, but for most farms it is probably not an option. Flooding the soil for seven to nine months kills nematodes by reducing the amount of oxygen available for respiration and increasing concentrations of naturally occurring substances—such as organic acids, methane, and hydrogen sulfide—that are toxic to nematodes (48). However, it may take two years to kill all the nematode egg masses (2). Flooding works best if both soil and air temperatures remain warm. An alternative to continuous flooding is several cycles of flooding (minimum two weeks) alternating with drying and disking (48). But note that insufficient or poorly managed flooding can make matters worse, as water is also an excellent means of nematode dispersal.

Summary

Each combination of nematode and host is different. When nematode population density reaches a certain level, host crop yields will suffer. Some hosts support faster population increases than others. Environmental conditions can also affect the relative dangers posed by nematode populations (1). As we begin to develop a better understanding of the complex ecologies of soils and agricultural ecosystems, more strategies for cultural and biological control of nematodes will be developed. The trick will be fine-tuning these general strategies to the unique ecology, equipment, and financial situation of each farm.

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Warminster, PA 18077
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North Chicago, IL 60064
(800) 323-9597

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16209 Flight Path Drive
Brooksville, FL 34609
(352) 544-0202
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Further Resources

Web Sites:

Nematode Management in Commercial Vegetable Production
<http://edis.ifas.ufl.edu/NG004>

Part of the Florida Agricultural Information Retrieval System (FAIRS). Although it is site-specific to Florida, this website provides information about managing nematodes using sustainable practices (such as crop rotation and soil management) as well as crop-specific information, although control options are chemically based for the most part. Adobe Reader can be downloaded in order to view full documents.

Methyl Bromide Alternatives On-Line Newsletter
<http://www.ars.usda.gov/is/np/mba/mebrhp.htm>

A USDA web site that features full-length articles and research summaries on methyl bromide alternatives such as steam, solarization, cover crops, and biological controls. Selected articles from this site:

Biologically Controlling Soilborne Pests: A Research Overview
<http://www.ars.usda.gov/is/np/mba/jan97/soilpest.htm>

Soil Amendments Instead of Methyl Bromide?
<http://www.ars.usda.gov/is/np/mba/jan97/amend.htm>

Effect of Soil Solarization & Cover Crops on Soilborne Pests & Plant Pathogens
<http://www.ars.usda.gov/is/np/mba/oct96/soil.htm>

Use of Hot Water for Nematode Control: A Research Summary
<http://www.ars.usda.gov/is/np/mba/april96/noling.htm>

DiTera: Controlling Nematodes Biologically
<http://www.ars.usda.gov/is/np/mba/jan97/ditera.htm>

Southern Root-knot Nematode Resistant Bell Peppers
<http://www.ars.usda.gov/is/np/mba/july1997/pepper.htm>

Summary of 1995-96 Large-Scale Field Demonstration/Validation Plots for Soil Solarization (Tomatoes)
<http://www.ars.usda.gov/is/np/mba/april97/techrpt.htm>

Selected Extension Publications (contact your local extension agents for materials available in your region):

Jardine, D. J. and T.C. Todd. 1990. The Sting Nematode. Publication L-817. Cooperative Extension Service, Kansas State University. 4 p. <http://www.oznet.ksu.edu/library/plant2/L817.pdf>.

Describes what the sting nematode is, symp toms, sampling, and control.

Todd, T. and D. Jardine. 1993. Nematodes: Management Guidelines for Kansas Crops. Publication MF-1063. Cooperative Extension Service, Kansas State University. 8 p. <http://www.oznet.ksu.edu/library/plant2/samplers/MF1063.asp>.

Discusses tolerance limits and economic thresholds, sampling for nematode assay, management methods, and various types of nematode: sting, lesion, lance, cyst, and root-knot.

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Grau, C.R. and R.L. Norgren. 1990. The Soybean Cyst Nematode. Publication A3092. Cooperative Extension Service, University of Wisconsin. 2 p. <http://www1.uwex.edu/ces/pubs/new.cfm?currentdate={d '2000-01-04'} - 270.7KB>.

Describes life cycle, host range, how it spreads, symptoms, and control.

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Kerr, E.D. and D.S. Wysong. 1984. Nebguide—Root and Soil Analyses for Nematodes in Corn. Publication G84-702. Cooperative Extension Service, University of Nebraska-Lincoln. 2 p. <http://www.ianr.unl.edu/pubs/plantdisease/g702.htm>.

Describes how to interpret lab results of soil samples submitted for nematode analysis, and discusses ten species that are potentially damaging to corn.

Wysong, D.S. and E.D. Kerr. 1980. Nebguide—How to Take a Soil Sample for Corn Nematode Assay. Publication G80-492. Cooperative Extension Service, University of Nebraska-Lincoln. 2 p. <http://www.ianr.unl.edu/pubs/plantdisease/g492.htm>.

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105 Ag. Comm. Bldg.
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Wrather, J. A. and D. Albers. 1992. Cotton Disease and Nematode Management. Publication G-4261. Cooperative Extension Service, University of Missouri. 4 p. <http://muextension.missouri.edu/xplor/agguides/crops/g04261.htm>.

Presents management methods for control. Includes a table with cotton diseases, cause, symptoms, and control.

University of Missouri
Extension Publications
2800 Maguire
Columbia MO 65211-0001
(800) 292-0969
extpubs@muccmail.missouri.edu

Bird, G.W. and F. Warner. 1990. Detecting and Avoiding Nematode Problems. Publication E-2199. Cooperative Extension Service, Michigan State University. 6 p.

Provides instructions for the detection methods necessary to avoid or diagnose nematode problems.

Michigan State University
Bulletin Office
10-B Ag. Hall
East Lansing MI 48824-1039
(517) 355-0240
bulletin@msuces.canr.msu.edu

Anon. 1997. Scouting for Corn Nematodes. Publication IPM-53S. Cooperative Extension Service, Iowa State University. 1 p. <http://www.extension.iastate.edu/Publications/IPM53S.pdf>.

Helps distinguish root damage between herbicide injury and nematode feeding, and helps to diagnose a corn nematode infestation.

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The electronic versionof **Alternative Nematode Control** is located at:
HTML
http://www.attra.ncat.org/attra-pub/nematode.html
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http://www.attra.ncat.org/attra-pub/PDF/nematode.pdf

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