Diseases Caused by Nematodes

English walnut is attacked by dagger, ring, root-knot, and root-lesion nematodes. Symptoms caused by nematode feeding and the biology and management of these nematodes are described in Part I, Diseases and Disorders Affecting Several Nut Crops.

Disorders of Uncertain Cause

Brown Apical Necrosis

Brown apical necrosis was first observed in Italy in 1998 and was later reported in France. Major losses have occurred in the cultivar Lara, with up to 30% of the fruit affected.

The first symptoms are brown spots (2–15 mm diameter) on the hull at the stigma insertion. The infection progresses inward and rots the entire inner fruit, causing it to drop (Plate 187).

The cause is uncertain but seems to involve invasion of stylar tissue by fungi through small walnut blight lesions. Several *Fusarium* spp., mainly *F. semitectum* Berk. & Ravenel var. *majus* Wollenweb., *F. culmorum* (Wm. G. Sm.) Sacc., *F. equiseti* (Corda) Sacc., *F. sporotrichioides* Sherb., are most commonly found in infected tissues. *Alternaria* spp. and *Cladosporium* spp. are occasionally present.

Multiple applications of copper and a dithiocarbamate or a demethylation inhibitor fungicide, starting at budbreak, control brown apical necrosis.

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Belisario, A., Forti, E., Santori, A., Corazza, L., Balmas, V., and Valier, A. 2001. Fusarium necrosis on Persian (English) walnut fruit. Acta Hortic. 544:389–393.

(Prepared by A. Belisario)

Stem Canker

Stem canker has been reported once, in South Africa. In affected trees, cankers girdle and kill twigs and young branches, causing dieback. The infection was associated with freeze injury. Symptoms were reproduced by inoculation of young plants with *Fusarium solani* (Mart.) Sacc. Nothing is known about the epidemiology or control of the disease.

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(Prepared by W. J. Swart)

Noninfectious Disorders

Apoplexy

Apoplexy is a rare disorder of unknown etiology, characterized by sudden midsummer wilting and collapse of mature trees. Tree collapse generally proceeds outward from localized points in affected orchards. Leaves of affected trees wilt, turn yellow and then brown, and mostly abscise within 5–20 days of the onset of symptoms. Fruit shrivel and mostly remain attached to the tree. The upper branches and lower scaffolds usually die, and vigorous adventitious shoots often arise later from the trunk and lower scaffold branches. Depending on the extent of damage, the tree canopy can be reestablished from this regrowth.

The disorder appears limited to orchards established on coarse to medium-textured soils. It is believed that cultivars do not differ in susceptibility. Apoplexy is more common in orchards propagated on black walnut than in orchards on other rootstocks, perhaps because of the greater population of trees on black walnut rootstocks in older orchards. Empirical and experimental attempts to link walnut apoplexy to biotic causes, soil moisture status, nutrient applications, and nutrient defi-

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(Prepared by J. A. Grant, W. H. Olson, and G. S. Sibbett)

Cold Injury and Heat Injury

See Part I, Diseases and Disorders Affecting Several Nut Crops.

Mesophyll Collapse

In some years and locations, areas of spotty interveinal necrosis develop in leaflets of some English walnut cultivars as they expand in early spring (Plate 188). The disorder is most common in early-leafing cultivars, such as Serr. It is thought to result from exposure of [illegible] nization of wounds by the pathogen and thus blocks gall formation. To be effective, it must be applied within a few hours of wounding. Not all strains of the crown gall pathogen are sensitive to K84. Strain K1026, a genetically engineered strain derived from K84, has provided protection for nut trees equal to or better than that given by K84.

Bactericides that contain copper, sodium hypochlorite, or streptomycin are ineffective as preplant dips or sprays, as are methyl bromide, metam-sodium, and formaldehyde as soil treatments. Surgical removal of galls from walnut and almond in the orchard followed by treatment with a mixture of 2,4-xylenol and metacresol has given mixed results.

Among walnut rootstocks, Paradox hybrid is more susceptible than northern California black walnut and English walnut. Peach and peach–almond hybrid are more susceptible than the plum rootstocks used in almond culture.

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(Prepared by L. W. Moore)

Diseases Caused by Nematodes

Plant-parasitic nematodes in more than 20 genera have been associated with nut crops (Table 3). In many cases no attempt has been made to demonstrate pathogenicity. Some of these nematodes may have been feeding on grasses or weeds around tree roots rather than the tree roots themselves. Only a few nematodes have been confirmed to be pathogenic to nut crops. The most injurious are dagger nematodes (*Xiphinema* spp.), ring nematodes (*Mesocriconema* spp.), root-knot nematodes (*Meloidogyne* spp.), and root-lesion nematodes (*Pratylenchus* spp.) (Fig. 4). Any nematode found in high numbers in an orchard with problems having no discernible cause should be suspected.

Nematodes are nonsegmented, microscopic, aquatic roundworms living in various habitats, including soil, fresh and salt water, plants, and vertebrate and invertebrate animals. Some feed on weeds, insects, or decaying plants and are considered beneficial. Those that parasitize and damage nut trees are less than 0.25 cm long and live either in soil or within roots. The nematode body is covered with a transparent external cuticle, through which the digestive tract and reproductive system can be seen. Plant-parasitic nematodes have a stylet through which they feed. A typical nematode life cycle consists of the egg stage followed by four gradually enlarging juvenile stages and finally the adult stage. The cuticle is shed between each stage. Adult females commonly lay several hundred to a thousand eggs apiece. The length of a single generation varies from a few weeks to more than a year, depending on the species, soil temperature, and other factors. Population levels in the soil and within roots fluctuate throughout the year.

Plant-parasitic nematodes are categorized as migratory or sedentary and as endo- or ectoparasitic. Migratory nematodes are motile in their juvenile and adult stages. Sedentary parasites are infective during a juvenile stage and establish permanent feeding sites within roots, where they progress to the adult stage. Ectoparasites complete their life cycle in the soil and are either migratory or sedentary as adults. Endoparasites can also be migratory or sedentary, but they spend a significant portion of their lives feeding and laying eggs within roots.

Control measures designed to reduce nematode populations are active only in soil and are more effective against ecto-

TABLE 3. Nematodes Associated with Nut Trees

Nematode genus	Almond	Chestnut	Hazelnut	Pecan	Pistachio	Walnut
Cacopaurus	...	...	...	...	...	×
Gracilacus	...	...	...	...	...	×
Helicotylenchus	×	...	...	×	...	×
Hemicriconemoides	...	...	...	...	...	×
Hemicycliophora	...	×	...	...	...	×
Heterodera	×	...	...	...	×	×
Longidorus	...	...	...	...	...	×
Meloidogyne	×	×	×	×	×	×
Merlinius	×	×	...	...	×	×
Mesocriconema	×	...	...	×	...	×
Ogma	×	...	...	...	...	...
Paralongidorus	...	...	×	...	...	...
Paratrichodorus	×	...	...	...	...	×
Paratylenchus	×	×	×	×	...	×
Pratylenchus	×	×	×	×	×	×
Radopholus	...	...	...	×	...	...
Rotylenchulus	...	...	...	...	×	...
Rotylenchus	×	×	...	...	...	...
Scutellonema	...	...	...	...	...	×
Trichodorus	×	...	...	×	...	×
Tylenchorhynchus	×	...	...	×	...	×
Tylolaimophorus	...	...	...	...	...	×
Xiphinema	×	...	×	×	×	×

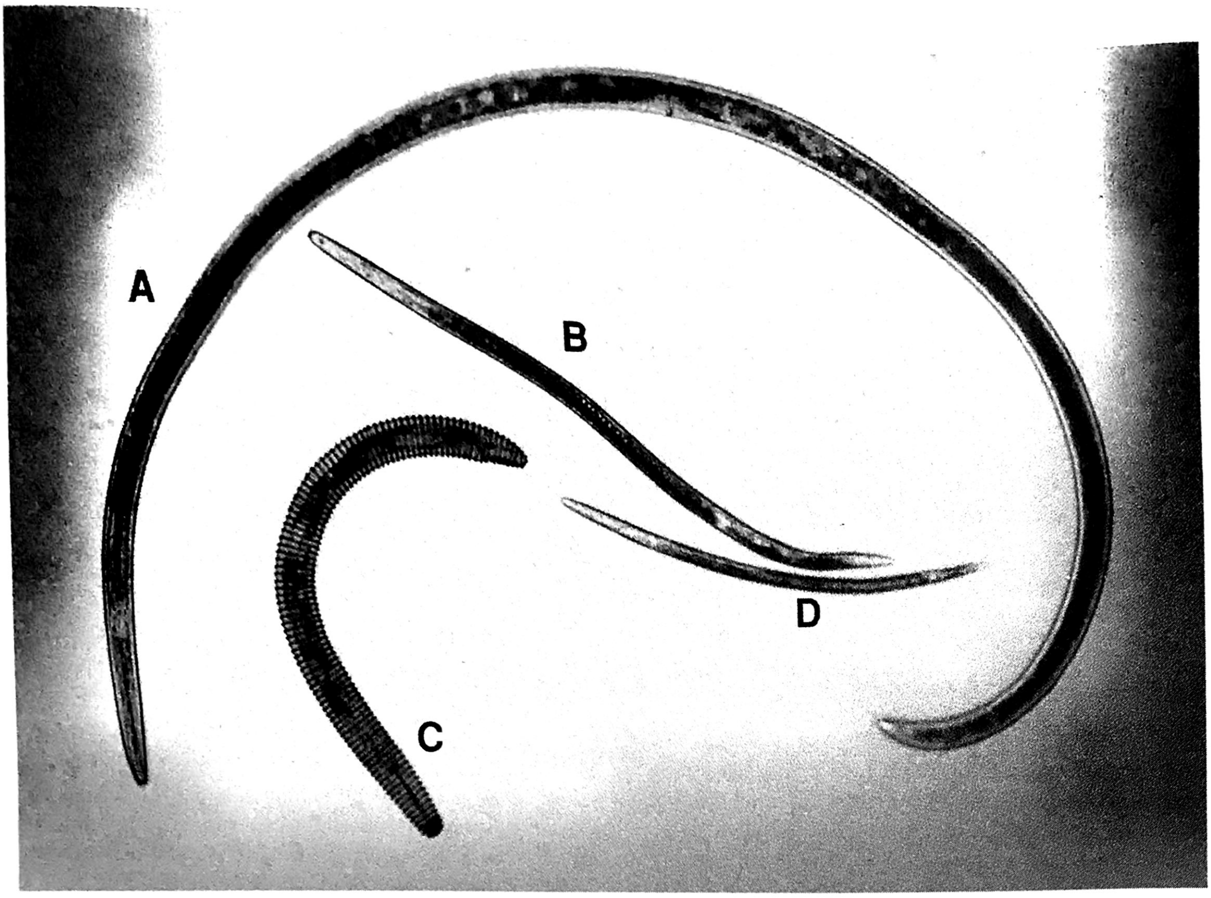

Fig. 4. **A,** Dagger nematode (*Xiphinema* sp.). **B,** Root-lesion nematode (*Pratylenchus* sp.). **C,** Ring nematode (*Mesocriconema* sp.). **D,** Root-knot nematode (*Meloidogyne* sp.). (Courtesy S. R. Kaku)

parasites than endoparasites. Successful treatment to control nematodes in endoparasitic stages requires multiple applications of nematicides or the use of systemic nematicides or nematode parasites that penetrate roots and actively seek out nematodes.

Nematodes do not kill trees, but they stress plants and act in conjunction with other stress factors in orchards to reduce growth and yields. Because these symptoms are not diagnostic and could result from other causes, soil and root samples should be examined whenever tree vigor seems limited without apparent cause. Nematode damage is usually most evident in coarse-textured sandy soils. In addition to limiting plant growth and yield, nematodes are involved in important disease complexes, including bacterial canker and almond brown line.

Nematode management requires several approaches. Orchards should be planted with trees certified to be free of nematodes. Where a certification program is not available, root samples from potential planting stock should be analyzed for nematodes.

Clean trees should be planted in soil that has not been planted with woody crops or has been planted with annual crops for several years. Cleaning soil from equipment before moving it between orchards helps minimize the introduction of nematodes. Annual monitoring of soil populations in fall and winter is helpful in establishing a successful nematode management program. Sampling is best performed soon after irrigation or rain, when populations of nematodes of most genera are usually highest and most stable.

Plants are susceptible, resistant, or immune to nematodes. Susceptible plants support nematodes for the full life cycle of the pathogen, resistant plants may allow nematode feeding but not reproduction, and immune plants resist feeding and reproduction. No rootstocks are resistant to all potential nematode pathogens, but rootstock selection is important in some situations. The length of a weed-free fallow period needed to reduce nematode populations to safe levels has not been determined for most species. Cover crops that do not support nematode reproduction should be chosen. Soils commonly contain predators and parasites of nematodes that provide some natural biological control but cannot yet be manipulated to our benefit.

Soil amendments, such as chitin, sesame chaff, animal manure, humic acid, organic fertilizer, compost, and proprietary mixtures of beneficial microbials, have not been demonstrated to improve plant growth or to aid in nematode management.

Preplant soil fumigants, such as methyl bromide and 1,3-dichloropropene, are the most effective tools in nematode management. Nematicides do not eradicate nematodes from soil but can allow as much as 6 years for the development of a healthy root system before nematode populations increase to damaging levels. Mycorrhizal fungi, which are essential to the growth of certain crops, can be killed by fumigation. A subsequent crop may not do well until these organisms are restored.

The postplant nematicide sodium tetrathiocarbonate is a liquid that releases carbon disulfide in soil and must be applied in water. It is useful against ectoparasitic nematodes. It is the only nematicide registered in the United States for postplant treatment of almond. No postplant nematicides are registered for use on other nut crops.

(Prepared by B. B. Westerdahl and M. V. McKenry)

Dagger Nematodes (*Xiphinema* spp.)

Symptoms

Dagger nematodes (*Xiphinema* spp.) in high populations occasionally injure nut crops, but their major importance is as virus vectors. Necrosis and destruction of feeder roots and the enlargement of root tips, resulting in stunted growth and reduced yields, have been reported in several crops. Damage levels and the presence or absence of galls are species-dependent responses. *X. diversicaudatum* often produces galls, but *X. americanum* usually does not.

Causal Organisms

Dagger nematodes are named for their long, prominent stylets. Four species, including *X. americanum* Cobb and *X. diversicaudatum* (Micoletzky) Thorne, have been associated with nut trees. Nematodes in the *X. americanum* group are the most important and most widespread. They have been found in almond, pecan, pistachio, and walnut orchards. Among the nut crops, almond is most at risk, because dagger nematodes transmit *Tomato ringspot virus,* the cause of almond brown line. The prevalence of *X. americanum* in walnut orchards depends mostly on the presence of overwintering grasses.

Life Cycle and Epidemiology

X. americanum is a migratory ectoparasite requiring as much as a year to complete a single generation. Individuals may live 4 or 5 years. Viruses are contracted when nematodes feed on virus-infected plants but are not retained after molting or passed from the female to the egg. Feeding by a single viruliferous nematode is sufficient for transmission.

Control

Preplant fumigants provide the most consistent control, but the proper choice of a planting site and use of certified planting stock are equally important. Dagger nematodes survive well on grasses and weeds, which may also harbor *Tomato ringspot virus,* and therefore crop rotation is not feasible as a means of control.

All almond, pistachio, and pecan rootstocks are thought to be hosts of *X. americanum.* Pistachio is a very good host, whereas walnut is a poor host.

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(Prepared by B. B. Westerdahl and M. V. McKenry)

Ring Nematodes (*Mesocriconema* spp.)

Symptoms

Ring nematodes damage feeder roots of almond, pecan, and walnut and thereby reduce yields. Almond trees in orchards infested with ring nematodes are at increased risk of bacterial canker. If soil, irrigation, and host conditions are not conducive to bacterial canker, the trees may lack vigor, and some buds may not break in spring. Trees more than 10 years old may only exhibit dieback in the tops and reduced vigor. The usual uneven distribution of nematodes is reflected in irregularly shaped patches of trees lacking vigor.

Causal Organisms

Ring nematodes (*Mesocriconema* spp.) have prominent striations, or rings, on the cuticle. Four species have been associated with walnut, two with almond, and one with pecan. Only *M. xenoplax* (Raski) Loof & de Grisse infects all three and has been studied extensively.

Life Cycle and Epidemiology

Mesocriconema spp. are sedentary ectoparasites whose feeding produces elaborate cellular modifications. They feed for up to 8 days at a single location, passing through several molts in the process. The optimum temperature range for reproduction is 22–26°C. Completion of the life cycle requires approximately 443 degree-days (with 9°C as the base temperature), so that a single generation lives for 30 days at 24°C and 40 days at 20°C.

Control

The selection of planting sites and cover crops, survival of nematodes on roots of a previous crop, and choice of certified planting stock are important management considerations. All *Prunus* spp. and walnut rootstocks are susceptible. Among peach rootstocks, Nemaguard is more susceptible than Lovell to the ring nematode–bacterial canker complex.

Preplant fumigants, such as methyl bromide and 1,3-dichloropropene, have generally provided the most consistent control. Follow-up postplant protection is required at sites with serious bacterial canker. Sodium tetrathiocarbonate is registered for postplant use on almond in the United States.

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(Prepared by B. B. Westerdahl and M. V. McKenry)

Root-Knot Nematodes (*Meloidogyne* spp.)

Symptoms

Root-knot nematodes (*Meloidogyne* spp.) are named for the galls, or knots, formed where they feed on infected roots. The galls are 3–10 mm in diameter and occur anywhere along roots. Larger galls, 1–10 cm in diameter, occasionally develop on English walnut. The penetration of plant tissues by root-knot nematodes and their movement through tissues results in minimal mechanical injury and necrosis of cells. The primary damage is a limited development of the root system, which leads to lack of vigor, small leaves, chlorosis, dieback of twigs, and yield reduction.

Causal Organisms

M. incognita (Kofoid & White) Chitwood, *M. javanica* (Trueb) Chitwood, *M. arenaria* (Neal) Chitwood, and *M. hapla* Chitwood are the root-knot nematodes found most frequently on nut trees. *M. partityla* Kleynhans has also been found on pecan and black walnut.

Identification of species of root-knot nematodes has traditionally been accomplished by morphological examination, sometimes together with host range testing. More recently, biochemical and molecular techniques have been developed for the identification of some species.

Life Cycle and Epidemiology

Root-knot nematodes are sedentary endoparasites. Second-stage juveniles enter roots just behind the root tip, establish permanent feeding sites, and then develop into either adult females, which remain immobile inside the roots, or adult males, which exit from the roots. Root cells around the head of the female enlarge and form a syncytium, the feeding site. The female deposits several to more than 1,000 eggs, in a gelatinous matrix exuded from the posterior of the body. A generation is completed in 4–8 weeks under optimal conditions at 18–29°C, and as many as seven or eight generations can be produced in a year, in some regions. *M. incognita, M. javanica,* and *M. hapla* require approximately 600 degree-days (with base temperatures of 5–12°C) per generation. The minimum temperature for reproduction of *M. incognita* is 10°C; for *M. hapla,* it is 6°C. The minimum temperature for infection by *M. incognita* is 18°C; for *M. hapla,* it is 6°C. The egg is the usual important survival stage following an annual crop, but root-knot nematodes survive on roots or tubers until they rot.

Control

Common root-knot nematodes damage English walnut, some Paradox hybrid, and approximately 10% of northern California black walnut rootstocks.

The almond rootstocks Nemaguard peach, almond–Nemaguard hybrids, and Marianna 2624 plum are resistant or immune to most common root-knot nematodes.

Pistacia atlantica, P. terebinthus, and *P. integerrima* are resistant or poor hosts. *P. vera* is susceptible, but it is seldom used as a rootstock.

A 1-year period of weed-free fallow reduces populations of root-knot nematode juveniles by 80–95%. Population reduction in excess of 98% is essential unless a resistant rootstock is used. Preplant soil fumigation is the most effective technique for achieving this level of reduction.

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(Prepared by B. B. Westerdahl and M. V. McKenry)

Root-Lesion Nematodes (*Pratylenchus* spp.)

Symptoms

Root-lesion nematodes are named for the dark lesions that they cause on infected roots. Characteristic dark, elongated lesions, 1 cm or more in diameter, can be seen in the inner tissue of walnut roots after the outer bark has been scraped away (Plate 29). *Prunus* roots may also display a few such lesions. Aboveground, trees show few distinctive symptoms of damage, except that infected trees may defoliate before healthy trees after an early frost. Infected trees may also be stunted and grow slowly, and dieback and chlorosis may occur in the upper branches.

Causal Organisms

Root-lesion nematodes (*Pratylenchus* spp.) are migratory endoparasites. Of the seven species causing damage to nut trees, *P. vulnus* Allen & Jensen and *P. penetrans* (Cobb) Chitwood & Oteifa have been studied the most. *P. vulnus* is often referred to as the walnut root-lesion nematode, because it is so common in walnut orchards. It is also associated with almond, pecan, and pistachio. *P. penetrans* is associated with almond, hazelnut, pecan, and walnut.

Identification of root-lesion nematodes to the level of species, based on morphological characteristics, is essential for control and requires considerable expertise.

Life Cycle and Epidemiology

Root-lesion nematodes are migratory endoparasites in the soil and root cortex. All free-living stages are infective. As roots decay, the nematodes migrate to healthier roots. *P. penetrans* and *P. vulnus* reproduce sexually and lay eggs singly in soil or the root cortex. The distribution of these two species appears to be affected by temperature, with *P. vulnus* being more prevalent in warmer areas of the world and *P. penetrans* in cooler climates. Walnut and peach are good hosts of *P. vulnus,* whereas several pistachio rootstocks are poor hosts or nonhosts. Across nut-growing regions of the world, several to seven or eight generations of lesion nematodes can be produced each year.

Control

Detection of a single pathogenic lesion nematode in a preplant soil sample is cause for concern in walnut orchards in California. Preplant fumigation is the most effective control. Nonchemical measures, such as crop rotation and the use of resistant cultivars, have generally not been feasible for the control of *P. penetrans,* because of its wide host range.

A peach cross (Okinawa × Nemaguard) used as an almond rootstock has shown resistance to *P. penetrans,* but Nemaguard peach, almond–Nemaguard hybrids, Lovell peach, almond, and Marianna 2624 are susceptible to *P. vulnus. P. vulnus* juveniles have been observed hatching from Nemaguard rootstock 2 years after the roots had been killed with systemic herbicides.

All walnut rootstocks are susceptible to lesion nematodes, but trees on Paradox hybrid are sometimes more vigorous than nearby trees on black walnut, even though high nematode populations are present in the roots and surrounding soil.

Most seedlings of *Pistacia atlantica, P. terebinthus,* and *Pistacia integerrima* appear to be resistant or poor hosts of root-lesion nematodes.

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(Prepared by B. B. Westerdahl and M. V. McKenry)

Compendium of Nut Crop Diseases in Temperate Zones

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