Nematicides

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Glossary

Nematode A multicellular, nonsegmented, true roundworm which can be pathogenic to specific agricultural crops
Soil Fumigants Chemicals volatile enough to move through soil pore spaces, dissolve into soil water films, and kill various microflora and fauna of soil
Soil Profile A vertical cross-section of the soil from the surface into the underlying, unweathered material

A nematicide is any agent lethal to nematodes. A nematicistat, or nemastat, is any chemical, situation, or phenomenon which holds a nematode population in equilibrium, but this term is frequently used to refer to sublethal dosages of nematicides which disrupt nematode behavior. Since root parasitic nematodes may reside as deep in soil as the deepest root, it is to be expected that any soil-applied nematicidal agent will provide a gradient of lethal to sublethal to nonlethal effects emanating from the point or line of chemical injection. Gradient concentrations of nematicides can also be expected to occur when systemic-type nematicides are applied to plant parts but these gradients can be expected to be affected by plant physiology and “sink” effects rather than distance from the point of application. In crops of lower value one attempts to reduce the nematode population enough to attain a nondamaged crop. For crops of higher value, such as nursery crops or permanent plantings of trees or vine crops, the attempt is to reduce pest populations as low as possible prior to planting. The most effective preplant nematicides are those biocides which also kill old roots and plant pests remaining throughout the soil profile. The most effective postplant nematicides are those which kill nematodes in soil and roots without damaging the existing root system. [See Plant Pathology.]

I. A Historical Perspective

The decades of the 1940s and 1950s were the years of discovery and development for nematicidal agents. It was the advent of nematicidal agents that permitted field-level confirmation of the usually subtle damage caused by nematodes. By the 1960s the best performing nematicides were widely used especially in crops of higher cash value. From 1975 to 1990 the ability to detect environmental concentrations of these nematicides improved by 10,000-fold. During this period of increased environmental monitoring and increasing concern about the environmental fate of nematicides, total nematicide usage continued to increase but the number of active ingredients decreased from four or five to one or two.

Nematicides have been one of the many inputs which have allowed for “intensive” agriculture. The ability to grow as many as three cash crops in a single year and the ability to sustain permanent tree and vine crops as economic units are testimony to the value of nematicides. For those crops where there is no nematode resistance or where resistance is to one nematode species but not to others, nematicides have been a valuable tool toward providing an inexpensive and diverse food and fiber supply. Nematicides have provided growers with a tool to avoid the expense of crop rotations and scarcity of new appropriate land.

The use of nematicides has also resulted in numerous incidents of off-target contamination. As the level
of chemical detection improved, scientific efforts were focused toward improvements in nematicide delivery systems, reductions in treatment rates and improvements in timing of applications. In the 1940s the requirement to obtain a registered nematicide was proof of nematicide performance. In the 1990s there are cancer studies, wild-life studies, groundwater studies, air pollution studies, ozone depletion studies, and at the Federal level no real requirement relative to chemical efficacy. Of course, the cost of these studies is passed on to the grower who constantly tries to lower his costs. For example, in the 1960s treatment rates for 1,3-dichloropropene were as high as 2500 kg/ha as a preplant treatment for grapes where Dagger nematode, Xiphinema index, and the grape fan leaf virus were known to occur. By the 1970s treatment rates were down to 350 to 800 kg/ha depending on soil conditions. By 1990 treatments of 1,3-dichloropropene above 120 kg/ha were not permitted in California because of part per trillion air pollution control requirements in areas adjacent to treated fields.

The greatest task in attaining efficient nematode control has been delivery of the nematicidal agent to the site of the pest. Nematicidal agents are commonly lethal at concentrations of 1 to 20 ppm. Formulations have included soil applied gases, liquids, or granules as well as plant systemic and root protecting agents. Gases applied at high rates (e.g., 450 kg/ha methyl bromide) are not easily kept beneath the soil surface. Liquids delivered for nematode control within soil can move deeper at part per billion levels unless there is a mechanism for gradual degradation of the toxicant. Some systemic materials may occur as residues in food if improperly applied. Root protectants, including manures and amendments, also carry salts and nitrates which have the potential to accumulate in groundwater or in the plant.

II. Delivery to the Target Pest

A. Volatile Nematicidal Agents

In a properly prepared soil the fastest movement of a pesticide is by those chemicals which are able to move through air passageways of soil. True soil fumigants are applied either as a gas or a liquid which quickly volatilizes to become a gas. Soil fumigants are usually delivered to soil through a tube just behind a steel shank. The shanks are inserted 15 to 75 cm beneath the soil surface as they are pulled across a field by a tractor. The disrupted soil surface is immediately resettled, smoothed, and packed. To avoid volatization the highly volatile chemicals must either be applied deep, applied through more shanks, or covered with a tarpaulin. In the case of methyl bromide a thin film of polyethylene tarpaulin may be applied to the field surface in order to hold concentrations at the surface for a longer exposure time. One advantage of highly volatile nematicidal agents is that the active ingredient reaches the pest or the woody roots surrounding the pest at high enough concentrations to kill the root and thereby the habitat of the pest. Highly volatile nematicides are useful as preplant treatments because they are general biocides at their usual delivery rates.

B. Less Volatile Nematicidal Agents

Several chemicals are occasionally referred to as fumigants but have a relatively strong affinity for soil water films and organic matter and therefore may only move distance of centimeters as a gas. An example is the methyl-isothiocyanate liberators (MIT) such as Vapam (Zeneca Co.). If the soil-borne pest is primarily in the surface 30 cm of soil profile such chemicals can be effective when applied to properly prepared soils. Since nematode pests can reside quite deep in soil and can travel up from 1 m below, this group of nematicides is usually most effective when applied by mixing into irrigation water and applying enough water to reach sufficient soil depths. The concentrations of nematicide delivered throughout the soil water films are lower than those from highly volatile substances and less apt to kill woody roots or tubers. The fact that water seldom moves uniformly through a soil profile indicates that the chemical must be well mixed into water and the water carrier must be uniformly applied to a properly prepared soil. Although this group of nematicides is termed less volatile it should also be noted that applications through sprinklers which atomize water droplets can result in much chemical loss before the water droplet strikes the soil surface.

C. Systemic Nematicidal Agents

Systemic chemicals may be applied to soil, plant leaves, roots, or the trunk. Waxy surfaces on leaves, the soil or organic mantle surrounding roots, and the bark on the trunk can each reduce successful introductions of the toxicant into the plant and consequently necessitate an increase in treatment rates.
attacking roots frequently develop specialized feeding cells within the plant and these may not necessarily be a “sink” for the nematicidal agent.

Several carbamate-type nematicides including aldicarb, oxamyl, and carbofuran exhibit acropetal translocation (from roots to leaves or fruits). These carbamates are also associated with increased growth response (IGR) or the “carbamate response” which can occur whether nematodes are present or absent. Growers have liked the carbamates because of the multiple benefits they provide including IGR, insecticidal value translocated to young leaves, and their early season nematicidal value. It should be noted, however, that unless the nematode is a foliar or stem feeder or unless the active ingredient can be translocated into specialized nematode feeding sites within roots, the preponderance of nematicidal effect occurs on soil-dwelling nematode stages. For this reason, multiple treatments are largely a result of effects on soil-dwelling nematode stages. This author did not see the first example of a true systemic nematicide until 1991 when working with fosthiazate, an organophosphate capable of indirectly or directly eliminating well-established nematode populations within 2-year old woody-rooted plants. In certain regions of the world today oxamyl is still recommended as a foliar treatment for soil-dwelling nematodes.

Organophosphate (OP) nematicides do not tend to promote an IGR effect within plants. Phenamiphos- and ethoprop-treated plants grow better after treatment but only if the nematodes are indeed causing growth reductions. The growth benefit occurs as a result of lethal and especially sublethal effects derived from a soil drench treatment and not due to systemic activity within the plant. Small percentages of phenamiphos can be basipetally translocated in the field (from above-ground to below-ground) but effective treatments are largely a result of effects on soil-dwelling stages. For this reason, multiple treatments of OP and carbamate chemicals have tended to be much more effective than single treatments when endoparasitic nematodes are attacking perennial crops. A true basipetally translocated nematicide is not yet commercially available. However, fosthiazate is an interesting candidate.

Since much of the nematicide benefit of OP and carbamate materials occurs outside the root, it follows that other root protectants might also be useful against nematodes.

D. Root Protectants

Root protectants include a mixture of nematode control mechanisms usually associated with increased biological activity in soil or along the rhizosphere. They are included here because undoubtedly some of the activity is in the form of toxins such as ammonia (NH₃) released by microbes but other methods of microbial competition play a role. These microbes may already be present in soil or they may grow along with the root surface as roots spread through soil. One difficulty with root protectants, in general, is that their performance is so sporadic that most large corporations have steered away from investing in them. Since many root protectants are products of, or the result of, biological control agents there is ever increasing interest and field testing of their worth. There are few success stories for addition of single biocontrol agents per se to soil, but there are nematode suppressive and nematode conducive soils found around the world and these are the focus of contemporary biological control studies.

Root growth stimulators or root protectants include substances such as humic acids, oil crops or oil cakes, naturally occurring plant substances or extracts, fatty acids, manures, amendments, and various organisms or compounds which release nematode antagonistic substances into soil. Many of these substances also promote IGR. It has been stated by numerous promoters of root protectants that root protectants provide increased growth or yield in a nematode infested soil without actually reducing the nematode population. To the contrary, this author would state that with an appropriate number of soil samples, a root protectant, if it is to provide viable nematode relief, must also provide a reduction in nematode population to complement the increase in plant growth if one is to call such a substance nematocidal. As an example, the chaff of sesame, *Sesamum nigrer, is federally registered as a nematicidal agent. Even at high treatment rates it seldom exhibits significant nematode reduction but it does exhibit some nematode reduction. These findings indicate that additional studies are needed but sesame chaff is probably more correctly referred to as a root protectant or soil amendment rather than as a nematicidal agent. However, what if sesame chaff only performs well in nematode infested sites? And how about substances like ethoprop which seldom give rise to significant nematode reductions in the field but are referred to as nematicidal?

E. Relative Performance of Various Preplant Soil Fumigants

Visualize a back yard location for summer vegetables in a warm climate. The yard is spotted with trees,
their roots criss-crossing beneath the vegetable garden. The root knot nematode has a very large host range and can be expected on the roots of most trees. What treatment does one use to control nematodes in such a garden? In some U.S. states today there is not one effective, legal nematicide treatment for such situations. When orchard and vineyard crops are removed much of the root system remains in the ground and portions of the old roots can be found alive 4 to 10 years later. Live roots result in viable nematode populations capable of attacking the subsequent crop. Planting of resistant crops can help. The best example is from stone fruit and nut crops, *Prunus* spp. Today, 300,000 hectares of *Prunus* spp in the United States are on Nemaguard rootstock with complete resistance to all *Meloidogyne* species. Unfortunately some of that land also has Ring nematode, *Crinonebela xenoplax*, or Root lesion nematode, *Pratylenchus vulnus*, to which this rootstock is highly susceptible. It follows that preplant fumigants have been a very important component in the re-establishment of orchard and vineyard land. A useful characteristic of methyl bromide and Telone has been their ability to kill old roots from the surface 1.6 m of soil when properly applied. In order to reduce costs, especially among annual crops the grower does not usually broadcast treat the entire field but only those zones where the plants are seeded.

The data in Table 1 depict the long-term performance of eight different preplant treatments made in the fall following the removal of an 80-year-old vineyard. Strawberries were planted 6 months after treatment and grown for 18 months. Data are shown as percentage nematode control compared to a non-treated check with eight replicates of each treatment. Numbers of 100% do not indicate that all the nematodes are gone but indicate that the sampling method is not sensitive enough to detect them at that point in time. A “flipped soil” involves a dual application with a 30-cm-deep plowing 10 days after the first treatment.

These data indicate the futility of organophosphate treatments in the presence of heavily infested older root systems. They indicate that MIT in large volumes of water can be effective. They indicate the value of a tarpaulin versus the value of a dual application with MB. We also observe that use of cis-1,3-D at treatment rates greater than 150 kg/ha results in a biological vacuum and that when nematodes do re-appear this occurs faster at higher treatment rates than at rates below 150 kg/ha.

### III. Mechanisms of Nematode Control

#### A. Direct lethal Effects

At the laboratory bench every one of the nematicidal or nematostatic agents is lethal to nematodes at some concentration. The *LD*<sub>95</sub> (lethal dosage for 95% of test animals) for root knot nematode, *Meloidogyne* spp, is 19 μg/ml of methyl bromide for 24 hr. Dosages of five-fold that value can kill nematodes in 5 hr and MB is frequently delivered to the site of the nematode at dosages 100 times the *LD*<sub>95</sub> value, thus killing old roots too. Sublethal effects are an insignificant event with regard to the more volatile nematicidal agents such as methyl bromide. Carbamates and OP compounds, on the other hand, have *LD*<sub>95</sub> values in the area of 1 μg/ml for a 72-hr exposure. They

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<th>Treatment</th>
<th>Nematode control expressed as a percentage of nontreated</th>
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<td>MB 336 kg/top 30 soil flipped then 174 kg/ha</td>
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<td>MIT 356 kg in 17 cm water</td>
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<td>MB 336 kg tarped</td>
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<td>Telone II 560 kg/top 30 cm soil flipped then 224 kg/ha</td>
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<td>Telone II 560 kg/ha</td>
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<tr>
<td>Cis-1,3-D 140 kg/ha</td>
<td>100</td>
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<tr>
<td>MB 336 kg, without tarpaulin</td>
<td>99.5</td>
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<tr>
<td>Ethoprop 22.4 kg/ha in 17 cm water</td>
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are frequently delivered via water at concentrations of 50 to 100 times that level but are quickly diluted as they move among the soil water films so that direct lethal effects may only occur within centimeters of the application site. Additionally, nematode stages residing deep within roots such as woody perennials or old tubers may be completely unaffected by the nematicide treatment.

B. Sublethal Effects

Carbamates and OP compounds at concentrations and exposure times delivered to the nematode site are frequently too low to achieve the lethal dosage value. With grapes, for example, 1 g of active ingredient is applied per vine throughout the surface 3 feet of soil profile using low volume drippers. This 20 to 50 mg/liter treatment is delivered into soil as a gradient and diluted by subsequent irrigations which occur at 2- to 5-day intervals. This treatment is repeated once or twice on a 2% day cycle and can result in 6 to 8 months of 75 to 90% relief from endoparasitic nematodes. A few weeks after the first treatment one can detect populations two to three times higher than the non-treated population indicating that there is a positive effect on egg hatch. One can calculate the exposure levels and determine that adsorption, biological degradation, and hydrolysis of the active ingredient ensures that lethal dosages are not present within a week of treatment, and yet these treatments are quite effective when timed to the root flush activity of the grapevine, the new roots being the target of the nematicide.

C. Comparative Performance of Three Postplant Nematicides

The use of low-volume irrigation results in a concentrating of plant roots and root parasitic nematodes, and allows for the concentration of nematicide therapeutics in a field setting with minimal application costs. Plant-nematode systems grown under a dripper system also become a useful tool for characterizing the difference in nematicides and their sites of action. One such model system that this author has used involves the repeated treatment of 2-year-old grapevines grown in individual 60 cm diameter by 1.3-m-deep microplots in the presence of varied root knot nematode species (Meloidogyne spp). In one such experiment these nematicide treatments were carried out on four specific Meloidogyne populations (see Fig. 1). On grape, M. hapla is one of the more nomadic species of Meloidogyne exhibiting small, superficial galls and producing relatively high soil to root ratios of juveniles which search for new root tips. They tend not to maintain old galls for lengthy periods and do not damage grape unless very high population levels are reached on young root systems. The M. incognita is Race 3, the cotton race, having large sized galls with multiple females present and providing high soil population levels. The M. javanica population is a pathotype from Thompson Seedless grapes which can maintain large galls but tends to produce low soil population levels relative to root population levels. It is possible that many juveniles of this pathotype seldom migrate through soil but stay within the root, successfully penetrating the giant cells developed by their mother. The fourth population, M. arenaria, is a pathotype of Cibola alfalfa near Blythe, California. Little is known about it except that it can provide very large galls on alfalfa and can cause substantial damage to grape.

After one year of nematodes and grapevines together the vines were treated with three sequentially spaced treatments of either Sincocin, a root protectant-type fatty acid, Phenamiphos, an OP with some systemic activity, or Fosthiazate, a basipetally systemic nematicide. Nematodes in roots and soil around the roots were sampled in the fall of the second year. Figure 1 depicts the root population level of juveniles 150 days after the last nematicide treatment. The active ingredient in Sincocin is the fatty acids which appear to promote microbial growth along the rhizoplane which is inhibitory to the nomadic M. hapla population but not the other three Meloidogyne spp. Phenamiphos exhibits useful nematode reduction in soil but is only moderate in its ability to affect adult females within roots and may be ineffective on juvenile nematode stages unless they migrate through soil. Fosthiazate treatments were highly effective against soil- and root-dwelling populations of Meloidogyne. This comparison provides an indication of the specificity of control which may occur depending upon the mode of action of the nematicide and the feeding or root penetrating preference of selected nematodes. Each compound is nematicidal but their performance will be determined by the specific nematode pest present in the field.

IV. Listing of Nematicidal Agents

A. Volatile Nematicidal Agents

Carbon disulfide or carbon bisulfide was first used in the late 1800s to control phylloxera, Daktlylosphaeria vitifoliae, in French vineyards at application rates of
2800 to 5000 kg/ha. This gaseous material has also been used to control oak root fungus, Armillaria mellea, of citrus. It has nematicidal value but has seldom been used specifically for that purpose. The major problem with its use is its high flash point. The pulling of steel shanks through a rocky soil can result in a spark and explosion. This active ingredient has now been complexed into solutions as Enzone (Gowan) for safer delivery into soil as a liquid.

Methyl-bromide is an odorless gas above 4°C which is delivered to soils with or without the use of a plastic tarpaulin. It is used for control of nematodes, weeds, certain soil fungi, and bacteria. It is an effective nematicide but will not control nematodes if they reside in the surface 15 cm of soil profile unless a tarpaulin is present or there is a dual application. Hydrolysis, methylation, and volatilization are major events in the final fate of methyl-bromide. It has not been a groundwater contaminant. The major contemporary concern about its future use is its volatility and its potential for transport to and degradation of the ozone layer of the stratosphere.

Chloropicrin or teargas is occasionally mixed with methyl bromide to provide control of a broader group of soil organisms. It may also occur at 2% in mixtures with methyl bromide to indicate the presence of methyl bromide. It is not used as a nematicide per se.

1,3-dichloropropene (1,3-D) consists of a mixture of cis and trans isomers, each having slightly different nematicidal and dispersion characteristics. Since 1943 there have been various mixtures including D-D (Shell), Telonc, and Telone II (Dow). In spring 1990 the use of 1,3-D in California was suspended as a result of its presence at part per trillion levels in the air space within two California communities. This mixture had been the backbone of many nematode control programs for decades. It has been reintroduced as a California nematicide but at treatment rates of 120 kg/ha or less with numerous restraints to avoid atmospheric contamination. Its relatively fast hydrolysis rate precludes it from being a groundwater contaminant. However, 1,2-dichloropropane, another component previously in the 1,3-D mixture, was highly persistent in soil and has been detected from groundwater. Dichloropropene was reported in the late 1980s to be a weak carcinogen.

1,2-dibromoethane or ethylene dibromide (EDB) is the least volatile of this group of fumigants but is highly persistent. Its spectrum of control included nematodes, some grasses, and soil insects. Treatment rates were in the order of 20 to 120 kg/ha to soil. In
1984 it was detected in U.S. bakery goods since it was a popular commodity fumigant especially for stored grains. It was also added to leaded gasoline as a lead scrubber. DBCP has proven to be a groundwater contaminant in Florida, Washington, California, Hawaii, and elsewhere. EDB is a known mutagen and carcinogen.

**B. Less-Volatile Nematicidal Agents**

1,2-dibromo-3-chloropropane or *DBCP* was marketed under brand names such as Nemagon(Shell), and Fumazone (Dow), and others. It became popular with growers in the late 1950s and its popularity gradually increased until August 1977 when laborers in its manufacture associated it with a reversible testicular dysfunction. The 1977 suspension by California was about to be lifted when in May 1979 it was found in a series of groundwater samplings from an area which had received heavy use. Over the next decade and a half numerous water wells were found contaminated in various locations worldwide. Some towns in the San Joaquin Valley of California have found all their water wells producing DBCP-contaminated water in excess of 0.2 ppb DBCP (the current action level). No well concentrations in excess of 48 ppb were ever reported from the United States. The half-life for DBCP is reported to be 54 to 138 years.

Metabolites of dinitrobenzyl isothiocyanate liberators (MIT) such as Metam Sodium are sold under a variety of trade names including Vapam (ICI Americas), Soil Prep (Buchmin Labs), Basamid (BASF), and several others. In 1991 this was the only nematicidal agent that could still be purchased by the homeowner in the garden section of the local hardware store. The performance of this product has always been inconsistent, largely due to application methodologies. In 1991 a train car of the active ingredient was accidentally dumped into a northern California river and lake, causing much attention and acute environmental damage. The product is a useful broad spectrum biocide with inconsistent performance attributed largely to problems of improper application and a relatively poor capability to penetrate and kill old woody roots or tubers.

The slow-release liquid formulation of carbon bisulfide called Enzone (Gowan) has value because of its short half-life. It is being tested as a postplant treatment but may have greater value as an alternative preplanting treatment.

There have been occasional reports that ammonia releasing fertilizers have nematicidal value. Commercial fertilizers such as urea and urea ammonium nitrate are both clearly nematicidal when re-applied at 30- to 45-day intervals via low volume irrigation systems. However, equivalent rates of calcium nitrate can be equally nematicidal when applied in a similar manner. In 1990 it was reported that potassium nitrate and ammonium nitrate had the potential to repel nematodes at relatively low treatment rates. Multiple treatments with these fertilizers can also reduce nematode populations. It may be that repeated interference with the osmoregulatory system of nematodes in soil is a major deterrent to endoparasitic and ectoparasitic nematodes, and the NH₃ release may only be a bonus. Treatments with 145 kg/ha sucrose, which also interferes with osmoregulation, through a low volume dripper in a vineyard setting has also proven nematicidal but reduced grape yield significantly after 2 years of retreatment.

**C. Nonvolatile Nematicidal Agents**

Aldicarb (Temik) has been a useful nematicide/insecticide for numerous crops. It has appeared in shallow groundwater of Florida and elsewhere and as residue in certain vegetables in fruits causing human sickness. This highly toxic material is currently available for only a few crops in the United States primarily on ornamentals and cotton.

Oxamyl (Vydate) provides an IGR similar to aldicarb and does not provide the breadth of nematode protection that aldicarb does. Multiple treatments increase the spectrum of activity but oxamyl is particularly useful against root lesion nematodes, *Pratylenchus spp*, as well as foliar nematodes.

Carbofuran (Furadan) has been most effective against certain insect pests but at rates two to four-fold that of aldicarb can provide some nematode relief. This product is most noted for its association with bird kills during its application which has severely restricted its use.

Phenamiphos (Nemacur) has proven to be an excellent nematicide for use on perennial crops. It provides relief from endoparasitic nematodes at relatively low treatment rates of 2 kg/ha via low volume irrigation. It is less effective against ectoparasitic nematodes and inconsistent in performance without low volume irrigation. Reports of it being found 10 m deep in soil at ppb levels appear to be erroneous since the parent material simply cannot move that far in soil without degrading.

Ethoprop (Mocap) is an organophosphate highly adsorptive to soil. It has provided inconsistent performance but is useful for specific crops such as potatoes.
D. Root Protectants

Organic matter including manure and composts have weak nematicidal value but the improved water holding capacity they provide to soil tends to reduce nematode damage without reducing nematode population levels. In a similar manner, more frequent irrigation scheduling can halve the damage caused by many nematode species. Manure also contains nitrates, ammonia, and humic acids which can reduce nematode populations to a slight degree.

Fatty acids especially those in the range of 6 to 12 carbons have nematicidal value and are occasionally marketed. One example of such a compound is Sinocin which along with cytokinins and various plant extracted components has been sold as a nematicide outside the United States. These substances may exhibit much of their effect at the root surface and not against those nematodes which live within roots or root galls.

Chitinase-producing microbes are reported to reduce nematode populations and they can be stimulated by high soil supplements of carbon and nitrogen and a source of chitin. Occasionally such products have become commercially available but they have been very expensive. The value of such products is that they show that the addition of a specific nematode controlling organism to soil has a much better chance for success if the proper habitat for the organism is also provided (e.g., food base).

Naturally occurring substances, many from plants, have been tested as nematicides over the last four decades. The author’s own work has confirmed the nematicidal properties of some. However, these plant residues or plant extracts can also be allelochemicals resulting in negative plant growth. Under arid conditions this author has reported that a crop of marigolds (Tagetes spp.) turned under in November and planted to cherries the following spring resulted in cherry trees of significantly reduced vigor. In wetter climates, marigolds have improved growth of certain nematode-sensitive crops such as potatoes.

Over this last decade the author has been studying a winter legume bred for wide resistance to nematodes. Cahaba White Vetch, developed in Alabama, is a non-host to the nematodes found in arid tree and vine crops-except Ring nematode, C. xenoplax-making it a useful winter cover crop. The refuse or the extract of the refuse contains nonfermenting nematicidal properties as well as a low amount of nitrogen when applied via dripper system to a field. As with commercial, fertilizers, repeated treatments appear to take their toll on soil-dwelling stages of the nematode. This extract and the extracts of marigold are also strong antioxidants being able to kill a small fish in 5 min at field treatment rates. Sesame chaff is a registered nematicide for the United States. It does appear to have nematicidal properties but performance data are lacking.

V. The Future of Nematicides

Over the last five decades there have been many useful nematicides with specific and general application. Some of them have included highly volatile substances that did not stay in soil, nondegradable substances that transported to groundwater, and highly toxic systemic substances that can translocate to food stuffs. Given the numerous incidents of off target nematicides, the number one priority for nematicides should be a downward translocating nematicidal agent. This agent could be an organism which colonizes along the rhizosphere, or it could be within the roots and effective on endoparasitic and ectoparasitic nematodes. The concept of treating large volumes of soil with large volumes of nematicide has been very useful to growers but the environmental concern of today will not permit continued use unless such chemicals are quick to degrade. The development of low-volume irrigation has provided a ready vehicle for nematicide delivery at relatively low treatment rates. Desperately needed is a procedure or pesticide that can kill the roots of previously planted perennial crops. These old roots provide nutrition for nematodes and other microbes for years after the top portion of the plant has been removed.

The food supply of America is abundant, diverse, and relatively inexpensive. At this point in time the American public is calling for a million-fold safety factor between the cancer-causing level of a pesticide and the action levels which protect our air, water, and food supply. Is this enough? The answer varies but relative to soil applied pesticides we are sure of one thing. Nematicides without a predictable degradation rate have no value in the future.

Bibliography


