Avoidance and Management of Nematode Problems in Tree Fruit Production in Michigan
Michigan State University Extension Service
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# Avoidance and Management of Nematode Problems in Tree Fruit Production in Michigan

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Michigan apple, cherry and peach orchards that have previously produced profitable yields may not support adequate tree growth when replanted. In many cases, this problem is caused or influenced by plant parasitic nematodes. Nematode management requires long-term planning, and is frequently essential for the establishment of uniform stands of healthy trees and a profitable orchard. This publication describes the nature of Michigan nematode problems associated with apple, cherry and peach production, and presents procedures for prevention.

MICHIGAN STATE UNIVERSITY EXTENSION

# Avoidance and Management of Nematode Problems in Tree Fruit Production in Michigan

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## Symptoms

Poor growth of replanted fruit trees is the most obvious symptom of nematode problems. Above-ground parts of plants are stunted and have short internodes and small leaves. Root systems are small, discolored, and have poorly developed feeder roots. Trees may die after the first or second growing season, or they may remain in a severely stunted condition for many years. In some cases, surviving trees may improve with age, but they are not likely to be as large or productive as trees that grew well during the first few growing seasons. Symptoms caused by plant parasitic nematodes can be similar to those caused by other factors.

Orchards or individual trees infested with high population densities of plant parasitic nematodes will become nonproductive earlier than normal. Peach and cherry trees are usually more susceptible to nematode problems than are apples. All three, however, have been shown to be susceptible to nematodes and to suffer significant economic yield losses. Nematodes can also be a problem in new orchard sites.

## Nematodes

Plant parasitic nematodes are microscopic (Fig. 1). Seven genera of plant parasitic nematodes are currently recognized as causing economic losses in Michigan orchards (Table 1). These include the root-lesion, northern root-knot, stubby-root, ring, needle, lance, and dagger nematodes. They either live and feed in roots as endoparasites, or they live in orchard soil and feed on the surface of roots as ectoparasites. Both types migrate through soil from root to root and can be moved from orchard to orchard on mechanical equipment, in root stocks or in irrigation water. Plant parasitic nematodes can also hinder the development of beneficial fungi necessary for normal tree growth. All plant parasitic nematodes of economic importance have a negative influence on the physiology of a plant through their impact on the root system, which in turn affects water and nutrient uptake.

Population densities of root-lesion, dagger and ring nematodes frequently exceed damage thresholds in Michigan orchards. The dagger nematode vectors the tomato ring spot virus which causes stem pitting of peach and cherry and brown ring union necrosis of apples. The ring nematode is a predisposition agent for canker diseases and winter injury in stone fruit production.

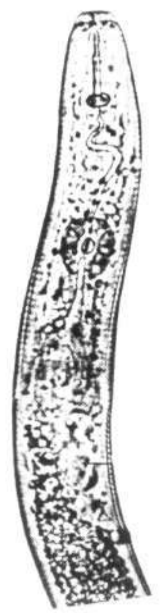

Fig. 2. The head region of the root-lesion nematode (*Pratylenchus penetrans*), a very common migratory endoparasite in Michigan fruit production.

**Root-Lesion Nematode**

The root-lesion nematode (*Pratylenchus penetrans*) has a medium body size and a strong stomatostyle (Fig. 2, and is described in detail in Appendix 1). It feeds in the cortex and damages the root system chemically and mechanically. Root-lesion nematodes reproduce sexually, and eggs are deposited throughout the root cortex. Under optimal soil temperature (25°C) the life cycle lasts about 30 days. All life cycle stages overwinter in Michigan. Root-lesion nematodes cause more damage and build up to higher population densities in sandy soils than in heavier soils. *P. penetrans* is the most common root-lesion nematode species in Michigan. It is also the most economically significant nematode in

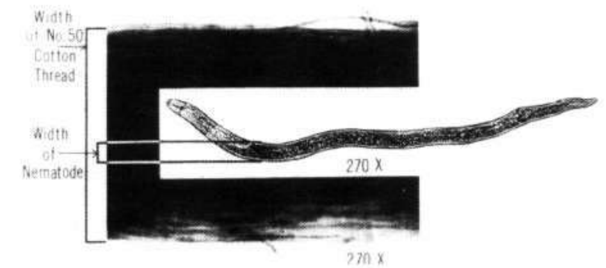


Fig. 1. A photomicrograph of the root-lesion nematode (*Pratylenchus penetrans*), superimposed over a No. 50 cotton thread, illustrates its microscopic nature.

**Table 1. Plant parasitic nematodes associated with economic losses in tree fruit production systems in Michigan.**

| Nematode | Parasitism | Mechanism |
|---|---|---|
| Root-lesion (*Pratylenchus penetrans*) | Migratory endoparasite | Pathogen |
| Dagger (*Xiphinema americanum*) | Ectoparasite | Virus vector and pathogen |
| Ring (*Criconemella xenoplax*) | Ectoparasite | Pathogen and predisposition agent |
| Root-knot (*Meloidogyne hapla*) | Sedentary endoparasite | Pathogen |
| Stubby-root (*Paratrichodorus minor*) | Ectoparasite | Pathogen |
| Lance (*Hoplolaimus galeatus*) | Ectoparasite | Pathogen |
| Needle (*Longidorus elongatus*) | Ectoparasite | Pathogen |

Michigan orchards. Other species such as *P. neglectus* and *P. crenatus* are frequently associated with Michigan grapes and agronomic crops, respectively. The population density of this nematode in an orchard site should be maintained below the action threshold. It is very important that both soil and root samples be submitted to a nematode assay laboratory for proper diagnosis of problems associated with this nematode. Nursery stock must be free of this endoparasite for the development of healthy trees.

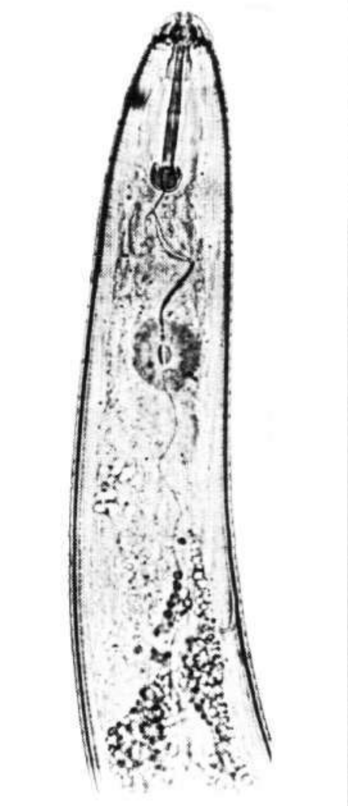

Fig. 3. The head region of a lance nematode (*Hoplolaimus galeatus*), illustrating the nematode stylet.

**Lance Nematode**

The lance nematode is a relatively large nematode, with a very strong stylet. It feeds as an ectoparasite on epidermal and outer cortical cells, and is known to be a problem in a few orchards in Michigan (Fig. 3, and is described in

Fig. 4. A dagger nematode (*Xiphinema americanum*), a vector of fruit viruses.

detail in Appendix 2). The only species known to exist in Michigan is *Hoplolaimus galeatus*.

### Dagger Nematode

The dagger nematode is a large-plant parasitic nematode (Fig. 4, and is described in detail in Appendix 3). Several species are found in Michigan, and it is possible that they are important in tree fruit production in Michigan. *Xiphinema americanum* is the most common. It feeds as an ectoparasite and causes a slight swelling of root tissue, which prevents the root system from functioning in a normal manner. The dagger nematode is also a vector of the tomato ring spot virus. This virus causes stem pitting of peaches and cherries, and brown ring union necrosis of apples and plums.

### Ring Nematode

The ring nematode, an ectoparasite of roots, is frequently recovered from Michigan orchards (Fig. 5, and is described in detail in Appendix 4). *Criconemella xenoplax* is the most common species. High population densities of this nematode can inhibit normal growth and development of roots. In California, this nematode was shown to predispose *Prunus* species to bacterial canker. This nematode is known to predispose peach trees in South Carolina to winter injury. It can prevent fall maturation of tissues, and leaves are retained later than normal.

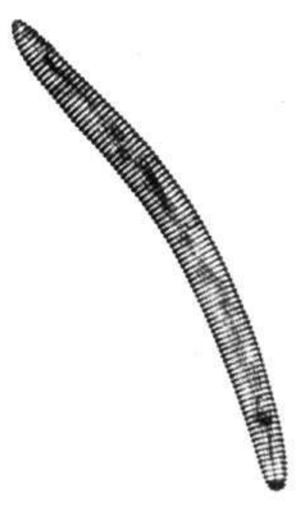

Fig. 5. The ring nematode (*Criconemella xenoplax*), an important predisposition agent.

### Stubby-Root Nematode

The stubby-root nematodes (*Trichodorus* spp. and *Paratrichodorus* spp.) occur in high population densities in a number of Michigan orchards (Fig. 6, and is described in detail in Appendix 5). These nematodes feed as ectoparasites just behind the root cap, and inhibit cell elongation. Feeding also results in a stimulation of secondary feeder roots, which become short and stubby. Relative to the

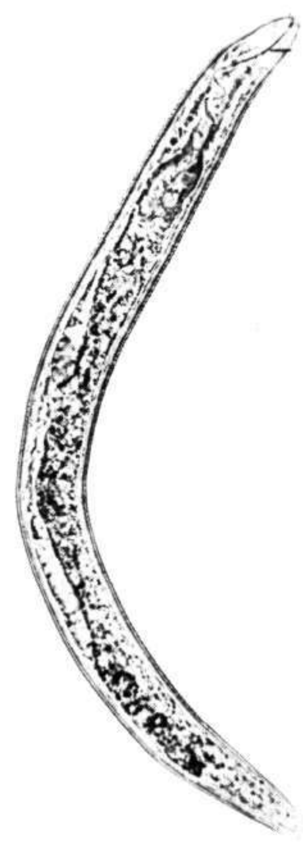

Fig. 6. A stubby-root nematode (*Paratrichodorus minor*), an ectoparasite.

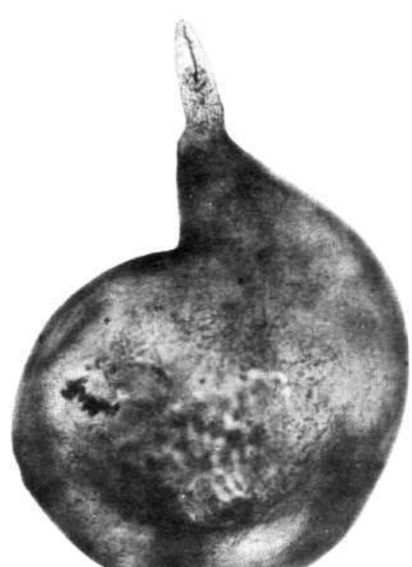

Fig. 7. A northern root-knot nematode (*Meloidogyne hapla*) female, a sedentary endoparasite.

needle nematode, most species of stubby-root nematodes are small and have a short life cycle.

**Root-Knot Nematode**

The northern root-knot nematode (*Meloidogyne hapla*) starts as a migratory endoparasite and becomes a sedentary endoparasite (Fig. 7, and is described in detail in Appendix 6). Root-knot nematodes are characterized by the formation of galls on the roots of fruit trees and other hosts. Once root-knot nematode second-stage juveniles reach their feeding site in the root, they begin to swell and remain sedentary. A chemical response produces the root galls. Several plant cells at the head of the nematode are modified to serve as nutritional sources for the nematode. Root-knot nematode females produce a large number of eggs which are deposited outside the nematode's body in a gelatinous egg mass. This nematode has about a 30-day life cycle at a soil temperature of 25°C. Eggs and second-stage juveniles overwinter in Michigan. This nematode can be introduced into orchard sites in infested nursery stock.

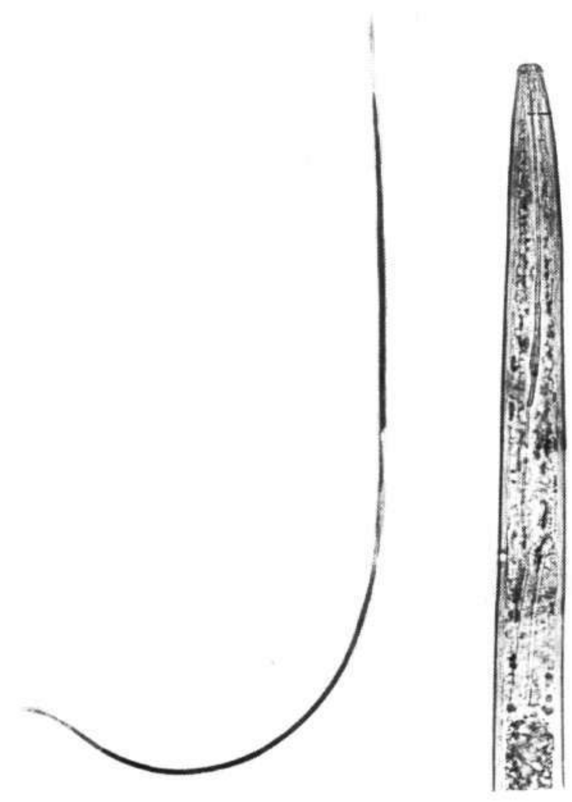

Fig. 8. The needle nematode (*Longidorus elongatus*), and an enlargement of the anterior region of this very large ectoparasitic nematode.

**Needle Nematode**

The needle nematode is the largest and longest of all plant parasitic nematodes (Fig. 8, and is described in detail in Appendix 7). The only species known to exist in Michigan orchards is *Longidorus elongatus*. This nematode has a long stylet, feeds as an ectoparasite and can cause root swelling. This nematode is found in a relatively small number of Michigan orchards. It is known to be a vector of a number of important viruses but is not known to be of significance as a virus vector in Michigan orchards. Other species are associated with corn and blueberry production.

## Nematode Problem Detection

Since plant parasitic nematodes are microscopic, the best way to determine if an orchard has a nematode problem or a potential problem is to examine the root system and submit soil and root samples to a nematology laboratory, such as the MSU Nematode Diagnostic Laboratory.

**When to sample**

Soil and root samples for nematode problem detection can be taken whenever the soil is not frozen. For best results, samples should not be taken until 30 days after annual root growth begins. Monitoring is divided into four categories: (1) orchard sites to be planted, (2) nonbearing orchards, (3) bearing orchards, and (4) orchards to be removed (Table 2).

Nonbearing sites must be sampled early to assess the need for a control procedure. Orchard sites to be planted the following year should be sampled before August 1 to allow time for nematode control before soil temperature decreases in the fall. Growers considering fall soil fumigation or nematicide application should take and submit samples between late July and mid-September.

Because plant parasitic nematodes feed only on living tissues, soil and root samples should be taken from the root zone, margin of the problem areas where trees are still living, or at random in fallow fields or fields containing a row crop (see Fig. 9-12). Use a soil sampling tube, trowel, or narrow-bladed shovel. Take samples at a 2- to 12-inch depth with as many feeder roots as possible. Each submitted sample should consist of a pint to a quart of soil taken from a larger sample composed of 10-50 subsamples. The number of subsamples (soil cores or borings) needed depends on the ecological and physical parameters (Table 3) of the area being investigated (Fig. 13-15). Mix subsamples in a clean pail or plastic

Fig. 1-8. The photomicrographs were taken by H.H. Lyon and Dr. W.F. Mai of the Department of Plant Pathology, Cornell University, Ithaca, NY 14852.

Figs. 9-15. Sampling procedures and patterns in fallow, orchard, individual trees, row crops, and different cropping systems.

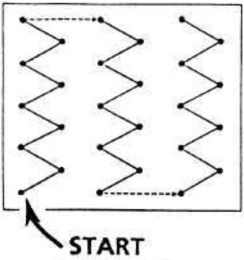


Fig. 9. Fallow fields or areas planted in a cover crop.

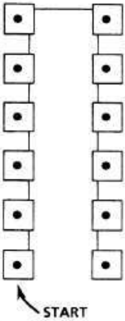


Fig. 10. Orchard.

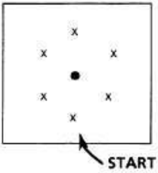


Fig. 11. Individual tree.

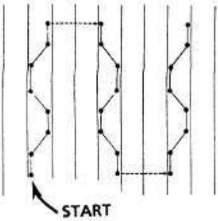


Fig. 12. Row crops (take samples from feeder root zone).

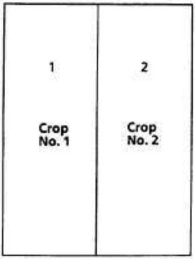


Fig. 13. Two samples required/160 A.

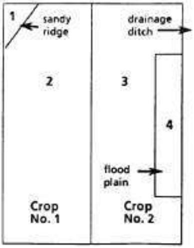


Fig. 14. Four samples required/160 A.

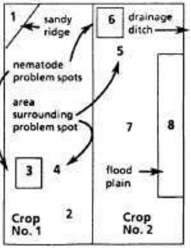


Fig. 15. Eight samples required/160 A.

Table 2. Nematode sampling for tree fruit sites.

| Nonbearing orchards | |
|---|---|
| When? | March 15-May 15 |
| What? | Soil and root samples |
| Why? | Management procedure selection |
| **Sites to be replanted the year after sampling** | |
| When? | June 15 - August 1 |
| What? | Soil and root samples |
| Why? | Management procedure selection |
| **Declining orchards** | |
| When? | August 1 - November 15 |
| What? | Soil and root samples |
| Why? | Orchard removal decision |
| **Bearing orchards** | |
| When? | As needed |
| What? | Soil and root samples |
| Why? | Orchard management and recordkeeping |

Table 3. Nematode sampling procedures.

| |
|---|
| 1. Select continuous area. |
| 2. Map area and estimate size. |
| 3. Subdivide based on soil type. |
| 4. Subdivide based on cropping history. |
| 5. Subdivide based on management unit objectives:<br>• Risk/benefit assessment<br>• Cost of additional subdivisions<br>• Cost to take samples<br>• Cost to process samples<br>• Management implementation cost |

bag: only one quart needs to be submitted for nematode analysis.

Use a nematode sample container, as provided by the Cooperative Extension Service, or a plastic bag for nematode samples. Put samples in containers as soon as possible. Nematodes will die if the sample is allowed to dry, and it is important that nematodes are living when the sample arrives at the laboratory.

### Sample storage

Soil and root samples should be regarded as perishable, handled accordingly, and processed as quickly as possible. Ideally, they should be stored at 10-15°C (50-58°F). Samples should not be exposed to direct sunlight or stored in trunks of automobiles. Temperatures greater than 40°C (100°F) will kill nematodes.

### How to submit samples

Samples should be submitted through the local Extension office, accompanied by a completed form, or to an appropriate private nematode laboratory (Fig. 16). The information requested on the Extension form is essential for diagnosis of nematode problems and subsequent management recommendations. It generally takes two weeks from the time a sample is submitted until the results are returned to the grower by the local Extension agent.

### Results and Recommendations

All results and recommendations will be returned to the grower directly, by the local Extension agent or by a crop consultant. The types and numbers of nematodes will be recorded on the assay report form, along with an indication of whether or not nematodes are a problem (Fig. 17). If nematodes appear to be a problem, you will be referred to the control section of this bulletin for a recommendation. If necessary, the recommendation should be discussed in detail with the local Extension agent or crop consultant.

## Orchard Nematode Control

Several nematode control procedures are generally required to prevent or alleviate nematode problems in Michigan apple, cherry or peach orchards. These include procedures such as cover-cropping, fallowing, soil fumigation, nonfumigant nematicides, nematode population

Fig. 16. Nematode sample form properly completed for a future peach orchard site.

**MICHIGAN COOPERATIVE EXTENSION SERVICE**
**MICHIGAN STATE UNIVERSITY, EAST LANSING, MICHIGAN 48824**
**AND U.S. DEPARTMENT OF AGRICULTURE COOPERATING**

**NEMATODE ADVISORY SERVICE SAMPLE SUBMISSION FORM**

**Name** Sam Smith
**Address** RR2CountyRoad3
Fruitville **Zip** 43958
**County** Burke **Township** Monroe
**Section** 16 **Sample Date** 20Aug89
**Sample/Field I.D.** Orchard No. 18
**Soil Type** McBay Sandy Loam

**Present Crop/Plant** Sudax
**Variety** M-42
**Planting Date** 5May89
**Future Crop 19 :** 92 Peach
**Past Crops 19 :** 68 Plum
**19 :** 18 Sweet Cherry
**Nematicide Use** Nemacur 1985
(Name and Treatment Date)

**SAMPLE METHOD (check):** As described in MSU Ext. Bull. E-800 [x] Other (describe) [ ]

**REASON FOR SAMPLE (check):** Problem Avoidance/IPM [ ] Problem Diagnosis [x]

**TYPE OF ANALYSIS REQUESTED**

- [x] Soil and root analysis for root-feeding nematodes ($10, $9 or $8/sample).
- [ ] Foliar nematode analysis ($10, $9, or $8/sample).
- [ ] Verticillium dahliae analysis for potato soil ($5/sample).
- [ ] Soybean cyst nematode race determination ($15/field).

**DISEASE SYMPTOMS**

| Above Ground Symptoms | % of Plants in Field with Symptoms |
|---|---|
| Yellowing | 40 |
| Necrosis | |
| Stunting | 40 |
| Wilting | |
| Other low yields | |

**Distribution (check):**
- [ ] Entire Planting
- [x] Localized
- [ ] Scattered

**Below Ground Symptoms (check):**
- [ ] Galls
- [ ] Excessive branching
- [ ] Rot
- [x] Reduced Growth

Return Results to Sam Smith, Consultants
Address RR2
Fruitville, MI County Burke
Zip 43958

**Previous plum orchard had a root-lesion, dagger and ring nematode problem. Objective of this sample is to determine what additional action is needed before planting a peach orchard in 1991.**

[1] $10/sample for 0-19 samples, $9/sample for 20-49 samples, $8.00/sample for >50 samples.
[2] A billing charge of $5 will be added for all sample lots of quarterly contracts not paid at the time of sample submission.

No. of samples 4 Amount enclosed $ 40.00

**DO NOT WRITE BELOW THIS LINE**

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Number of samples received 1
Samples number(s): 43067
Date received 25Aug90
Amount received $ 0.00

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Fig. 17. Nematode sample results form for a soybean cyst nematode problem site.

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AND U.S. DEPARTMENT OF AGRICULTURE COOPERATING

## NEMATODE ADVISORY SERVICE REPORT

**Name** Sam Smith

**Sample Number** 43067

**Date Received** 25 Aug 90

**Date Processed** 26 Aug 90

**Nematode Analysis Method** [x] C [x] S [ ] BA [ ] VA [ ] SCNRD [ ] OA

**Sample Condition** ______

**PLANT PARASITIC NEMATODES, POPULATION AND THRESHOLD**

| Nematode | Population Soil[1] | Population Root[2] | Risk Index[3] |
|---|---|---|---|
| Root-lesion [x] Penetrans [ ] ______ | 86 | 243 | 4 |
| False root-lesion | | | |
| Root-knot [ ] [ ] Northern | 5 | 23 | 3 |
| Cyst [ ] Soybean [ ] Oat [ ] Sugarbeet [ ] Clover | | | |
| Pinewood | | | |
| Stubby-root | | | |
| Dagger | 9 | | 3 |
| Needle | | | |
| Stunt | | | |
| Lance | | | |
| Sheath | | | |
| Ring | 110 | | 4 |
| Pin | | | |
| Spiral | | | |
| Foliar | | | |
| Other | | | |
| Other | | | |

[1] Nematodes/100 cm³ soil
[2] Nematodes/1.0 g root
[3] Risk Index
0 = None detected
1 = Low
2-3 = Moderate
4 = High
5 = Severe

Sample Fee $ 10.00
Billing Fee $ 5.00
Amount Billed $ 15.00

**OCCURRENCE OF BENEFICIAL NEMATODES**

Saprophagous Nematodes CM
Predaceous Nematodes FW
Endomycorrhizal Fungi CM
Nematode Trapping Fungi NN

NN = none AB = abundant
FW = few EX = extreme
CM = common

**DIAGNOSIS:**
Nematode problem site [x]
Disease complex problem site [ ]
Possible problem site [ ]
Future problem site [ ]
Possible future problem site [ ]
No problem detected [ ]

**GENERAL RECOMMENDATION:**
Action advisable [x]
Employ tactic on a trial basis [ ]
Refer to MSU Ext. Bulletin No.
E-154 pages 86-87
______ pages ______

No action strategy available [ ]
Submit root sample [x] Fall of 1992
Submit additional soil sample [x] ______
No action required at this time [ ]

**SPECIFIC RECOMMENDATIONS/COMMENTS:**
- Nematode problem site
- Replant to Sudax in 1991
- Cut & disc Sudax in mid-August
- Fall soil fumigation with Telone II or Vorlex recommended

______
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monitoring and tolerant cultivars. Proper integration of these procedures requires long-term planning. This should begin during orchard site selection or upon making the decision to replant an orchard site, and continue through the maintenance of the non-bearing trees. The objective of this section is to provide information on the nematode control procedures available for use during orchard site selection and development, and to guide the use of soil fumigants and nonfumigant nematicides.

**Considerations prior to removal of old orchard**

Before removing an orchard, determine the severity of potential nematode problems as follows:

- Examine the general top vigor and root condition of the trees.
- Examine the soil structure for problems such as faulty drainage and hardpan.
- Make a complete chemical analysis of the soil and foliage to serve as a basis for adjusting soil pH and fertility. Low pH can increase risk to other nutrient disorders and infectious diseases. Information concerning the various soil and leaf tissues is available through an agricultural nutrient testing laboratory.
- Examine the soil and roots of old trees for plant parasitic nematodes (see section on Nematode Problem Detection, pages 6-8).
- Appropriate nematode management recommendations will be made if the population density of the nematodes present is equal to or above the action threshold (Table 4).

**Soil preparation immediately after orchard removal**

- Work the soil and remove as many of the remaining roots as possible.
- Plant a suitable covercrop. Sudan grass and sudax can reduce most potential orchard nematode problems in Michigan. Procedures that increase organic matter and biological diversity in the soil will decrease nematode problem risk.
- Do not plant new trees until <u>at least</u> one year after removal of the old orchard.

**Soil preparation during fall before planting new trees**

- Work the soil to remove any remaining tree roots, and incorporate organic matter.

**Table 4. Nematode population management action thresholds for Michigan apple, cherry and peach production systems.**

| Nematode | Sample Date Action Threshold/ 100 cm³ soil + 1.0 g root | | | |
|---|---|---|---|---|
| | March to May | May to August | August to November | November to March |
| Root-lesion | 15 | 20 | 30 | 30 |
| Root-knot | 10 | 15 | 20 | 20 |
| Stubby-root | 15 | 20 | 30 | 30 |
| Dagger | 1 | 1 | 1 | 1 |
| Lance | 10 | 15 | 20 | 20 |
| Ring | 50 | 100 | 150 | 100 |
| Needle | 5 | 5 | 5 | 5 |

**Table 5. Soil Fumigant Compounds, Formulations and Toxicity.**[a]

| Common Name | Trade Name | Chemical | Formulation | Toxicity VA[b] | OA[c] |
|---|---|---|---|---|---|
| Methyl bromide | Brom-o-gas Meth-o-gas | Methyl bromide | Gas | 200 | -- |
| 1,3-D | Telone II | 1,3-dichloropropene | Volatile liquid | 500 | 250 |
| 1,3-D chloropictrin | Telone C-17 | 1,3-dichloropropene + trichloronitromethane | Volatile liquid | -- | -- |
| 1,3-D + MIC | Vorlex | 1,3-dichloropropene + methyl isothiocyanate | Volatile liquid | -- | 100 |
| Metham | Vapam | Sodium methyldithio-carbamate | Emulsifiable | -- | 820 |

a Soil fumigant recommendations for Michigan fruit production are presented in the annual CES Bulletin E-154, Fruit Spraying Calendar.

b Vapor acute toxicity — the amount, in parts per million, in the air that could be fatal in a single exposure by inhalation.

c Oral acute toxicity — the amount, in milligrams per kilogram of body weight, that could be fatal in a single exposure by ingestion.

- Subsoil if necessary.
- If the population density of one of the seven plant parasitic nematodes of concern in Michigan orchards is above the action threshold, a soil fumigant or nematicide may be recommended (see Table 4, and sections on soil fumigants, nematicides and chemical control recommendations).
- Follow appropriate pH and soil fertility recommendations.

**Spring soil preparation and planting**

- If a fumigant was applied, aerate the soil by cultivation.
- Follow appropriate soil fertility, irrigation and planting recommendations.
- Plant nematode-free trees.
- If recommended, plant trees in fumigated or nematicide-treated orchard soil.
- Plant trees in a manner designed to allow unrestricted growth and development of root systems.

High quality nursery stock produced on nematode-free, fumigated or nematicide-treated soil is essential for the development of a healthy young orchard. Since many plant parasitic nematodes live in root tissue, they can be introduced into orchard sites in nematode-infested nursery stock produced on nontreated soil. While existing nursery certification programs do not assure that nursery stock is free of plant parasitic nematodes, the small additional cost of purchasing high quality nursery stock grown in nematode-free or nematicide-treated soil should be considered as an important first step in the prevention of orchard nematode problems.

## Cultural, Biological and Chemical Control

Cultural, biological and chemical tactics have potential for use in nematode control in Michigan fruit production. The cultural control tactics are discussed in the previous section of this Bulletin. Biological control tactics may involve either naturally occurring organisms or purchased inputs. The recommended cultural controls are designed to enhance naturally occurring biological factors. Relatively few biological control products are currently available. This, however, will be changing. Clandosan and entomopathogenic nematodes are early examples. The remainder of this section will be divided into fumigant and nonfumigant nematicides.

## Soil Fumigants

Soil fumigants are pesticides that exert their toxic action as gases. Most are halogenated hydrocarbon compounds (Table 5). They can be formulated and sold as gases, gels, volatile liquids, emulsifiable concentrates or granules. All formulations volatilize when applied, and move through the soil as a gas. They are absorbed or actively taken into the pest, resulting in death of the target organism. Soil fumigants can be used for control of nematodes, soil fungi, weeds and soil insects. Not all fumigants are active against all of these pests, and frequently a specific material or rate is required for control of a specific pest or group of pests.

### Fumigants, formulations and containers

Gaseous and liquid formulations of soil fumigants are frequently recommended for control of plant parasitic nematodes in Michigan orchards.

- Gases—Gaseous formulations of soil fumigants are sold in 1- or 2-pound seamless cans or pressurized cylinders similar to the acetylene tanks used in welding. Various sizes of cylinders are available, ranging from 10 to 2,400 pounds.

- Volatile liquids—Soil fumigants that exist as liquids at normal temperatures are the most commonly used materials. They are sold in 5-, 30- or 55-gallon metal or plastic drums. The liquid volatilizes and becomes gas when injected into the soil.

### Factors influencing fumigant action

For satisfactory nematode control, soil fumigants must be injected into properly prepared soil. Factors such as soil structure, ground trash, soil moisture, soil temperature, soil type, time of application, soil sealing, exposure period and soil aeration influence fumigant action in soil. All of these must be considered before beginning a soil fumigation operation. Most soil fumigants are toxic to plants and are registered for use only on a preplant basis.

**Soil structure**—Proper tilth is an important factor with regard to penetration of fumigants through soil. Fumigants will not move well in compacted soil and good pest control will not be achieved. Cultivation prior to soil fumigation is essential. The soil should be free of clods and worked into a good seedbed condition.

**Ground trash**—Excess debris such as decaying plant material is detrimental to soil fumigation. Soil fumigants are absorbed by organic debris. This prevents the chemical from penetrating the soil and providing good pest control. Existing vegetation should be cut or chopped and worked into the soil three to six weeks prior to fumigation. Excess organic matter can also clog fumigation chisels.

**Soil moisture**—Soil moisture has a direct influence on the movement of fumigants through soil. Too much soil moisture prevents movement of the fumigant and not enough soil moisture allows the chemical to escape from the soil too rapidly. Good seedbed condition provides the proper soil moisture for fumigation. The soil should barely retain its shape when squeezed in the palm of the hand.

**Soil temperature**—Soil fumigants should be applied when the temperature at a soil depth of 6 to 8 inches is 50° to 80°F. Some fumigants may be applied when the soil temperature is between 40° and 50°F. Pest control, however, may not be as good as with the higher range of temperature. Fumigants will not volatilize and penetrate uniformly throughout the soil if the soil temperature is below 50°F. Above 80°F, the fumigant will volatilize too rapidly and be lost from the soil prior to the optimum exposure time for pest control.

**Soil type**—For fumigation purposes, Michigan agricultural soils can be divided into mineral and organic (muck) soil. Because of the absorptive properties (absorption and adsorption) of the soil fumigants in organic soils, it is necessary to use higher rates when fumigating muck soils. In most cases, a rate approximately two times the fumigant rate recommended for mineral soils is required for good pest control in organic soils.

**Time of application**—It is usually best to apply soil fumigants in Michigan in early fall. They can, however, be applied in the spring. At this time, it is much more difficult to obtain proper soil temperature, moisture and structure. If spring fumigation is followed by a period of cold and wet weather, the waiting period prior to planting must be extended to prevent the possibility of severe phytotoxicity.

**Soil sealing**—Because of rapid surface volatilization, the first several inches of the soil are the most difficult area for pest control. A temporary soil seal is necessary to maintain a lethal concentration of the fumigant. This can be achieved by cultipacking, rolling, dragging or lightly irrigating the soil immediately after fumigation in this region. With fumigants formulated as gases, such as methyl bromide, it is necessary to cover the treated area with a plastic tarpaulin either before or immediately after fumigation. Some Michigan fruit growers use soil fumigants to control nematodes below the upper four inches of soil, and phosphate or carbamate nematicides to control nematodes close to the soil surface.

**Exposure period**— With most soil fumigants, an exposure period during which the soil is left undisturbed is necessary after application and sealing. The length of the exposure period depends on the fumigant used, rate applied, and environmental factors such as soil temperature and moisture. The pesticide label should be used to determine the proper length of the exposure period for each specific soil fumigation operation.

**Soil aeration**—Fumigated soil should be aerated at the end of the fumigant exposure period, prior to tree planting. The soil should be tilled to the depth of the fumigant treatment zone.

**Phytotoxicity**—The potential of phytotoxicity must always be considered before soil fumigants are applied. Most soil fumigants are phytotoxic and, depending on the dosage, must be applied several weeks or months before a crop is planted. A few plants are so sensitive to specific soil fumigants that they cannot be planted for several years after treatment.

Phytotoxicity is influenced by soil type, temperature, moisture, tilth and type of plant grown. The pesticide label must be used to determine the potential phytotoxicity of a soil fumigant to a specific crop plant.

**Application types**

Soil fumigants can be used for control of specific nematodes, fungi, weeds and insects in greenhouses, topsoil, seedbeds or small areas in fields, individual tree sites, in larger agricultural sites and numerous other situations. Most oil fumigants must be applied on a preplant basis.

**Small areas**—Small areas in orchards can be treated with gaseous or liquid fumigants. If a gaseous formulation is used, the procedure is similar to that used for fumigating greenhouse soil. A small ditch should be dug around the outside of the area to be treated, and a polyethylene or plastic-coated nylon tarpaulin used to cover the area. If a volatile liquid or emulsifiable concentrate fumigant is used, the chemical should be injected to a depth of 6 to 8 inches below the soil surface and the area tightly sealed.

**Tree sites**—Individual sites to be used for planting orchards or ornamental trees and shrubs can be fumigated with a gaseous or volatile liquid formulation. The center of the site should be marked and the fumigant injected into the soil. The size of the area to be treated depends on the size of the tree to be planted. The injection hole(s) should be sealed and, in some cases, an appropriate cover may be needed.

**Orchard treatments**—Soil fumigants can be applied in a number of ways in orchards. Volatile liquids are most commonly used. In orchards, it is frequently most economical to use a strip treatment. Only the areas where the trees are to be planted are fumigated. In most Michigan tree fruit orchards, a 7- to 8-foot strip is fumigated and the trees planted in the center of the strip. If the rows in the orchard are 24 feet apart, then only one-third of the area is fumigated.

**Subsoil fumigation**—In some situations it may be necessary to inject fumigants to soil depths greater than those achieved with normal chisel application equipment. Nematode control in vineyards is one example where it is essential to control dagger nematode populations to as great a depth as possible. Deep applications can be made with subsoil shanks. Fumigant rates must be adjusted because of the greater area treated. This can be done on a broadcast, strip or row basis. Deep applications of soil fumigants are often made when treating individual tree sites.

**Fumigation equipment**

Various types of soil fumigant applicators are commercially available. These generally meet fumigation needs; however, in some cases it is necessary to have equipment custom-designed and built for specific purposes. Fumigation equipment is not usually expensive. Many Michigan growers, however, either rent fumigation equipment or obtain it on a loan basis from their fumigant supplier. Regardless of the type of fumigation equipment used, proper care is essential. Appropriate soil sealers or drags should follow or be attached to the fumigant applicator. Most soil fumigants are highly corrosive and if fumigators are not constructed from materials tolerant or resistant to these chemicals, they will be damaged. It is also essential that all application equipment be cleaned and stored with the system at least partially full of lightweight fuel oil.

**Gaseous formulations**—Several simple devices are commercially available for puncturing 1- or 2-pound seamless cans of gaseous soil fumigants and releasing the chemical through a plastic tube to an evaporation pan placed under the sealed plastic. **Always use an approved, commercially-designed opening dispenser!** The fumigant flows under pressure from the can to the soil to be fumigated. Large cylinders of gaseous fumigants require valves and pressure regulators to control the delivery of the gas to the evaporation pan. A separate pressurized cylinder of nitrogen should be used to maintain a constant pressure in the fumigant cylinder and insure application of the chemical at a uniform rate. Equipment used with pressurized cylinders can be complex. One must be certain that all aspects of the system are designed to deliver and withstand the fumigant under pressure.

When gaseous formulations are used for fumigation on a **broadcast or strip basis**, a manifold is added to assure even distribution of the gas to the chisel or shank injectors. The injectors should be mounted 12 inches apart on a tool bar connected directly to a tarping machine. The most commonly used tarping machine consists of two discs that open small furrows immediately outside the area to be treated. Rolled polyethylene is mounted on the tarp machine and unrolled over the treated area; small press-wheels insert the tarp into the open furrows. The tarp is sealed with soil thrown back into the furrow by closing discs. This type of fumigant applicator is suitable for strip application. The rate of application depends on the speed the rig is driven and the rate of flow of the chemical. To treat a field on a broadcast basis with a gaseous formulation, one strip is applied as described above and then one set of discs removed and replaced with an adhesive dispenser.

One side of the second tarp is sealed with the adhesive to the first tarp, and the other side of the second tarp is sealed in the furrow made by the remaining discs. This is repeated, and the entire field is fumigated and covered with polyethylene.

Augers for site injection of gaseous formulations are available. They can be used with either the 1- or 2-pound seamless cans or with large cylinders of gaseous fumigants. Augers for site injection are powered by a large, electrically operated drill or a hydraulic system.

**Liquid fumigants**—Chisel applicators are used to inject volatile liquid fumigants to a soil depth of 6 to 8 inches. The chisels are mounted 10 to 12 inches apart on a tool bar. The fumigant is injected to a soil depth of 6 to 8 inches. This equipment can be used for broadcast and strip application. The applicator may be either pump- or gravity-flow driven. The fumigant passes through a manifold where its rate of flow can be regulated and the proper amount of material metered to each chisel through plastic tubing. Filter screens and metering orifices are usually used in the manifold. Several types and sizes of gravity flow- and pump-driven chisel fumigation applicators are commercially available. Broadcast application of soil fumigants can also be made with a fumigant applicator mounted on a bottom plow. These applicators usually work on the gravity flow principle.

Applicators for strip fumigation are similar to broadcast treatment except that fewer chisels are used. The fumigant is only applied where the crop is to be planted and this area must be marked. This is usually done with a small disc or lister hiller. Subsoil-bedders are also excellent for row application of liquid fumigants.

**Drenchers**—Drenchers consist of a container for the emulsifiable concentrate and a metering device for depositing the fumigant on the soil. They are not used very often in Michigan. Pest control may not be adequate unless the fumigant is worked into the soil.

**Irrigation**—Application of soil fumigants in irrigation water is not presently a common practice in Michigan. It may hold some promise for future post-plant application of fumigants. Because of the nature of the fumigants in relation to irrigation equipment, a professional fumigation consultant should assist in the design of any system to be used for application of soil fumigants in irrigation water.

**Applicator calibration**

All fumigant applicators must be calibrated to deliver the desired rate of pesticide. All commercially constructed applicators are designed so that fumigant rates can be altered. Applicator calibration is usually done by applying the fumigant over a small area (or for a short time), measuring or weighing the amount of fumigant used, computing the amount per acre equivalent to the amount measured or weighed, and adjusting the equipment to more closely approach the desired amount. This may be repeated several times until the equipment has been adjusted to deliver the exact amount required per acre.

A useful equation for determining the desired amount of fumigant per acre is:

$$A = \frac{W \times D \times R}{43560}$$

where A is the amount that should be delivered, W is the width (in feet) of the test swath, D is the length (in feet) of the test swath, and R is the desired amount (in pounds or gallons) per acre. For example, if you wished to apply 50 gallons of fumigant per acre (R=50) and are testing the equipment on an area 8 feet wide (W=8) and 100 feet long (D=100):

$$A = \frac{W \times D \times R}{43560} = 0.918 \text{ gal.}$$

Some figures to keep in mind while checking your calibration are:

| | | |
|---|---|---|
| 1 acre | = | 43,560 square feet |
| 1 gallon | = | 128 fluid ounces = 8 pints = 4 quarts |
| 1 gallon | = | 3,785 milliliters (ml) |
| 1 fluid ounce | = | 29.57 milliliters (ml) |
| 1 pound | = | 16 ounces = 453.6 grams (gm) |
| 1 mile per hour | = | 88 feet per minute = 1.467 feet per second |

**Gaseous formulations**—The number of 1- or 2-pound seamless cans of gaseous fumigant necessary for good pest control depends on the volume of soil to be treated and the previously discussed environmental parameters. When pressurized cylinders are used, calibration is accomplished by weighing the cylinder, releasing a small amount of fumigant for a known period of time, and then reweighing the cylinder. The rate can be calculated after determining the area covered during the period of time. The rate of flow is then adjusted with the pressure regulator valve. Additional test fumigant releases are made as necessary and the cylinder reweighed. This is repeated until the proper rate is obtained.

Problem 1 — Methyl bromide is used in a fruit nursery at a broadcast rate of 350 pounds/acre for control of nematodes, weeds and soil-borne fungi. The grower will apply the chemical with a tarp machine that is 8 feet wide. The tractor and chisel will be operated at 2.0 miles per hour. How many pounds of methyl bromide must be deposited by the fumigant applicator every 30 seconds for proper calibration?

Answer to Problem 1 — The test swath covered is 8 feet wide (W=8) by 88 feet long (D+88; 2 mph x 1.467 ft./sec x 30 sec).

$$A = \frac{8 \times 88 \times 350}{43560} = 5.66 \text{ gal.}$$

Volatile liquids—Both ground-driven and tractor-speed-dependent fumigation equipment can be used to apply volatile liquid and emulsified concentrate soil fumigants. Tractor speed does not have to be taken into consideration in the calibration of most ground-driven equipment; however, it must be used in the calibration of gravity flow and tractor-speed-dependent equipment.

Problem 2 — An orchard soil is to be fumigated on a broadcast basis using a formulation of 1,3-D at 30 gallons per acre. The fumigant applicator is 12 feet wide and uses a ground-driven pump to supply the chemical to the chisels. The applicator is equipped with 12 chisels, each spaced 12 inches apart. How much 1,3-D should be deposited by each chisel during a calibration test over a swath 100 feet in length?

Answer to Problem 2 — During the calibration test, each chisel covers 1 foot wide (W=1) by 100 feet long (D=100).

$$A = \frac{1 \times 100 \times 30}{43560} = 0.1148 \text{ gal. (14.7 fl. ounces)}$$

**Safety**

**Fumigants are penetrating toxic gases.** They are a very special hazard because of this and must be handled with full precautions. The first element in safety is to **READ THE LABEL** of the container before you buy the fumigant. Be sure that you read and understand all the instructions, particularly those dealing with the safe storage, handling and application of the fumigant. Always use all of the safety equipment (gloves, respirator or gas mask, and goggles, for example) that is required. Equipment is probably available where you buy the fumigant. Most fumigants are hazardous if inhaled or in contact with the skin. An emergency supply of water should be available at all times. Some fumigants are irritating to the skin or eyes and a few are vesicants (cause burns or blisters on the skin). All of the fumigants can cause poisoning by a single large exposure. Some can cause poisoning through repeated small exposures. The label will have information on how the specific fumigant is hazardous, symptoms of poisoning, and first aid in case of poisoning. Be sure to read these instructions. Instructions to a physician on treating the poisons are also given. In case of poisoning, be sure to take the container along with the victim to the doctor.

Storage of fumigants is a hazard. They should be purchased just before use whenever possible to shorten the storage period. Store them on sturdy shelving in an area apart from food, feed or seed. They are best stored in a separate building that can be well ventilated and securely locked. The storage area should be posted to warn others of the presence of the fumigants. Fumes can escape from faulty valves or from damaged or corroded cans and build up to a dangerous concentration in closed storerooms. Valves and containers should be checked frequently for possible leaks. The ventilator should be run to clear the air before entering the storage area.

All equipment, including safety equipment, should be thoroughly checked and adjusted before use. Check that approved pressure components are used, and tightly sealed. Make sure that all components will withstand the corrosiveness of the fumigants. Time of exposure to the fumigant is reduced by getting everything set before the fumigant container is opened. Be especially sure that there is adequate ventilation if you are using fumigants indoors.

**A special word of warning**: Fumigants can be especially hazardous under special circumstances. The instructions and precautions for their use are written for "normal" operations and cannot include all unusual combinations. The best rule to follow is: If you are in doubt as to the safety of the fumigant, do not use it.

## Nonfumigant Nematicides

Nonfumigant nematicides, organophosphates, or organocarbamates are available for nematode control. Although they are relatively nontoxic to plants, they are highly toxic to animals. Nonfumigant nematicides are dispersed through the soil by incorporation and soil moisture. Some nonfumigant nematicides are systemics. In addition to direct toxicity, nonfumigant nematicides may inhibit numerous aspects of nematode behavior. Application equipment is readily available and environmental constraints on application are somewhat less than for fumigants. Although nonfumigant nematicides have been available for less than a decade, there are several alleged cases of nematode resistance and a number of very significant environmental concerns. Many organophosphate and organocarbamate insecticides, fungicides and herbicides reduce populations of plant parasitic nematodes.

Oxamyl (Vydate®) and phenamiphos (Nemacur®) are registered in Michigan for nematode control in orchard site development and nonbearing tree maintenance (Table 6). These materials provide nematode control when applied to the soil. Oxamyl can be used as a root dip or foliar spray.

**Formulations**—Oxamyl and phenamiphos are formulated as liquid solutions (L,S,F). Vydate 2L contains 2 pounds of active ingredient per gallon, whereas Nemacur 3S contains 3 pounds of active ingredient per gallon. Both nematicides must be diluted with water. These nematicides are frequently tank-mixed.

**Application Equipment**—The nematicide application equipment used is important to the success of nematode control. First select the right kind of application equipment, and then use it correctly. Both low- and high-pressure sprayers can be used to apply Nemacur 3S or Vydate 2L to the soil. Air blast

**Table 6. Nonfumigant nematicides for Michigan apple, cherry and peach production.[a]**

| Common Name | Trade Name | Chemical | Formulation | Toxicity VA[b] | Toxicity OA[c] |
|---|---|---|---|---|---|
| Oxamyl | Vydate 2L: | Methyl N',N'-dimethyl-N -((methylcarbamyl)oxy)-1-thio -oxamimimidate | liquid 2 lb gal. | 2960 | 5.4 |
| Phenamiphos | Nemacur 3S | Ethyl-3-methyl-4-(methylthio)phenyl(1-methyl ethyl) phosphoramidate | liquid 3 lb gal. | 154 | 24 |

a Nonfumigant nematicide recommendations for Michigan fruit production are presented in CES Bulletin E-154, Fruit Spraying Calendar.

b Dermal acute skin absorption, $LD_{50}$ (male rabbits)

c Oral acute toxicity, $LD_{50}$ (male rats) equipment is appropriate for foliar applications of Vydate 2L only. Only commercially purchased applicators should be used for the application of Nemacur or oxamyl granules. Proper calibration is essential for nematode control.

## Chemical Control Recommendations

Plant parasitic nematodes can cause extensive injury to tree fruit crops. Research has shown that many fruit crops respond to nematicides. As a first step, however, it is important to purchase high quality nursery stock produced on nematode-free, fumigated or nematicide-treated soil. Populations of plant-parasitic nematodes can be reduced below fruit-crop injury levels through fallowing, use of cover crops and application of fumigant or nonfumigant nematicides. Soil fumigation or use of a nonfumigant nematicide prior to planting in old fruit sites is often essential for development of healthy and productive orchards and vineyards (Table 7).

Proper soil preparation prior to soil fumigation is essential for maximum effectiveness. The soil should be cultivated to promote thorough decomposition of previous crop debris. Undecayed roots harbor nematodes, protect them from nematicide contact and interfere with fumigant application. The soil should be in excellent tilth and soil moisture should approach that desirable for seeding. Dry soil allows too rapid escape of fumigants. Dispersion of fumigants in excessively wet soil is poor. At soil temperatures below 50°F, soil fumigants do not volatilize and spread properly. Above 80°F, the materials escape too rapidly from the soil. Late summer or early autumn is usually best for the application of soil fumigants in Michigan.

While detailed soil preparation procedures are not as important for nonfumigant nematicides as for soil fumigants, proper soil cultivation and moisture conditions influence the movement of the nematicides. Soil temperature also has less influence on nonfumigant than on fumigant nematicides. In general, the recommended rate of a nonfumigant nematicide is the same for both mineral and organic soils.

Where need for control of plant-parasitic nematodes has been established, nematicides may be recommended as described in E-2199, *Detecting and Avoiding Nematode Problems*. All tree fruit nematicide recommendations for Michigan are presented in CES Bulletin E-154, *Fruit Spraying Calendar*.

**Table 7. Nematicides can be used in apple, cherry and peach orchard establishments in the following ways:**

| Orchard Establishment |
|---|
| 1. Preplant<br>a. Broadcast<br>b. Row<br>c. Site |
| 2. At-planting root dip |
| 3. Nonbearing post-plant<br>a. Soil<br>b. Foliar |
| 4. Bearing post-plant soil application |

## Appendices

**Appendix 1.** *Pratylenchus* spp. Taxonomic Description (after Thorne, 1961). — Pratylenchinae. Stout, cylindroid nemas less than 1.0 mm in length, with relatively broad heads and bluntly rounded tails. Phasmids located 1/3 of tail length or more behind latitude of anus. Lip region set off by a narrowing of the head. Cephalic framework sclerotized, refractive. Spear strong, 14 to 19 um long, with massive basal knobs. Median esophageal bulb spheriod, more than half as wide as neck. Basal bulb extending back over intestine, usually in a lateroventral position. Three prominent esophageal gland nuclei. Esophageal lumen and intestine joined by an obscure muscular valve. Excretory pore prominent, about opposite nerve ring. Intestine packed with numerous dark granules. Slender, muscular rectum ending in a transverse, slitlike anus. Vulva a depressed transverse slit, vagina extending in and slightly forward. Anterior ovary outstretched, with oocytes arranged in a single file except for a short region of multiplication. Posterior uterine branch rudimentary. Males known in about half the species. Bursa enveloping tail, with phasmids located near its base. Spicula slightly arcuate, resting on a thin, troughlike gubernaculum. Testes outstretched, with spermatocytes irregularly arranged, especially in region of multiplication.

**Appendix 2.** *Hoplolaimus* spp. Taxonomic Description (after Sher, 1963). — Hoplolaiminae. Lip region set off, with longitudinal striations; cephalic framework massive. Spear knobs massive, with anterior projections. Dorsal esophageal gland opening near base of spear knobs (1/4 or less the spear length). Esophageal glands overlapping intestine dorsally and laterally, with three to six nuclei. Excretory pore above or below hemizonid. Female tail round, shorter than width of body at anus. Phasmids (scutella) enlarged, not opposite one another on each side of the body. Lateral field with four or fewer aerolated incisures.

**Appendix 3.** *Xiphinema* spp. Taxonomic Description (after Thorne, 1939). — Longidorinae. Spear greatly attenuated with long extensions bearing basal flanges. Guiding ring located near base of spear. Esophagus beginning as a slender, coiled tube which is straight only when the spear is extruded. This slender portion suddenly expands to form the elongate basal bulb which usually is about three times as long as the neck width. Dorsal esophageal gland nucleus at extreme anterior end of bulb. Intestinal cells packed with coarse refractive granules. Prerectum present. Vulva transverse. Ovaries one or two, reflexed. Spicula with lateral guiding pieces. Supplements consisting of an adanal pair and a ventromedian series, two testes.

**Appendix 4.** *Criconemella* spp. Taxonomic Description (after Raski and Golden, 1965). — Criconematinae. Body fusiform with annules, generally coarse and retrorse with plain, irregular or finely serrated margins. Stylet knobs with forwardly-directed processes. Tail short and conical or broadly rounded. Males with two, three or four incisures in the lateral fields that extend on to the tail on narrow caudal alae that reach almost to the terminus. Development through juveniles that have smooth or crenated annules or with rows of scale-like cuticular protrusions.

**Appendix 5.** *Trichodorus* spp. Taxonomic Description (after Thorne, 1961). — Trichodorinae. Plump nemas with blunt, rounded tails, and thick cuticle. Onchiostyle, dorsally arcuate and slender. Amphids elongate, pocketlike, with ellipsoid apertures. Esophagus with a pyriform basal bulb containing three large and two very small gland nuclei. Two ovaries, reflexed. Testis single and outstretched. Males of certain species with bursae. Gubernaculum present.

**Appendix 6.** *Meloidogyne* spp. Taxonomic Description (after Allen, 1952). — Meloidogyninae. Marked sexual dimorphism. Adult females pear-shaped to spheroid with elongated neck. Body not transformed into cyst. Spear slender with weakly developed basal knobs. Excretory pore located anterior to median bulb, usually 12-25 annules posterior of lip region. Vulva terminal or subterminal. Anus opening on border of slight depression occupied by vulva. Cuticle of female with simple cross annulation, forming a variable more or less circular pattern in perineal region. Eggs not retained in body, but deposited in a gelatinous matrix. Females usually endoparasitic, causing formation of galls or knots on roots of most hosts. Obligate plant parasites. Males elongate cylindrical. Lip region with or without distinct annulation, bearing a cap-like structure. Spear strongly developed with well-developed basal knobs. Bursa absent. Spicules and gubernaculum present. One or two testes, out-stretched anteriorly, sometimes reflexed at distal end. Second-stage infective juveniles with slender spear and with well-defined basal knobs.

**Appendix 7.** *Longidorus* spp. Taxonomic Description (after Thorne, 1961). — Longidoridae. Body and stylet greatly attenulated. Guiding ring located near lip region. Esophagus reduced to a slender, flexible tube with an elongated basal bulb. The dorsal and the anterior pair of submedian gland nuclei are easily visible, while the posterior submedian pair is rather small and obscure. Ovaries two, reflexed, and very short compared with the total body length. Vulva transverse.

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