CHAPTER 10

Nematodes

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Using cover crops to manage plant-parasitic nematodes in California vineyards is an area of research in soil ecology and agronomy that is still in its scientific infancy. Accordingly, this discussion draws heavily from the general literature on nematodes and cover crops, regardless of whether the primary crop in the study was grapes, and presents information on cover crop options for nematode management in California vineyards. As the desire for management strategies to augment or replace nematicides has grown, so have research endeavors to increase our knowledge of soil and nematode ecology. As our understanding of cover crops and their influence on nematodes increases, practices will improve and will, hopefully, increase the efficacy of this nematode management tool in vineyards.

Nematode Morphology and Habits

Nematodes are wormlike unsegmented invertebrate animals found in marine, freshwater, and terrestrial habitats (fig. 10-1). Depending on the species, nematodes may feed on a variety of organisms, including plants, other nematodes and their eggs, fungi, protozoa, bacteria, tardigrades, enchytraeids, and insect larvae (Freckman and Caswell 1985).

Nematodes are poikilothermic (cold-blooded) organisms, so their metabolic rate and physiology depend on the ambient temperature. When soils are cool, nematodes are less active. Of the known nematode species, approximately 14 percent are plant parasites, 15 percent are animal parasites, 25 percent are free-living (feeding on fungi, bacteria, or detritus), and 46 percent are marine nematodes (Ayoub 1980). Although plant-parasitic nematodes are the focus of this chapter, other soil-dwelling nematodes play important roles in soil ecology and participate in biological processes such as nutrient cycling that affect crop plants.

The typical nematode life cycle consists of six stages: egg, first-stage juvenile, second-stage juvenile, third-stage juvenile,

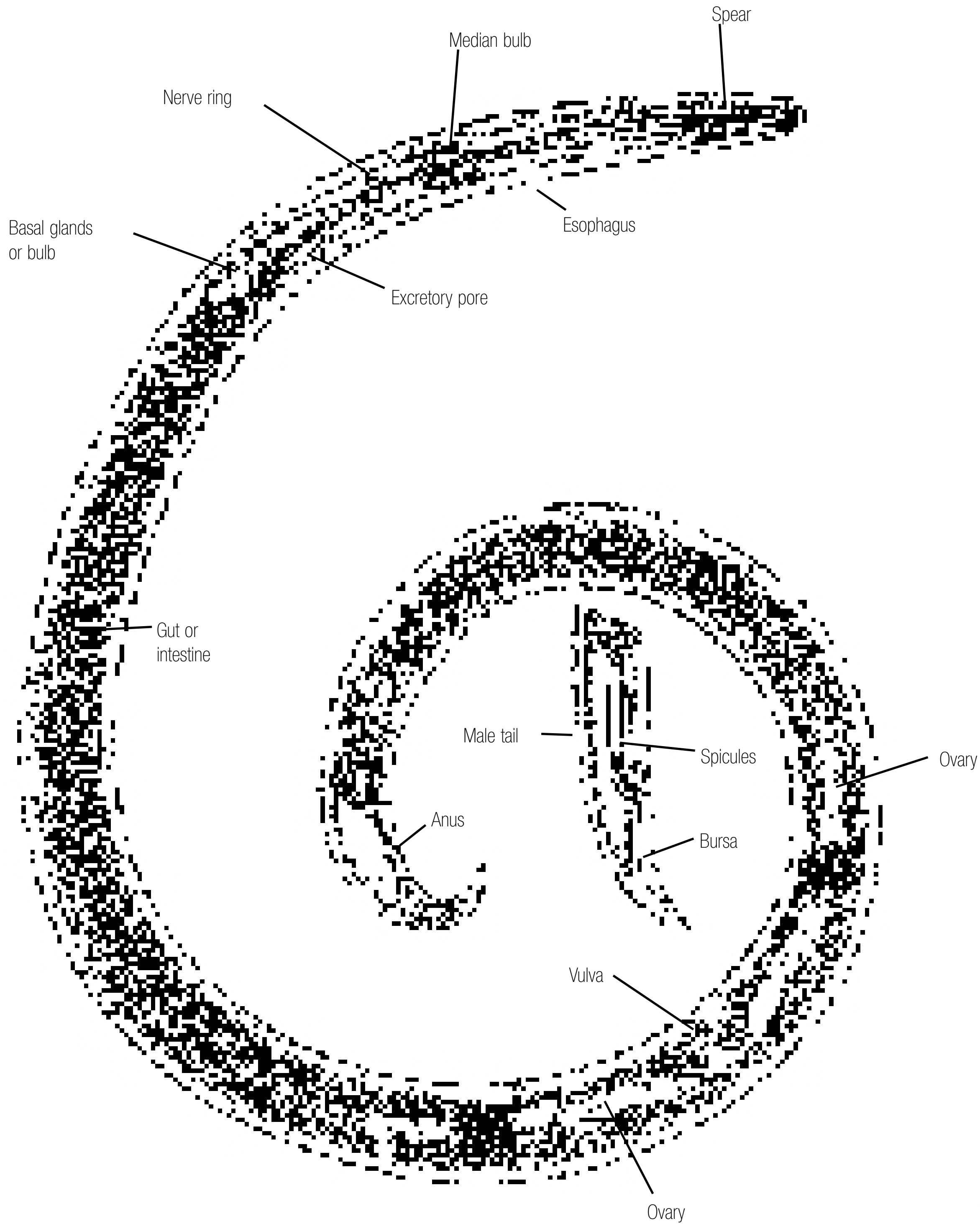

Figure 10-1. The anatomy of a typical plant-parasitic nematode. Nematodes have complete nervous, reproductive, digestive, muscular, and excretory systems. The feeding apparatus is an oral spear that is used to remove plant cell contents. *Source*: Redrawn from Radewald 1977.

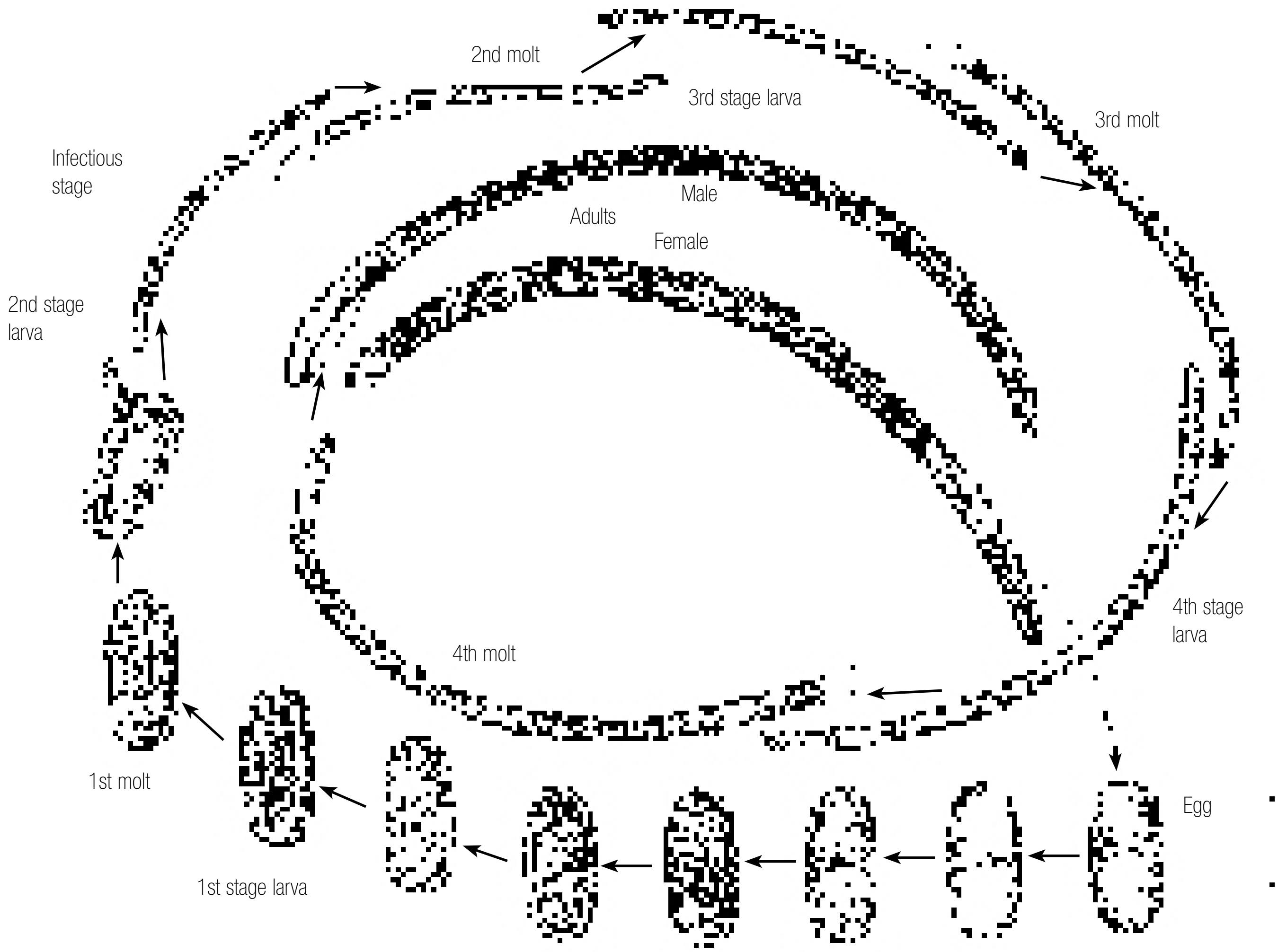

Figure 10-2. The life cycle of a typical plant-parasitic nematode. In this case the nematode remains worm shaped throughout its life. In some nematode species, such as the root knot nematodes, the adult females are swollen and pear shaped. *Source*: Redrawn from Radewald 1977.

fourth-stage juvenile, and adult (fig. 10-2). In most plant-parasitic nematodes, the second-stage juvenile leaves the egg and moves into the soil to parasitize a host plant. As the juvenile nematode feeds, it matures through the different life stages and eventually reproduces on reaching the adult stage. Individuals typically become larger as they pass through the life stages, and in some cases the adult females are swollen. The duration of a single generation (from egg to egg) can vary from a few days to more than a year, depending on the species, the soil temperature, and other factors. Adult female nematodes can lay several hundred to a thousand eggs during their life span.

A knowledge of nematode life-history patterns may 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 would be more effective against ectoparasites than endoparasites. Other nematicidal agents might move systemically through a root, or parasites might be able to penetrate roots and actively seek out nematodes, and would then be effective against endoparasites.

Although it is common for a vineyard to have more than one type of plant-parasitic nematode pres-ent, not all the species are equally likely to be present statewide. In the three major grape-growing regions in California (1, North and Central Coast; 2, San Joaquin Valley; and 3, Southern California), dagger, ring, and lesion nematodes are common in areas 1 and 2; citrus nematodes in areas 2 and 3; needle nematodes in area 3; and root knot and stubby root nematodes in all three areas.

Because there are no distinctive signs of nematode damage to vineyards that are unique to nematodes alone, nematode damage may be attributed to another problem. Above ground, plants may appear stunted, exhibit slower growth than expected, or have unexplained dieback or chlorosis.

Nematodes do not typically kill plants. They are plant stressors and act alone and in conjunction with other stress factors in vineyards to reduce growth and yields. Generally, nematode infestations occur in areas of the vineyard where vines lack vigor and have restricted growth and reduced 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, and some species are able to transmit viruses from one plant to another. All these factors increase the susceptibility of plants to environmental stress.

Plant-parasitic nematodes are frequently present in vineyards. If nematodes potentially damaging to vines are present in a field, preplant and postplant management strategies should be developed for pathogenic species. If a vineyard or a potential planting site is not infested, a grower should implement strategies to avoid introduction of harmful species to the site. In addition to factors covered in other chapters, for growers to use cover cropping effectively they should be familiar with nematode biology, how to determine if a vineyard has a nematode problem, management practices that minimize the spread of nematodes between vineyards, and how to select cover crops with respect to the nematodes present. Primary strategies to consider when choosing a cover crop for a nematode-infested vineyard are selecting cover crops based on what is known of their host status for different plant-parasitic nematodes and using and managing cover crops relative to nematodes and other pests.

Nematodes Likely to Cause Problems on Grapes in California

Many different species of plant-parasitic nematodes are capable of parasitizing grapevines, although their ability to parasitize other plant species is variable, an important point with respect to cover cropping. It is not uncommon for a single field to have several different nematode species present. Nematodes that parasitize grape show a range of parasitic habits, and they have different life histories and biology. Some of the important nematode pathogens of grapes, grouped by parasitic mode, include the following.

Ectoparasites

All stages of the ectoparasite nematode life cycle occur in the soil outside of roots.

Dagger nematodes (*Xiphinema index* and *X. americanum*). Dagger nematodes, which are relatively large, use their long stylets to feed on root tips from outside the root (Raski and Krusberg, 1984). *Xiphinema americanum*, the most common species of dagger nematode, weakens vines by feeding near the root tip and is a specific vector of yellow vein virus (also known as tomato ringspot virus). Excessive root branching is characteristic of *X. americanum* feeding. Feeding by *X. index* results in swellings or galls on root tips; *X. index* is important as a vector of grapevine fanleaf virus.

Ring nematodes (*Criconemella xenoplax*). The ring nematodes derive their name from the prominent striations or rings on their cuticle. Ring nematodes are relatively small, slow-moving ectoparasitic nematodes, and they are generally considered to cause significant damage only when they are present at very high population densities.

Needle nematodes (*Longidorus africanus*). Needle nematodes are very large ectoparasitic nematodes that have been observed in association with grapevines, though the damage they actually cause to grapevines has not been well defined.

Stubby root nematodes (*Paratrichodorus* spp.). These nematodes are small ectoparasites that feed on a range of different crops. Greenhouse experiments have revealed that this nematode can significantly reduce the growth of young Thompson Seedless vines (Hafez, Raski, and Lownsbery 1981).

Migratory Endoparasites

At least a part of the life cycle of a migratory endoparasitic nematode is spent inside host roots.

Lesion nematodes (*Pratylenchus vulnus* and *P. penetrans*). Lesion nematodes move through the root as they feed and reproduce. Their feeding and movement causes mechanical damage to roots, thus compromising general root integrity and allowing secondary invasions by fungi and bacteria.

Sedentary Endoparasites

The second-stage juveniles of sedentary endoparasitic nematodes enter a root, take up a permanent feeding site, and then develop into immobile, swollen adult females within the root.

Root knot nematodes (*Meloidogyne* spp.). Five species of root knot nematode are associated with vineyards in California: *Meloidogyne hapla* (northern root knot), *M. javanica* (Javanese root knot), *M. incognita* (southern root knot), *M. arenaria* (peanut root knot), and *M. chitwoodi* (Columbia root knot). These species have wide and variable host ranges, different temperature optimums, and different degrees of pathogenicity.

Citrus nematodes (*Tylenchulus semipenetrans*). Citrus nematodes were initially recognized as a pathogen of citrus, although they are also common on grapes in some areas of California.

Nematode Management

Before considering possible cover crops that might be used to manage nematodes in vineyards, it is important to discuss the fact that although a cover crop may be used to reduce numbers of a particular nematode, the cover may act as a host for other nematodes, pathogens, or pests. Cover crops are not, generally, biological nematicides. Effective nematode management using cover crops should be based on the integrated application of several control tactics. Manipulating the soil environment to reduce pest densities and increase plant tolerance requires recognition of the soil food web and the ecological relationships among host plants, their parasites, and other soil fauna.

Some of the interactions involving nematodes within vineyards are depicted in diagrammatic form in figure 10-3, and the use of cover crops influences these interactions. The main grapevine host and the nematode community are influenced by external inputs such as cultural practices, water, and nutrients. The diagram shows three different nematode species present (A, B, and C). The nematodes act on the vines and the cover crop, and the numbers of each nematode are affected by the vines, cover crops, weeds, biological control agents, and nematicides. Nematodes A, B, and C may react differently to the grapevines, the cover crops, and control tactics, resulting in changes in the densities of A, B, and C. For example, suppose that the most numerous nematode is A, and that it is very damaging to grapevine. Suppose that B and C are less damaging to grapevine and that they are present in low and moderate numbers, respectively. The use of a cover crop susceptible only to B will eventually change the nematode community to a structure where B may become more numerous and A and C are rare. Although B was not a problem previously, because of the cover crop it has increased to the point where it damages the grapevine. The ultimate value of using such a cover crop depends on the pathogenicity of nematode B relative to the vines. The presence of weed hosts for our nematodes may alter this scenario.

Importantly, the nematode community consists of many species, certainly more than the hypothetical A, B, and C, and all nematodes present may not be plant-parasitic nematodes. They may be bacterial or fungal-feeding nematodes, and they may be influenced by the unique bacteria associated with the roots of alternative crops.

It has been suggested that an increase in the numbers of bacterial and fungal-feeding nematodes that serve as prey for nematode-parasitizing bacteria or fungi may, in turn, stimulate an increase in natural biological control, further reducing the numbers of plant-parasitic nematodes in the community (Linford, Yap, and Oliveira 1938). Incorporation of cover crops may act to reduce nematode numbers via such a mechanism. As figure 10-3 reveals, successful nematode management requires that many ecological interactions of potential importance be considered.

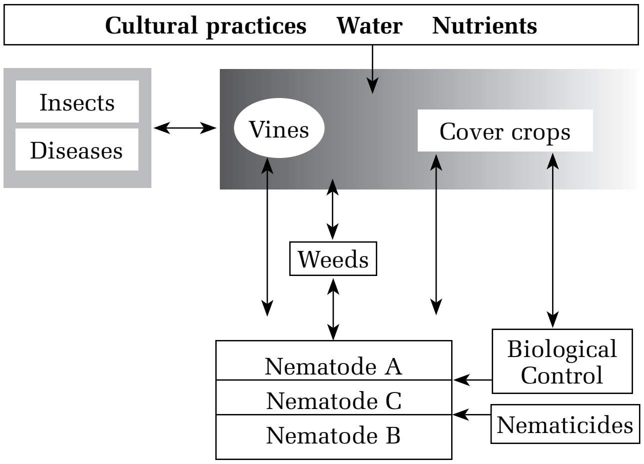

Figure 10-3. A vineyard is a system of many different interactions, and nematode management strategies may affect other aspects of the system. A particular cover crop may only influence one of the nematodes in a field, potentially allowing the others to increase to pest status. Thus, nematode management practices should consider other potential problem pests.

Nematode Genetic Variability

Geographic isolates of nematode species, which may be designated as races, pathotypes, or biotypes, differ significantly in their ability to parasitize certain plants. Thus, a cover crop that is reported to reduce numbers of a particular nematode species in one geographic location may not reduce numbers of that nematode species in another geographic location. For example, there are currently four distinct host races of *Meloidogyne incognita* as characterized by its ability to parasitize cotton, peanut, pepper, tobacco, and tomato, and the recognition of these races allows us to detect only a small fraction of the variability in host specificity that occurs among root knot nematodes (Caswell and Roberts 1987; Roberts 1995; Thomason and Caswell 1987).

Cover Crops and Nematode Management

Cover crops can provide a number of benefits in vineyards, as described in chapter 1. They can be grown during replant intervals or between vines in established vineyards. If cover crops are used as part of a nematode management program, there are several potential problems that may become evident, including competition with the grapevines and the potential of elevating a secondary nematode or insect pest to primary pest status. Therefore, cover crops should be selected with consideration of the cropping system and other potential pests that exist at a site (see fig. 10-3).

Plant-parasitic nematodes are obligate parasites and require a host plant for reproduction, thus offering opportunities to interfere with the nematode life cycle. Cover cropping specifically for the suppression of nematode populations is receiving increased attention (Reddy et al. 1986; Yeates 1987; Rodríguez-Kábana et al. 1988a). Cover crops may be grown in place for nematode control as a trap crop (Godfrey and Hoshino 1934), or for their foliage, which may be incorporated or used to obtain pesticidal extracts.

Cover crop influence on nematode life cycle. Successful reproduction by plant-parasitic nematodes is achieved only after feeding on a host plant, and in some species only after males find females and mate (fig. 10-2). The goal of nematode management is to interfere with some stage in the nematode life cycle and thereby reduce nematode reproduction. Cover crops can affect the nematode life cycle in many important ways (fig. 10-4), including:

- Acting as nonhosts and preventing nematode reproduction
- Generating root exudates that stimulate nematode hatch and activity in the absence of a host, resulting in increased nematode mortality
- Producing root exudates that attract nematodes to penetrate roots, but the roots do not support nematode development and maturation (a trap crop)
- Producing root exudates that interfere with nematode orientation to host roots or with male orientation to female nematodes
- Creating nematicidal root exudates
- Producing foliar compounds that are nematicidal when incorporated into soil
- Acting as a poor host that allows only limited nematode reproduction (fig. 10-4).

Because different cover crops may affect the nematode life cycle at a different point, it is possible that combinations of cover crops, each of which targets a different stage in the nematode life cycle, may be particularly effective.

There are many advantages to using cover crops to manage nematodes, including decreasing nemati-

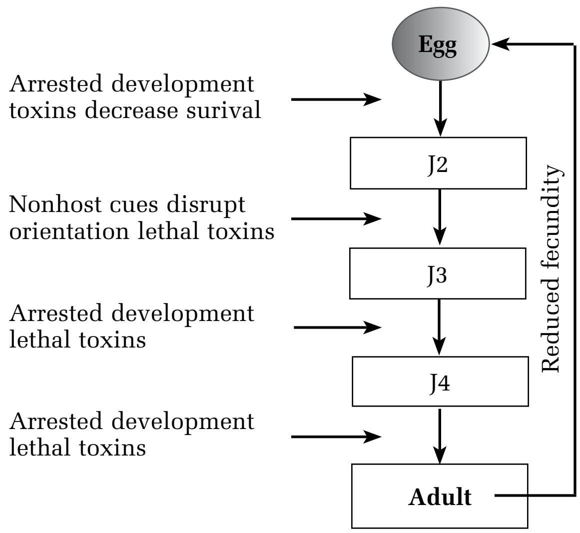

Figure 10-4. A diagrammatic representation of the life cycle of a plant-parasitic nematode (for detail of stages see fig. 10-2). Between each of the stages in the life cycle, the potential influence of cover crops on each stage are mentioned. Different cover crops may influence different stages in the life cycle.

cide use, improving soil fertility and structure, and possibly aiding in the management of other pests. Potentially negative aspects of using cover crops include the potential for elevating a secondary nematode pest to primary pest status, possible phytotoxicity to the primary crop following incorporation of the cover crop, and the potential of some cover crops to become weeds. An additional consideration is that cover crop effectiveness in reducing nematode numbers depends on nematode population densities, with many cover crops being less effective at high nematode densities (Reddy et al. 1986)

Research addressing the influence of cover crops on nematodes is often limited to single nematode species, and most agricultural fields have several different nematode species present. Selecting appropriate cover crops to reduce nematode numbers requires a knowledge of the different nematode species and pathotypes or races (if possible) present in a field. Each cover crop species may be a host to one or more of the nematode species present in a field and a nonhost for remaining species. The cover crop selected should depend on which of the nematodes are the object of the management strategy. An additional problem that relates to the interpretation of available information on cover crops for use in California is that much of the research was not conducted over long time periods. More long-term studies for observing changes in fields over years have been initiated.

Nematode–host plant interactions. A substantial amount of information on plant-nematode interactions has been compiled into a computer database (NEMABASE) by UC Davis nematologists (Caswell-Chen et al. 1995). Once a grower knows what nematodes are present in a field, the database can be searched for plants resistant to those nematodes. Consult the University of California IPM program or your local University of California Cooperative Extension Farm Advisor for information on access to the database, or consult the UC Davis Department of Nematology World Wide Web site http://ucdnema.ucdavis.edu.

Effects of cover crops on nematode numbers. Much of the research on cover crops and nematodes has been conducted in the southeastern United States and often deals with cover crops used in rotations. When consulting the literature to aid in selecting a cover crop, it is important to consider several factors. First, several different nematodes may be pres-ent in a field, and a potential cover crop will have a different host status relative to different nematode species (table 10-1). Different geographic populations or isolates of a nematode species may possess different capacities to parasitize certain plant species, so that the results reported from one geographic location for a nematode species may not hold in another location. Also, different cultivars of the same plant species may have different capacities to support certain nematode species. In addition, when grown as companion cover crops, some covers may reduce crop yield or act as hosts for other pests or pathogens.

Cool-season cover crops grown during the fall, winter, and early spring may be able to escape nematode damage because this period is when plant-parasitic nematodes are least active. Timing of seeding and tillage can also be important in determining the degree of nematode activity and the extent to which nematodes attack the cover crops.

Rodríguez-Kábana and Ivey (1986) explored the effects of crop rotations for managing *Meloidogyne arenaria* in peanut. They found that a winter cover of rye (*Secale cereale*) had no effect on nematode densities in the following summer crops of peanut, soybean, or corn, but the cover crop did lead to increased yields in the soybean and corn.

In Florida, Gallaher et al. (1988) tested hairy

Table 10-1. Summary of nematode-host interactions on several potential cover crops

Cover crop	*Meloidogyne hapla*	*M. incognita*	*M. javanica*	*M. arenaria*	*Pratylenchus vulnus*	*Criconemella xenoplax*	*Xiphinema americanum*	*X. index*
Alfalfa, 'Moapa' (*Medicago sativa*)	susceptible	poor host	poor host	nonhost	nonhost	host	host	NDA*
Barley, 'Columbia' (*Hordeum vulgare*)	host	poor host	good host	host	nonhost antagonistic	host	antagonistic	nonhost
Brome, 'Blando' (*Bromus hordeaceus* ssp. *molliformis)*	host	nonhost	NDA	NDA	nonhost	host	good host	poor host
Marigold (*Tagetes* spp.)	host	host	host trap crop	nonhost	NDA	host	NDA	NDA
Sudangrass, SS-222 (*Sorghum sudanense*)	poor host	good host	host	host	nonhost antagonistic	antagonistic	antagonistic	nonhost
Strawberry clover, 'Salina' (*Trifolium fragiferum*)	host	poor host	poor host	nonhost	probable nonhost	probable host	NDA	NDA
Vetch, 'Cahaba White' (*Vicia sativa* × *Vicia cordata*)	good host	poor host	host trap crop	host	host	host	antagonistic	nonhost
Wheat, 'Coker 916' (*Triticum aestivum*)	NDA	NDA	NDA	NDA	NDA	probable nonhost	NDA	NDA
Vetch, 'Nova II' (*Vicia* spp.)	probable host	probable nonhost	probable nonhost	probable nonhost	probable nonhost	probable nonhost	NDA	NDA

*No data available.

Note: Data summarized from McKenry (1992) in California and Nyczepir and Bertrand (1990) in Georgia and South Carolina.

vetch and four vetch cultivars ('Vantage,' 'Cahaba White,' 'Vanguard,' and 'Nova II') in sandy loam soil using tillage and no-till regimes preceding corn or sorghum. Densities of *M. incognita* were much higher on hairy vetch than on any of the four hybrid vetch cultivars, and the root-gall index was greatest for hairy vetch. McKenry, Buzo, and Kaku (1990) found that 'Cahaba White' vetch (*Vicia sativa* × *V. cordata*) is an excellent host for *M. hapla* but a poor host for *M. javanica*. The ring nematode (*Criconemella ornata*) occurred at high densities on 'Vantage,' 'Cahaba White,' and 'Vanguard' (Gallaher et al. 1988). Numbers of *Pratylenchus brachyurus* in roots were particularly high for 'Cahaba White' and 'Vanguard.' *Pratylenchus brachyurus* and *Paratrichodorus minor* attained statistically similar densities on all five vetches. The tillage regime had little effect on nematode densities, except that ring nematode occurred at significantly higher densities under no-till management.

To date, subterranean clovers (*Trifolium subterraneum*) have shown very limited resistance to *Meloidogyne* spp. (Baltensperger et al. 1985; Kouame et al. 1989; Pederson and Windham 1989). This indicates problems for their use as cover crops with grapes in areas where *Meloidogyne* spp. are a problem. Sacka-Kuri et al. (1986) evaluated five cultivars ('Auburn Reseeding,' 'Tibbee,' 'Chief,' 'Dixie,' and 'Autauga') and three advanced lines of crimson clover for reaction to three *Meloidogyne* species, and all were intermediately to highly susceptible. In Mississippi, Windham and Pederson (1989) assessed the sensitivities of three white clover cultivars and two accessions to four races of *M. incognita*. All the white clover strains were excellent hosts to all the root knot nematode populations and races tested. The germplasm SC-1 was moderately tolerant to race 1 and race 4, and 'Louisiana S-1,' a cultivar, appeared moderately tolerant to race 2.

Warm-season cover crops are grown during warm periods when plant-parasitic nematodes are most active. Some of these covers have shown marked resistance to several important nematodes. In the southeastern United States, Rhoades (1980, 1983, 1984), Reddy et al. (1986), and Rodríguez-Kábana et al. (1988a, 1988b) have shown that warm-season cover crops suppress nematodes that might otherwise seriously damage succeeding cash crops. American jointvetch (*Aeschynomene americana*), cowpea (*Vigna unguiculata* ssp. *unguiculata*), and hairy indigo (*Indigofera hirsuta*) appear promising for reducing *Meloidogyne* species.

Various marigolds (*Tagetes* spp.) can suppress several different nematode species (Gommers and Bakker 1988). The mode of action has been hypothesized to be through nematicidal chemicals contained in marigold tissues (Gommers and Bakker 1988). Incorporation of fresh marigold (*Tagetes patula* cv. Janie) refuse followed by irrigation reduced populations of lesion (*Pratylenchus vulnus*) and pin (*Paratrichodorus minor*) nematodes in a plum orchard (McKenry 1991). However, plum yields collected 11 months after incorporation revealed slight phytotoxicity (McKenry 1991), indicating a potential problem. Although most populations of the northern root knot nematode, *M. hapla*, failed to reproduce on *T. erecta* cv. Carnation, a biotype from Virginia was observed to reproduce (Eisenback 1987). Field populations of *M. incognita* were effectively reduced by growing *T. erecta* in Florida (Reddy et al. 1986). *Tagetes erecta* did not support reproduction of *Pratylenchus penetrans* (MacDonald and Mai 1963) and has been observed to reduce populations of *P. brachyurus* in the field (Reddy et al. 1986).

Some grasses and tropical legumes, although not currently used in California vineyards, may actually suppress nematode populations. Several cultivars of bermudagrass (*Cynodon dactylon* 'Coastal,' 'Coastcross-1,' and 'Tifton 44') are resistant to root knot nematodes (*M. incognita* and *M. arenaria*) and can be used in rotation with crops susceptible to root knot (Windham and Brink 1991). *Elymus glaucus* was not galled by *M. javanica* but did support nematode reproduction (Araya and Caswell-Chen 1994a). *Agrostis alba* (redtop), *Festuca rubra* var. *commutata* (chewings fescue), *F. rubra* (red fescue), *Poa compressa* (Canadian bluegrass), and *Hordeum vulgare* (barley cv. 'Erie') were observed to be very poor hosts for *P. penetrans*, although subjecting the plants to frequent foliar pruning seemed to improve their host status, especially for *P. compressa* and *F. rubra* var. *commutata* (MacDonald and Mai 1963).

Other warm-season tropical legumes such as *Concanavalia ensiformis* and sunn hemp (*Crotalaria juncea*) may reduce nematode numbers. Sunn hemp is reported to reduce soil populations of several different species of plant-parasitic nematodes, including the root knot nematodes and reniform nematodes (Caswell et al. 1991; Good, Minton, and Jaworski 1965; McKee et al. 1946; Roman 1964; Rotar and Joy 1983). *Crotalaria juncea* cv. Tropic Sun and PI 207657 were resistant to penetration (Araya and Caswell-Chen 1994b) and did not develop galls when inoculated with *M. javanica*.

However, nematode reproduction was supported in some plants (Araya and Caswell-Chen 1994), which was probably the result of genetic variation among individual plants.

Cover crops as green manure. The benefits of adding organic matter to soils have long been recognized. The beneficial effect of organic matter incorporation for nematode management is generally considered to be due to direct or indirect stimulation of nematodes and soil microorganisms that are predators and parasites of plant-parasitic nematodes. The incorporation of organic matter may serve to increase the nematode community diversity. This increased diversity can prevent the domination of the nematode community by a single species, encourage the activity of nematode antagonists, and increase linkages within the soil food web. The addition of organic matter may provide an energy source for facultative nematode parasites, such as some fungi. Linford and coworkers (Linford 1937; Linford, Yap, and Oliveira 1938) proposed the hypothesis that adding organic matter to soil increased the activity of nematode-trapping fungi.

Many of the successful experimental additions of nematode-parasitic fungi to soil have included the addition of organic matter to the soil along with the fungus. The enhancement of nematode-trapping fungi by organic matter often lasts for only short periods of time, a few weeks for example, and does not typically exert a strong effect on nematode population densities (Kerry 1987). Van den Boogert et al. (1994) provided some confirmatory evidence for Linford's hypothesis, observing the importance of organic soil amendments for reductions in numbers of plant-parasitic nematodes. In microcosm experiments, the addition of lucerne meal or barley root systems resulted in increased densities of bacteria-feeding nematodes, corresponding with increased densities of a nematode-parasitic fungus, *Drechmeria coniospora* (Van den Boogert et al. 1994). Brzeski et al. (1993) incorporated residues of white mustard, phacelia, oat, and field pea that had been grown as intercrops, and subsequently observed rapid increases in bacteria, closely followed by increased numbers of bacteria-feeding nematodes. Fungal densities increased later, although fungal-feeding nematode numbers did not increase. The increased populations of microorganisms and the nematodes grazing on them declined 3 months after incorporating the green manure (Brzeski et al. 1993). Addition of earthworm compost (vermicompost) to soil suppressed *Phytophthora nicotianae* var. *nicotianae* and *Fusarium oxysporum* f. sp. *lycopersici*, but did not decrease numbers of *Meloidogyne hapla* or another plant-parasitic nematode, *Heterodera schachtii* (Szczech et al. 1993). Thus, the simple addition of organic matter should not always be counted on to reduce numbers of plant-parasitic nematodes. The condition and decomposition status of organic amendments may influence nematode suppressiveness, but the relationships are not currently defined, and further studies are required in this area (Stirling 1991).

Soil amendments. The addition of a range of soil amendments, such as cover crop residue, 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 stimulation of the growth of nematophagous fungi that may be present; improvements in soil structure, water retention, and plant nutrition, which would reduce stress on nematode infested plants; and production of nematicidal breakdown products. Because of the complex nature of the interactions that may occur, interpretation of results following addition of soil amendments is difficult. Sufficient data is not available to predict with any certainty the nematode mortality that might be obtained with these materials. In some cases, the addition of amendments has resulted in phytotoxicity on some crops. Also, it is possible that nematode populations could increase following use of an amendment. If the amendment results in reduced stress on the crop and the development of a healthier root system, this root system could support a larger nematode population. Leaving untreated areas to compare with amended areas is a good method for judging the success or failure of soil amendments. Evaluation should include both nematode samples and plant yield.

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