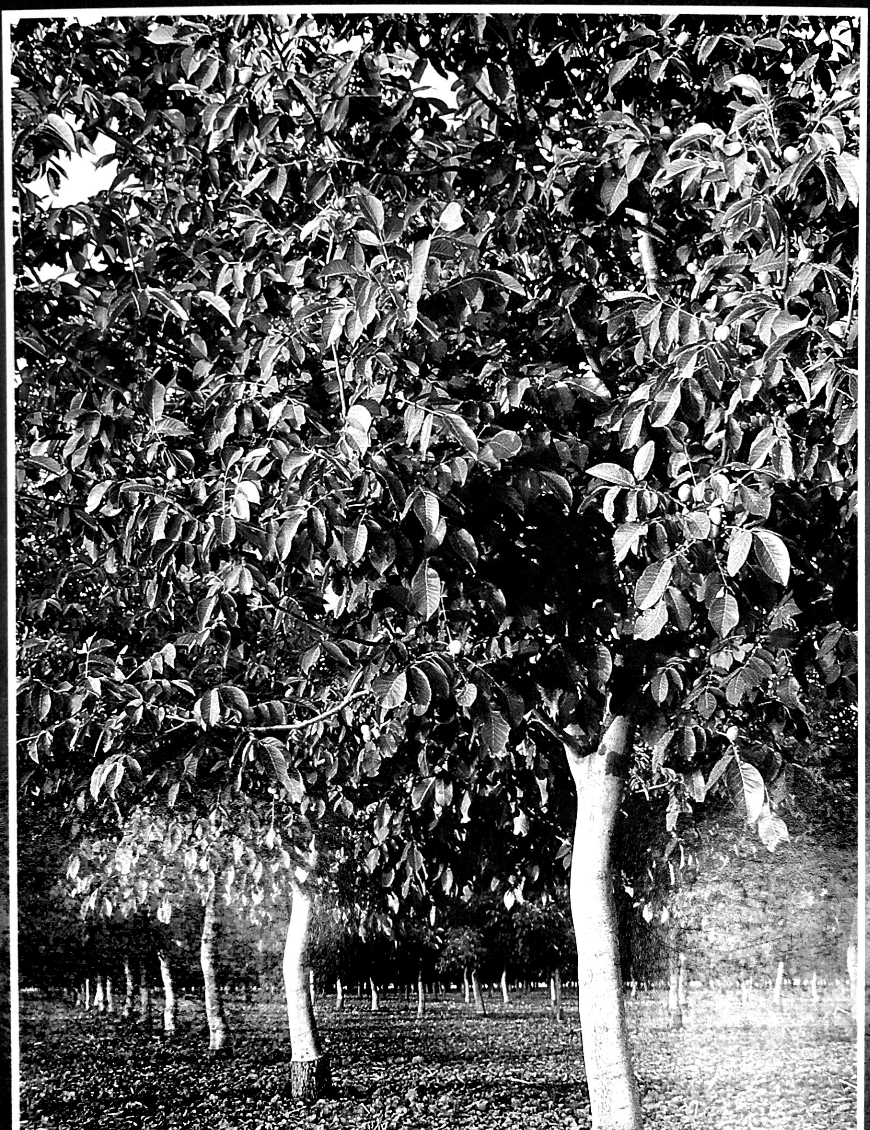
WALNUT
PRODUCTION MANUAL



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Walnut Production Manual

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Controlling Nematodes that Parasitize Roots

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Plant-parasitic nematodes, which are nonsegmented microscopic roundworms, are one of the factors that a grower should consider when planning to plant a walnut orchard. If the orchard site is not infested, the grower should be aware of techniques to prevent the introduction of harmful species. If an orchard is to be planted in a nematode-infested area, the grower should develop both pre- and postplanting management strategies.

To carry out a nematode management program requires familiarity with nematode biology and population dynamics, pathogenicity, symptoms and signs of nematode damage, sampling techniques, and the principles underlying various management techniques.

BIOLOGY AND POPULATION DYNAMICS

Nematodes are aquatic animals that live in a variety of habitats, including soil, fresh and salt water, within plants, and within vertebrate and invertebrate animals. Those living within plants and animals (such as hookworm, pinworm, dog heartworm, and ascarid worms) may become damaging if their population level gets too high. Other nematode species—such as those feeding on weeds, insects, or decaying plants—are considered beneficial to humans and the environment.

The nematodes that parasitize and damage walnuts are less than 1⁄10 inch long and are found either in soil or within roots. Within the soil, they live and move within the film of water that lines soil pore spaces. They are small enough to move between individual soil particles. It is not uncommon for a single teaspoon of soil from a walnut orchard to contain 50 nematodes or for a single inch of feeder root to contain 200.

Nematodes have a relatively simple body structure. When viewed under a microscope, the external covering, or cuticle, is transparent, permitting the viewing of major organs such as the digestive tract and reproductive system. Nematodes have a spear, or stylet, which they use to pierce and feed on plant tissues (color plate 27.1). The four most common genera of nematodes found in walnut orchards are root lesion (*Pratylenchus* spp.), ring (*Criconemella* spp.), root knot (*Meloidogyne* spp.), and dagger (*Xiphinema* spp.). Root lesion nematodes get their name from the lesions that can sometimes be found on roots in which they have been living. The root lesion nematode that attacks walnut, *P. vulnus*, has also been referred to as the walnut root lesion nematode because it is so common in walnut orchards. The common names *ring nematode* and *dagger nematode* are derived from the morphology of the nematodes. The cuticle of a ring nematode has prominent striations, or rings (color plate 27.2), and the stylet of a dagger nematode is very long and prominent (color plate 27.3). The common name *root knot nematode* is derived from the galls, or knots, visible on infested roots. These knots can become very large on some cultivars of English, or Persian, walnut.

The nematode life cycle consists of an egg stage, four gradually enlarging juvenile stages, and an adult stage. The length of a single generation varies, depending on the species, the soil temperature, and other factors. Under optimal conditions (which include temperatures of 65° to 85°F, or 18° to 29°C) the life span of one generation of root lesion, ring, or root knot nematodes is 4 to 8 weeks. In most walnut-growing areas, there can be several generations of these parasites each year. Dagger nematodes, on the other hand, may require a full year. Adult females of all these nematode genera can lay several hundred to a thousand eggs apiece.

The nematodes commonly found in walnut orchards exhibit several different life history patterns. The ring nematode is a sedentary ectoparasite whereas the dagger nematode is a migratory ectoparasite. Ectoparasites use stylets to feed on roots and pass all stages of their life cycle outside roots, in the soil. An endoparasite spends all stages of its life cycle within roots as well as in the soil. Root lesion nematodes are migratory endoparasites. Root knot nematodes are sedentary endoparasites. The second-stage juvenile of a sedentary endoparasite enters a root, takes up a permanent feeding site, and then develops into an immobile adult female within the root. The root cells around her head enlarge to form a gall, or knot. A knowledge of these life history patterns can be helpful when making management decisions. For example, some nematicides, parasites, or soil amendments can be expected to be active only in the soil and so are more effective against ectoparasites than endoparasites. Effective against endoparasites would be nematicidal agents that move systemically through roots or parasites that penetrate roots and actively seek out nematodes.

Although detailed population studies have not been conducted on the nematodes found in walnut orchards, we know from studies of other crops (such as grape, peach, and prune), that nematode population levels fluctuate predictably during the year. For example, in peach orchards, ring nematode population levels were found to be highest in February and lowest in the summer months. The reasons for these population fluctuations are not well understood.

A knowledge of nematode population dynamics is valuable to a grower contemplating a management technique expected to reduce the number of nematodes in an orchard. For example, if a grower determines the population level in winter and then again the following summer, he or she might find a population reduction whether or not any treatment had been used. A better approach is to leave some trees untreated within the orchard and then compare populations in treated and untreated areas on the same day, both before and after the application. Conversely, an application conducted in summer (when populations are typically at their lowest) and sampled in the winter (when populations should be highest) would seem ineffective unless untreated trees were available for comparison. For a variety of reasons, anyone intending to test the effectiveness of a nematode control should be prepared to take a number of soil or root samples.

PATHOGENICITY

Although a random survey of walnut orchards has not been conducted, researchers have a good idea of the most common nematodes in California orchards and of the pathogenicity of the species. A summary of 1,400 samples received by California Department of Food and Agriculture and University of California (UC) diagnostic laboratories demonstrates that six genera are common: (1) root lesion nematode (predominantly *P. vulnus*) was present in 717 samples, (2) ring nematode (predominantly *C. xenoplax*) was present in 263 samples, (3) dagger nematode (predominantly *X. americanum*) was present in 240 samples, (4) root knot nematode (*Meloidogyne* spp.) was present in 240 samples, (5) pin nematode (*Paratylenchus* spp.) was present in 84 samples, and (6) spiral nematode (*Helicotylenchus* spp.) was present in 30 samples. It is common for one orchard to contain several species.

Of the six most common nematode genera, only two or three (root lesion, ring, and root knot) are of major concern to walnut growers, and their level of concern depends on which rootstock is being considered. When discussing the merits of different plant rootstocks, it is important to understand the terminology used by nematologists. Immune plants do not allow nematode feeding. Resistant, or nonhost, plants may be invaded by nematodes and may show damage, but chemical or physical unsuitability of the plant prevents or greatly limits nematode reproduction. None of the three common walnut rootstocks (English, black, and Paradox) are immune to nematode feeding. Northern California black walnut has resistance to *Meloidogyne* species only. All other rootstocks are susceptible but have varying tolerance to nematode feeding. These susceptible, or host, plants allow normal nematode reproduction and may or may not tolerate nematode attack. Among susceptible plants, tolerant hosts are able to withstand nematode feeding and penetration; for example, all three rootstocks can withstand *X. americanum*, *Paratylenchus* and *Helicotylenchus* species. Intolerant, susceptible, hosts are damaged by nematodes; for example, *P. vulnus*, and *C. xenoplax* damage all three rootstocks and *Meloidogyne* species damage English rootstock. Environmental conditions can greatly influence the degree of tolerance. For example, Paradox hybrid seems to have more tolerance to *P. vulnus* in fine- than in coarse-textured soils. Paradox rootstocks are open-pollinated hybrids of English rootstock and black walnut. Therefore, they contain different proportions of these two parents so some hybrid rootstocks are host to root knot nematodes but others are not.

At times in root lesion nematode–infested orchards, Paradox hybrids are more vigorous than nearby black walnut trees, even though large populations of nematodes live within roots and in the soil surrounding both rootstocks. In one field experiment both rootstocks were grown in fumigated and unfumigated soil. Compared to growth in fumigated soil, growth of both rootstocks in the unfumigated, nematode-infested soil was reduced. The results demonstrated that the nematode is pathogenic to both rootstocks.

Nematodes do not typically kill trees. They are plant stressors and act in conjunction with other stress factors in orchards to reduce growth and yields. Penetration and movement by nematodes through plant tissues results in mechanical injury to cells and subsequent cell death and necrosis. Mechanical injury interrupts the uptake and flow of water and nutrients from roots and the flow of food from leaves to roots. In addition, nematodes create openings in roots through which other microorganisms can enter.

The host and pathogenicity status of root lesion, ring, dagger, root knot, pin, and spiral nematodes to walnut rootstocks have been determined in greenhouse or microplot experiments. In experiments with young black walnut rootstocks, the root lesion nematode reduced growth in the first few years by 30 to 40 percent. Once a tree has reached 10 years of age, it is difficult to improve growth with the use of nematicides, although these chemicals can greatly reduce nematode populations.

Because in field situations stress factors other than nematodes are present, precise measurements of yield and growth reduction caused by nematodes are difficult to obtain. Increases in tree growth (17–48%) and in yield (29–68%) have been demonstrated in field experiments following the application of nematicides and the subsequent reduction of lesion nematode populations. Interpreting the results of such experiments is not as straightforward as might first appear, however. The nematicides used could have affected other organisms as well, and some nematicides have been shown to stimulate the growth of plants that are not nematode-infested.

SYMPTOMS AND SIGNS OF NEMATODES

Roots of about ½-inch diameter or more, infested with either root lesion or ring nematode, may exhibit dark elongated lesions on the inner tissue after the bark has been scraped away (fig. 27.4). If roots have been infested with root knot nematode for some time, knots, or galls, may be visible on roots. Above ground, trees may appear stunted, grow more slowly than expected, or suffer unexplained dieback and chlorosis in the upper branches (fig. 27.5). If a new walnut orchard is planted on the site of a walnut orchard in which nematodes caused problems, the new orchard is highly likely to have nematode problems. None of the signs or symptoms caused by nematodes is unique to nematode damage, however.

SAMPLING FOR NEMATODES

Because nematodes cause no distinctive diagnostic symptoms or signs, send soil and root samples to a diagnostic laboratory whenever tree vigor seems limited without apparent cause. To begin the procedure, visually divide the orchard site into sampling blocks that represent differences in soil texture, drainage patterns, or cropping history. Take a separate sample from each block so that each can be managed separately. Because nematodes are usually not distributed uniformly within a field, take a series of subsamples from throughout the area to determine if nematodes are

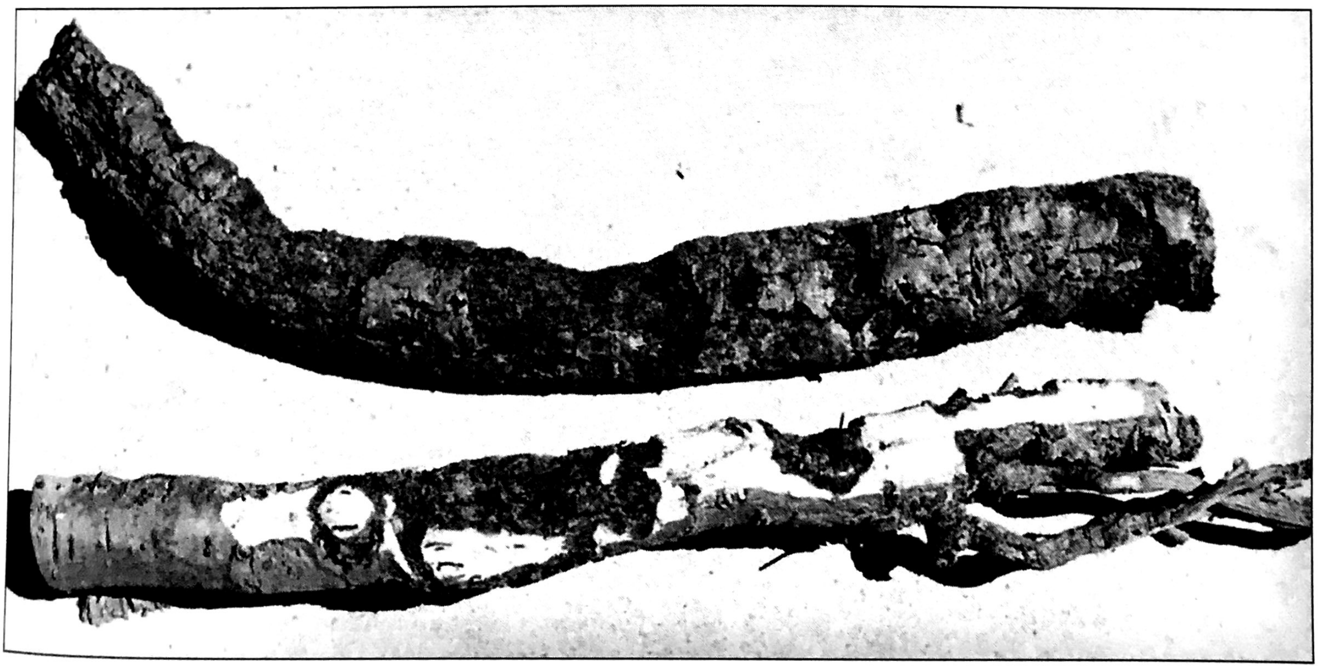

Figure 27.4 Both these roots are from a Northern California black walnut tree. The top one is unscraped; the bottom one is scraped to show damage by the root lesion nematode.

present. In a fallow field, collect subsamples from several locations within the sampling block. Be sure to sample to 3 feet deep if the field previously contained woody perennial crops. In an established orchard collect separate subsamples, for comparison, from the soil around trees that show symptoms and from the soil around adjacent, healthy-looking trees. Because nematodes feed on roots, they are more prevalent in the rooting zone of a tree and this is the area from which subsamples should be taken. Subsamples should include small-diameter roots, when possible, and be taken in frequently wetted zones at the edge of the tree canopy.

Mix the subsamples together and place about 1 quart of the mixed soil and roots into a plastic bag. Seal the bag, place a label on the outside, and keep samples cool (do not freeze them). As soon as possible, transport the samples to a diagnostic laboratory. Inform the laboratory that you want to know if the nematodes listed as pests are present so that the lab staff can use appropriate extraction techniques. Because a number of different species of root lesion nematode can be found in a sampling site and only one of them is known to be pathogenic to walnut, request a species diagnosis if root lesion nematode is found. Your local Farm Advisor can help you locate a diagnostic laboratory.

During recent years increasing emphasis has been placed on the development and use of damage thresholds in regard to management decisions about aboveground pests. For many reasons, establishing damage thresholds for nematodes is difficult. These include difficulties in obtaining representative samples, variability in extraction methods and efficiencies of different laboratories, and the many biotic and abiotic factors that influence populations. However, a routine soil-sampling program can be very helpful in establishing the need for, and the success of, a nematode management program. If the nematodes this chapter has cited as pathogens are present in an orchard with below-normal growth and yield and no other explanation of the problem can be found, it is likely that nematodes are contributing to the problem. To determine if the nematode population is increasing or remaining stable, sample an infested orchard at least once a year, at the same time each year. Also, as discussed previously, leave some trees in an orchard untreated, to establish the effectiveness of the technique with respect to nematode control and crop production.

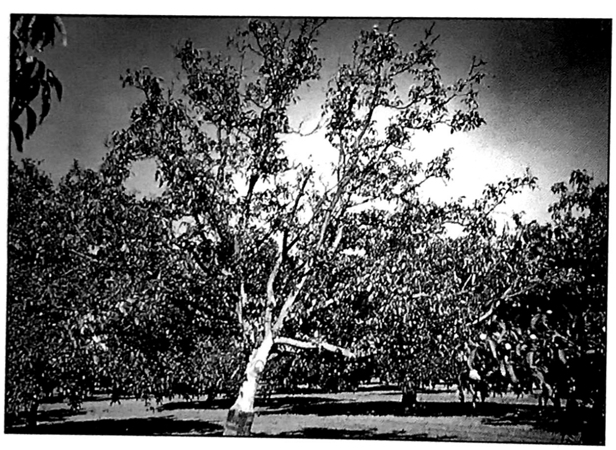

Figure 27.5 Walnut trees growing in soil infested with root lesion nematode may exhibit stunting, canopy dieback, or chlorosis.

MANAGEMENT TECHNIQUES

Select the planting site carefully. Whenever possible, plant an orchard on land that has not previously been used for woody crops or has been used for annual crops for several years. An annual crop site may contain the same nematode species as an old orchard or vineyard site, but fleshy crop roots rot more quickly than woody ones and leave nematodes unprotected in the soil.

Allow an appropriate fallow period. Until host roots from a previous crop have rotted, they could continue to support nematodes. The length of time that root lesion and ring nematodes can survive in weed-free fallow soil is unknown. Root knot nematode populations are likely to decrease by 80 to 90 percent within one year.

Choose appropriate rootstock. Buy only those rootstocks that a regulatory agency has certified free of nematodes. This minimizes the chance of contaminating previously uninfested land or of adding nematodes to soil that has been treated to reduce nematode populations prior to planting.

In addition to freedom from contamination, consider the rootstock characteristics discussed in chapter 15 and make appropriate choices. From the standpoint of nematode management alone, remember that English, black, and Paradox hybrid are all susceptible to damage by root lesion and ring nematode. English and some Paradox hybrid rootstocks are susceptible to damage by root knot nematode as well.

Clean equipment. To minimize transfer of plant-parasitic nematodes, use water to remove soil from farm equipment prior to moving it from orchard to orchard.

Irrigate with nematode-free water. Be aware that surface irrigation water has been shown to be a potential source of nematode contamination. The extent to which contaminated water is a serious threat has not been determined, however. Clearly, you should not use, to irrigate an uncontaminated orchard, runoff water from an orchard known to be infested with nematodes. If you suspect irrigation water is a serious threat, use settling ponds to remove nematodes.

Consider cover crops. Interplanting cover crops in orchards can be beneficial for a number of reasons. Cover crops can (1) reduce erosion, (2) add organic matter and nitrogen to the soil, and (3) provide protection for beneficial insects. However, cover crops may interfere with other walnut management practices. To find out how a cover crop will work in your orchard, try it on a small scale before planting it throughout. From the standpoint of nematode management, choose a cover crop that does not support nematode reproduction or is antagonistic to nematodes. As stated previously, knowing which species are present in an orchard is important. If two or more species of nematodes are present, finding a nonhost cover crop becomes more difficult than if only a single species is present. Table 27.1 summarizes current knowledge about the host status of cover crops in regard to the most common nematodes found in walnut orchards. The table shows that, if an orchard is infested with *P. vulnus*, seven of the nine cultivars listed would be good choices for cover crops. If the orchard has both *P. vulnus* and *C. xenoplax*, the choice is reduced to two.

Consider biological control. Many soils contain predators and parasites of nematodes; these may result in some level of natural biological control. There are no registered microbial nematicides.

Consider soil amendments. The addition of amendments—such as green manure, chitin, sesame chaff, animal manure, humic acid, organic fertilizer, compost, or proprietary mixtures of beneficial microbials—is generally proclaimed to be beneficial to plant growth. With respect to nematode management, such benefits may include (1) stimulation of the growth of nematophagous fungi that may be present; (2) improvements in soil structure, water retention, and plant nutrition that reduce stress on nematode-infested plants; and (3) production of nematicidal breakdown products. Because of the complex nature of the interactions that may occur following addition of a soil amendment, interpreting results is difficult. Some question remains whether an amendment that is applied no deeper than 4 inches from the surface can have any effect on nematodes, which reside 3 to 4 feet deep. If you choose an amendment with the hope of reducing the nematode population, the best way to apply it may be to dig holes several feet deep with a backhoe and mix the amendment with the soil as you refill the hole. Sufficient data are not available to pre-

Table 27.1 Host status of cover crops for common nematodes in walnut.

Cultivar	*Pratylenchus vulnus*	*Criconemella xenoplax*	*Meloidogyne hapla*	*M. incognita*	*M. javanica*	*M. arenaria*
Marigold	—	H*	H	H	H, TR†	NR‡
Sudan, SS-222	NR, A§	A	PH‖	GH**	H	H
Barley, Columbia	NR, A	H	H	PH	GH	H
Cahaba White Vetch	H, NR	H	GH	PH	H, TR	H
Salina Sweet Clover	PN††	+	H	PH	PH	NR
Moapa Alfalfa	NR	H	S‡‡	PH	PH	PH
Coker 916 Wheat	—	PN	—	—	—	—
Nova II Vetch	PN	PN	+	PN	PN	PN
Blando Bromegrass	NR	H	H	NH	H	PH

*H = host (0.5 to 25 nematodes/g root)
†TR = trap crop
‡NR = no reproduction (<0 .2 nematode/g root)
§A = plant antagonistic to nematodes
‖PH = poor host (0.2 to 0.5 nematode/g root)
**GH= good host (25+ nematodes/g root)
††PN = probable nonhost based on information from South Carolina or Georgia
‡‡S = good host with plant damage
+ = probable host based on information from South Carolina

dict with any certainty the nematode mortality or yield increase an amendment might cause. In some cases, the addition of amendments has resulted in phytotoxicity in some crops. Leaving untreated trees for comparison is the best method for judging the success or failure of soil amendments.

Consider a nematicide. At present no nematicides are registered in California for postplanting use with walnut. Methyl bromide is currently the only preplanting fumigant available that has shown consistent positive results in orchard situations. It does not eradicate nematodes from soil, but methyl bromide properly applied can allow as many as 6 years before nematode populations increase to damaging levels. During that time root systems can develop sufficiently to withstand moderate stress, including stress from nematode populations that arise. When using a nematicide, follow the manufacturer's usage recommendations in all respects. Planting too soon after application can result in phytotoxicity. Fumigating could kill mycorrhizal fungi, which are symbionts essential to the growth of certain crops. The subsequent crop may not do well until these organisms are restored.

Soil preparation is extremely important for successful use of any of the registered preplanting nematicides. Consider a nematode-infested location that used to be an orchard or vineyard and is soon to be planted to walnut. To prepare the area for fumigation takes a year. Beginning in summer or fall, remove trees or vines along with as many residual roots as possible. Destroy plant residues, deep-cultivate, and break up cultivation pans and soil layers. Next, during winter and spring, plant deep-rooted grasses (for example, sudangrass) to help dry the soil and harvest the grass in summer.

If you will be planting in a field following an annual crop, a shorter procedure can be used to prepare the area for fumigation. Plant the annual crop in spring, use it to dry the soil, and harvest it in summer. Following harvest of the grass or annual crop, level the land (if necessary), cultivate, and do other operations required for planting. Finally, in late summer or fall, rip the soil to at least 24 inches deep. If surface clods are a problem and you are in an area where light rains (less than 1 inch) occur in summer and fall, you may delay fumigation until after a light rain. The rain will help to break up surface clods.

Prior to fumigation, check the soil temperature at a depth of 1 foot and check soil moisture at 1-foot intervals to 5 feet. This is important because the amount of fumigant that should be used is based on the soil texture and temperature and the percentage of soil moisture. In general, the finer the soil texture, the more fumigant is necessary. A coarse-textured soil (containing a high percentage of sand) has large pore spaces in which the fumigant can disperse more readily than it can in a fine-textured soil, which has small pores and dries slowly. If soil temperatures are too low, the fumigant will not volatilize and move through pore spaces. If temperatures are too high, the fumigant will volatilize and dissipate too quickly. If soil moisture is too low, the fumigant will not move properly and may adsorb to soil particles. If it is too high, the water in the soil pore spaces will hinder movement. *The Phytonematology Study Guide* (UC Agriculture and Natural Resources Publication 4045) contains a chart indicating the amount of fumigant needed for various soil types and the ranges of temperatures and soil moistures over which they can be successfully fumigated.

Complete fumigation prior to November 15. After that date the increasing possibilities of heavy rainfall and low soil temperatures make fumigating inappropriate. If surface clods are not a problem, fumigate in September or October, when soils are dry. Before planting observe the waiting period stated on the fumigant label.

Although tarping is expensive, for optimal results, put a tarp over methyl bromide applications. Untarped methyl bromide applications will miss nematodes present in the top 6 inches. In fields that have been fallow for several months during hot weather before fumigation, this may not be a problem because high soil temperatures can kill the nematodes near the surface. An alternative to tarping is using a plow to turn the top 12 inches of soil and then fumigating again, after the initial fumigant has dispersed. Strip treatments and treating individual replant sites will also miss a significant number of nematodes and will result in more rapid reinfestation of the root zone than will broadcast applications.

Most nematicide failures result from failure of the chemical to reach the nematodes. In preplanting applications, this is usually due to improper land preparation or applications made outside the acceptable ranges of soil temperature and moisture.