NEMATODES

Integrated Pest Management in the Garden and Landscape

Nematodes are microscopic, eel-like roundworms. The most troublesome species in the garden are those that live and feed within plant roots most of their lives and those that live freely in the soil and feed on plant roots. Although there are many different species of root-feeding nematodes in California, the most important in gardens are the root knot nematodes (*Meloidogyne* species). Root knot nematodes attack a wide range of plants, including many common vegetables, fruit trees, and ornamentals. They are difficult to control and can be spread easily from garden to garden in soil (for example, on tools, boots, etc.) and plant parts. A number of other nematode species may also damage home garden and landscape plants, including the citrus nematode (*Tylenchulus semipenetrans*), the ring nematode (*Criconemoides xenoplax*), root lesion nematodes (*Pratylenchus* spp.), the stem and bulb nematode (*Ditylenchus dipsaci*), the sugarbeet cyst nematode (*Heterodera schachtii*), and others. Table 1 lists some common garden plant species and their nematode pests.

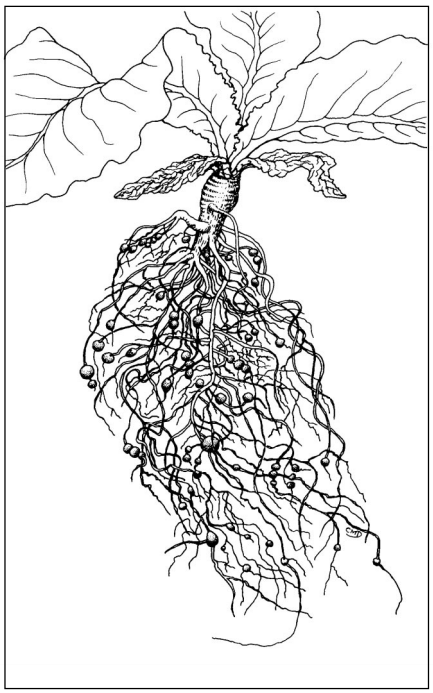

Figure 2. Root galls caused by root knot nematode.

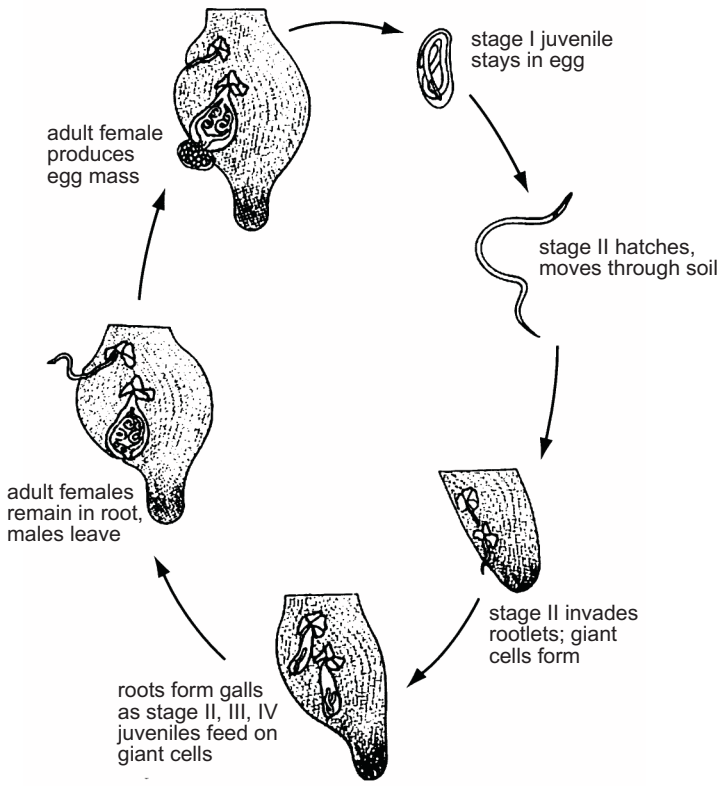

Figure 1. Life cycle of a root knot nematode.

LIFE CYCLE

Plant-feeding nematodes go through six stages: an egg stage, four immature stages, and an adult stage (Fig. 1). Many species can develop from egg to egg-laying adult in as little as 21 to 28 days during the warm summer months. Immature stages and adult males are long, slender worms. The mature adult females of some species, such as root knot nematode, change to a swollen, pearlike shape, whereas females of other species such as lesion nematode remain slender worms.

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Table 1. Landscape, Fruit, Nut, and Vegetable Plants Known or Suspected of Being Damaged by Nematodes in California.

Host plant	Nematodes[1]
Landscape plants	
albezia	root knot
alder	root knot
azalea	stunt
boxwood	root knot
cactus	root knot, cyst
catalpa	root knot
cedar	root knot, pinewood
euonymus	root knot
fir	dagger
ginkgo	root knot
hibiscus	root knot
hydrangea	root knot
juniper	root knot
larch	pinewood
lilac	citrus
mulberry	root knot
oak	root knot
palm	root knot
pine	pinewood
pittosporum	root knot
poinsettia	root knot
rose	root knot, root lesion
spruce	pinewood
tamarisk	root knot
Grapes and small fruits	
grape	root knot[2], root lesion, ring, citrus, dagger, stubby root
blackberry, raspberry	root lesion, dagger
strawberry	root knot, root lesion, foliar
Fruit and nut trees	
almond	root knot[3], root lesion, ring
apple	root knot, root lesion
apricot	root knot[4], root lesion[4], ring
avocado	root lesion
cherry	root lesion
citrus	root lesion, citrus
olive	root lesion, citrus
peach, nectarine	root knot[3], root lesion, ring
pear	root lesion
plum, prune	root lesion, ring, pin
walnut	root knot, root lesion
Vegetables	
beans	root knot[5], root lesion
beets	root knot, cyst
carrots	root knot
celery	root knot
cole crops	root knot, cyst
corn	root lesion
cucumbers	root knot
eggplant	root knot
lettuce	root knot
melons	root knot
onions, garlic	stem and bulb
peas	root knot, root lesion, cyst
peppers	root knot
potatoes (Irish)	root knot, root lesion
potatoes (sweet)	root knot
radish	root knot, cyst
spinach	root knot, cyst
squash	root knot
tomatoes	root knot[6]
turnips	root knot, cyst

1 Most varieties susceptible to at least one species of the nematode.
2 Harmony and Freedom grape rootstocks are resistant to root knot nematodes.
3 Nemaguard and Nemared peach rootstocks are resistant to root knot nematodes.
4 Royal Blenheim rootstock is resistant to root knot and root lesion nematodes.
5 Some blackeye, lima, and snap bean varieties are resistant to *Meloidogyne incognita*, a species of root knot nematode.
6 Tomato varieties designated N are resistant to most root knot nematode species.

Nematodes are too small to be seen without the aid of a microscope.

It is believed that root knot nematode survives from season to season primarily as an egg in the soil. After the eggs hatch, the second stage juveniles invade roots, usually at root tips, causing some of the root cells to enlarge where the nematodes feed and develop. The male nematodes eventually leave the roots, but the females remain embedded within roots, where they lay their eggs into a jellylike mass that extends out through the root surface and into the soil.

DAMAGE

Root knot nematodes usually cause distinctive swellings, called galls, on the roots of affected plants (Fig. 2). Infestations of these nematodes are fairly easy to recognize by digging up a few plants with symptoms, washing or gently tapping the soil from the roots, and examining the roots for galls. The nematodes feed and develop within the galls, which may grow to as large as 1 inch in diameter on some plants but are usually much smaller. The water- and nutrient-conducting abilities of the roots are damaged by the formation of the galls. Galls may crack or split open, especially on the roots of vegetable plants, allowing the entry of soil-borne, disease-causing microorganisms.

Root knot nematode galls are true swellings and cannot be rubbed off the roots, as can the beneficial nitrogen-fixing nodules on the roots of legumes. Root knot nematodes may feed on the roots of grasses and certain legumes without causing galling.

Aboveground symptoms of a root knot nematode infestation include wilting, loss of vigor, yellowing, and other

symptoms similar to a lack of water or nutrients. Infested vegetable plants grow more slowly than neighboring healthy plants, beginning in early to midseason. Plants often wilt during the hottest part of the day, even with adequate soil moisture, and leaves may turn yellow. Fewer and smaller leaves and fruits are produced, and plants heavily infested early in the season may die. Damage is most serious in warm, irrigated, sandy soils.

Root injury caused by other nematode species may produce aboveground symptoms similar to those caused by root knot nematodes. However, the actual injury to the roots is more difficult to detect. Roots may be shortened or deformed with no other clues as to the source of the injury. You can confirm a nematode infestation by collecting soil and root samples and sending the material to a laboratory for positive identification of the infesting species.

While annual plants may be killed by nematodes, woody plants are rarely killed. Nematode injury to woody plants is usually less obvious and often more difficult to diagnose. Infested fruit and nut trees may have reduced growth and yields. Woody landscape plants that are heavily infested may have reduced growth and branch tip dieback and may defoliate earlier than normal.

MANAGEMENT

Management of nematodes is difficult. The most reliable practices are preventive, including sanitation and choice of plant varieties. Existing infestations can be reduced through fallowing, crop rotation, or soil solarization. However, these methods reduce nematodes primarily in the top foot or so of the soil, so are effective only for about a year. They are suitable primarily for annual plants or to help young woody plants establish. Once an area or crop is infested, try to minimize damage by adjusting planting and harvesting dates and irrigation or by the use of soil amendments.

Sanitation

Nematodes are usually introduced into new areas with infested soil or plants. Prevent nematodes from entering your garden by using only nematode-free plants purchased from reliable nurseries. To prevent the spread of nematodes, avoid moving plants and soil from infested parts of the garden. Do not allow irrigation water from around infested plants to run off, as this spreads nematodes. Nematodes may be present in soil attached to tools and equipment used elsewhere, so clean tools thoroughly before using them in your garden.

Resistant or Tolerant Varieties and Rootstocks

One of the best ways to manage nematodes is to use vegetable varieties and fruit tree rootstocks that are resistant to nematode injury. Tomato varieties with VFN after their name are resistant to most root knot nematodes, as are 'Nemaguard' rootstock used for stone fruit and almond trees and 'Harmony' and 'Freedom' rootstock used for grapes. Citrus trees growing on 'Troyer' and 'Trifoliate' rootstocks are resistant to the citrus nematode. Consider replacing severely infested plants with plant species and varieties that are more tolerant of the nematodes present. Unfortunately, resistant varieties are not available for many crops and ornamentals.

Fallow/Rotation

Growing a crop on which the nematode pest cannot reproduce is a good way to control some nematodes. For example, the sugarbeet cyst nematode (*Heterodera schachtii*) attacks only a limited number of crops, including cole crops (broccoli, Brussels sprouts, cabbage, cauliflower) and related crops and weeds. Growing nonsusceptible crops for 3 to 5 years reduces the sugarbeet cyst nematode population to a level where susceptible crops may be grown again. Unfortunately, rotation is not as easy for controlling root knot nematodes because so many vegetable crops and weeds are hosts of the pest. However, with careful planning, rotation in combination with fallowing and solarization can reduce root knot nematode numbers. Annual crops that are useful in a rotation plan for reducing root knot nematode populations include small grains such as wheat and barley, sudangrass, and resistant tomato and bean varieties.

Fallowing is the practice of leaving the soil bare for a period of time. Fallowing for 1 year will lower root knot nematode populations enough to successfully grow a susceptible annual crop. Two years of fallow will lower nematode numbers even further. When fallowing, it is important to keep the soil moist to induce egg hatch and to control weeds on which nematodes may survive. As a result, eggs will hatch but the nematodes will die if there is nothing to feed on.

Fallowing will have to be repeated when you begin to see root injury again, as nematodes can build up to damaging levels even in a single season. A good way to conduct a fallowing program is to split the garden into thirds and fallow one-third every year or two on a rotating basis. If you intend to grow woody plants in a nematode-infested area, consider fallowing the soil for 4 years before planting.

Table 2 gives an example of a rotation/fallow plan that would be useful for root knot nematode control.

Soil Solarization

Solarization can be used to temporarily reduce nematode populations in the top 12 inches of soil to allow the production of shallow-rooted annual crops and to help young woody plants become established before nematode populations increase. However, solarization will not provide long-term protection for fruit trees, vines, and woody ornamental plants. For effective solarization, moisten the soil and then cover it with a clear plastic tarp. The tarp must be left in place for 4 to 6 weeks during the hottest part of summer.

Table 2. Example of a Rotation Plan for a Root Knot Nematode-infested Garden[1]

	1st winter	1st summer	2nd winter	2nd summer	3rd winter	3rd summer
Section A	fallow	fallow	fallow	plant summer-susceptible crop	plant winter/ spring crop	plant summer-resistant crop
Section B	plant winter/ spring crop	summer solarize	plant winter/ spring crop	plant summer-susceptible crop	fallow	summer solarize
Section C	plant winter/ spring crop	amend soil, plant summer-susceptible crop	fallow	fallow	fallow	fallow or plant summer-resistant crop

[1]Garden is divided into three sections: A, B, and C.

Root knot nematodes, including eggs, are readily killed when soil temperature exceeds 125°F for 30 minutes or 130°F for 5 minutes. The effectiveness of solarization is reduced in cool coastal areas, where summer temperatures commonly remain below 80°F. For a complete discussion of solarization, see *Soil Solarization* listed in "References."

Planting and Harvesting Dates

Most nematode species are active during the warm summer months and cannot penetrate roots at soil temperatures below 64°F. Therefore, you can reduce nematode injury to fall-planted crops such as carrots, lettuce, spinach, and peas by waiting until soil temperatures have dropped below 64°F. Plant summer vegetables as early as possible in spring before nematodes become active. Plants with larger root systems, even though nematode-infested, may be able to remain productive longer. It is also helpful to remove annual vegetables (including their roots) as soon as harvest is over, to prevent nematodes from feeding and breeding on root systems.

Nematode-suppressive Plants

Certain marigolds (*Tagetes*) suppress root knot and lesion nematodes. French marigolds (varieties include 'Nemagold,' 'Petite Blanc,' 'Queen Sophia,' and 'Tangerine') are most effective. Signet marigolds (*Tagetes signata* or *tennifolia*) should be avoided because nematodes will feed and reproduce on these. Marigolds do not work well against the northern root knot nematode (*Meloidogyne hapla*), a species common in areas with cool winters. The effect of marigolds is greatest when they are grown as a solid planting for an entire season. When grown along with annual vegetables or under trees or vines (intercropping), nematode control is usually not very good. To prevent marigold seed from getting in the soil, cut or mow the plants before the flowers open. As with other cultural control methods, nematode populations will rapidly increase as soon as susceptible crops are grown.

Soil Amendments and Irrigation

Various organic amendments can be added to the soil to reduce the impact of nematodes on crop plants. The amendments, which include peat, manure, and composts, are useful for increasing the water- and nutrient-holding capacity of the soil, especially sandy soils. Because plants that are water-stressed are more readily damaged by nematodes, increasing the soil's capacity to hold water can lessen the effects of nematode injury. Likewise, more frequent irrigation can help reduce the damage caused by nematodes. In either case, there will be just as many nematodes in the soil, but they will cause less damage.

Pesticides

There are currently no chemical nematicides or soil fumigants available to home gardeners for nematode control in backyard gardens and home landscapes.

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