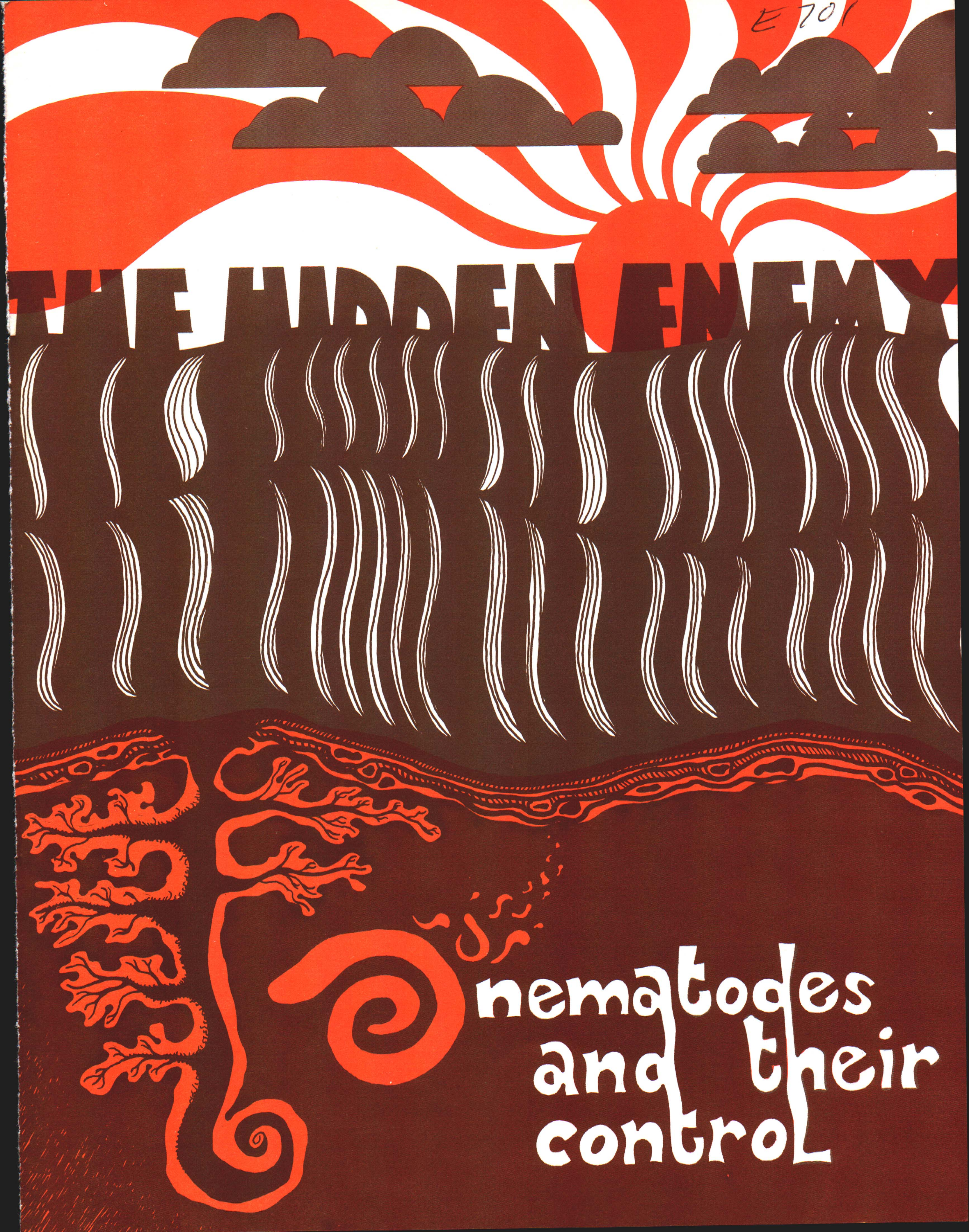
THE HIDDEN ENEMY
nematodes and their control

Nematodes and Their Control

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Nematodes cost Michigan farmers millions of dollars in crop losses annually. More important, perhaps, is the fact that we are often unaware of the total loss caused by nematodes or of the extent of their spread. As a result of nematode soil infestation, thousands of acres of once highly productive Michigan farmland have been abandoned because adequate yields could no longer be obtained. This land has been mislabeled "exhausted or tired soil".

Nematodes are thread-like, round worms (Figure 1). They are NOT a stage of insect development, nor are they closely related to earthworms. Nematodes are multicellular, non-segmented, animals. These animals have reproductive, nervous, and excretory systems, but lack respiratory and circulatory systems. Nematodes are not able to regenerate or repair damaged tissue, so that nearly any injury is fatal. Their body cells are constant in number from the early larval stages. Therefore, growth results from increases in cell size. Adult plant parasitic forms range in length from 1/125 to 1/5 inch.

NEMATODE GROUPINGS

Plant nematodes can be divided into two major groups according to their method of parasitism: ectoparasites and endoparasites (Figure 2). An ectoparasitic nematode spends its entire life cycle outside of the host but feeds on the plant tissues by inserting its spear or stylet into the plant. Ectoparasitic nematodes of economic importance in Michigan include the dagger, stubby root, ring and stylet nematodes.

An endoparasitic nematode spends part or all of its life cycle feeding within the plant tissues. Examples of endoparasitic nematodes which attack Michigan crops: root-knot, root lesion, cyst, stem and bulb nematodes.

Some nematodes, such as the lance and spiral nematodes, do not fit either classification since they feed both internally and externally. Unlike most external feeders, which only insert the spear or a portion of the head into the host, these nematodes may enter the root as far as one-third of their body length. The females of some nematode species establish a feeding site and never move. These sedentary (non-migratory) parasites, like the cyst and root-knot nematodes, lose their slender, eel-like shape and assume a sac-like or spherical form. Migratory endoparasites feed randomly as they move through a host plant and generally retain their worm-like shape.

REPRODUCTION AND LIFE CYCLE

Mode of reproduction varies among different species of nematodes, but all reproduce by the production of eggs. Nematodes reproduce both sexually and asexually. In species where only females occur, some reproduce parthenogenetically (embryo development without fertilization), while in others, the "female" produces both sperms and eggs (hermaphroditism).

The number of eggs deposited by female nematodes varies with species from less than 100 to more than 2000. A single larva develops from each egg. While

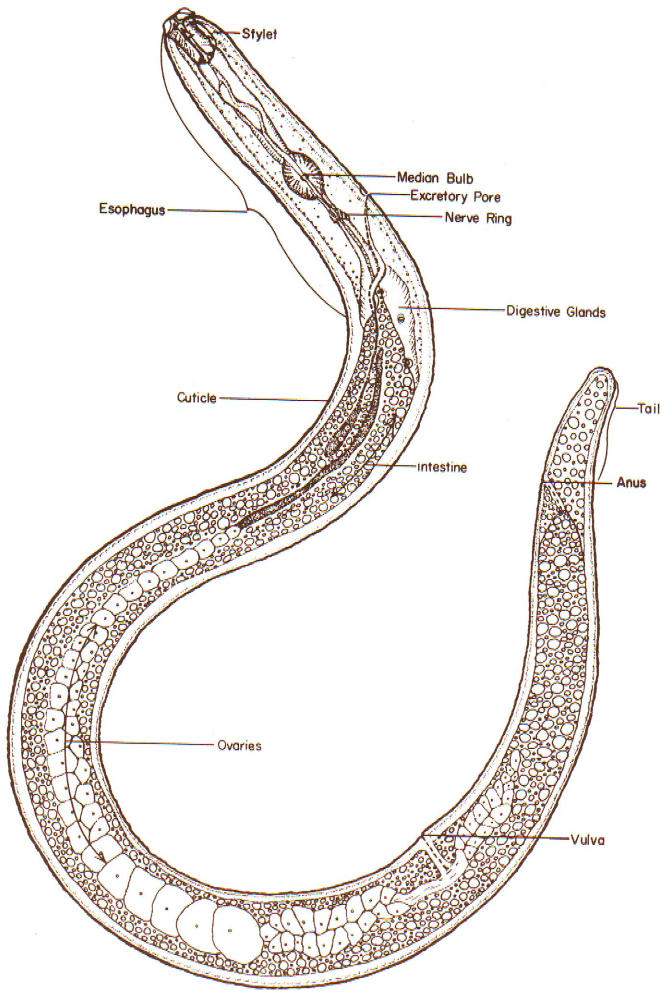

Fig. 1 — A plant parasitic nematode.

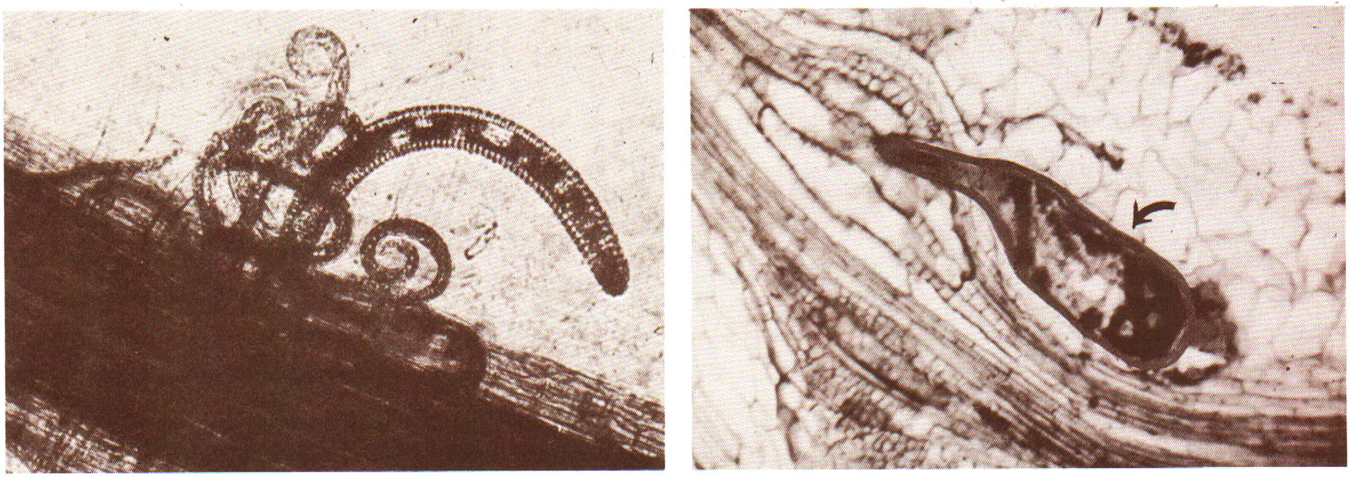

Fig. 2 — Ectoparasitic nematodes pierce the roots from the outside (left), while endoparasitic nematodes partially or totally inhabit the roots (outlined nematode, right).

migrant endoparasitic nematodes deposit most of their eggs within the plant tissue, some are also deposited in the soil. Sedentary endoparasitic species deposit their eggs within or upon the roots and the eggs are held together by a gelatinous matrix. Ectoparasitic species deposit their eggs in the soil near the roots which are being fed upon.

Species of the genus *Heterodera,* the cyst nematodes, differ from most other nematodes in the manner of egg deposition. The female, while depositing some eggs, retains most of them within her body. At death, the body becomes an egg-filled cyst which provides protection for the eggs. When environmental conditions are favorable, and a suitable host plant nearby, the eggs hatch within the cyst and the larvae move through the soil.

The life cycle of nematodes consists of an egg, four larval stages, and an adult stage. Each larval stage is terminated by a moult. Developmental changes, such as increased size and maturity occur with each moult, and culminate in fully developed, sexually mature individuals that can reproduce and start the next cycle. The length of the life cycle varies significantly with different species and variations in the environment.

FEEDING HABITS

Plant parasitic nematodes are true parasites and derive their food from living host plants. Their digestive tract consists of the stylet, the esophagus, digestive glands and the intestine. The stylet is a hypodermic needle-like structure which is used to puncture the plant cell wall and deliver digestive gland fluid into the plant cell. This fluid predigests the plant cell materials, which are then drawn into the nematode by the muscular median bulb (Figure 1). In some nematode species, specialized feeding sites are induced in the host by the feeding parasite. These abnormally large, specialized giant cells provide special food products that can be utilized by the nematode.

It is not the simple mechanical rupturing of plant cells by the stylet, but the host response to nematode digestive secretions, which results in severe plant injury. Root-knot nematodes cause gall and giant cell formation; necrotic spots at feeding sites are incited by root-lesion nematodes; stubby root nematodes devitalize root tips and stunt the root system. Nematodes can mechanically disrupt water conductive tissues or induce cell abnormalities resulting in inefficient translocation of water and nutrients from the soil, through the roots to the above-ground plant parts.

NEMATODE INJURY SYMPTOMS

Symptoms of nematode injury vary with the species of nematode, age of the plant, and the plant part attacked. A generalized classification of nematode damage symptoms follows:

- *Stunted Growth* — Reduced growth results in woody plants with poor vigor and dwarf size. Nematode infested areas in fields of herbaceous crops are often conspicuous due to the stunted appearance of plants growing in these areas in contrast to plants in non-infested portions of a field (Figure 3).

- *Root Galls* — Some feeding nematodes induce gall formations on plant roots. Nematodes may, or may not, be present in the gall tissue. Nematode incited galls should not be confused with nitrogen-fixation nodules on legume roots or bacterial or fungal infections (Figure 4).

Fig. 3 — Stunting of corn growth by plant parasitic nematodes. Plant on the left is non-infected while plant on the right has been stunted by nematodes.

- *Root Lesions* — Root cells destroyed by feeding nematodes result in dark, discolored areas (necrotic regions) on the root system. The size of these root lesions increases with continued feeding and secondary invasion by other soil microorganisms. Eventually, small roots may be completely girdled causing extensive root pruning (Figure 5).
- *Excessive Root Branching* — Certain nematodes feed on young roots, stimulating formation of numerous, short lateral roots near the region of invasion. Such terms as "witch's broom" and "hairy root" have been applied to this abnormality (Figure 6).
- *Injured or Devitalized Root Tips* — Nematode feeding at or near the root tip often induces devitalization of the root tip, though feeding may not actually kill the tissue or cause the root tip to turn brown (Figure 7).
- *Leaf, Stem, Flower and Seed Damage* — Nematodes which attack above-ground plant parts may cause leaf and stem galls, distortion or twisting of stems and leaves, foliar discoloration and lesions, dead or devitalized buds, abnormal development of flower parts and formation of seed galls (Figure 8).

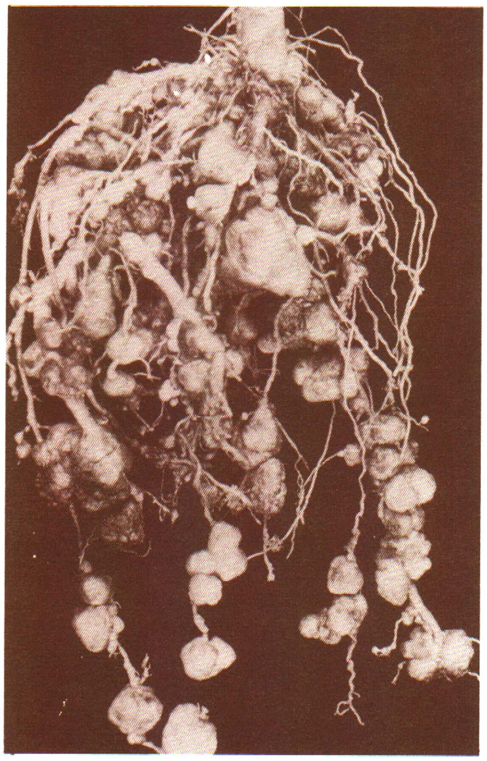

Fig. 4 — Root galls induced by nematodes on tomato roots.

Fig. 5 — Absence of secondary roots and lack of vigor on strawberry plant at left were caused by root-lesion nematodes. Plant at right was grown in nematode-free soil.

DIAGNOSIS OF NEMATODE DISEASES

It is difficult to predict the amount of damage a given population of nematodes can cause in a particular crop and field. Because of all the factors involved, predictions must be based on past production in that field and on the population size and species of the nematodes present. The diagnosis is, of course, more accurate when moderate or high levels of nematode populations, such as lesion or root-knot, are identified from samples. However, these are usually found only in low numbers when crops are not growing. A knowledge of past cropping history is essential for predicting damage in a given field.

Diagnosis is much easier when a crop is in the young to intermediate stages of growth. Symptoms, except for the galls of root-knot, are not distinctive enough for definite diagnosis. The nematode involved must be isolated, identified, and its population estimated. Then, plant symptoms, such as chlorosis, wilting, abbreviated root systems, necrotic tissues, and stunting can be evaluated.

Different nematode species affect host plants differently. And, the same nematode may produce quite different degrees of damage to different hosts. Annual plants are not usually damaged severely unless significant populations of the parasites are present when the plants are young. Thus, large populations of injurious nematodes are frequently found around, and/or in, the roots of healthy-appearing plants.

Anyone may examine the roots of plants or nearby soil and find nematodes. However, it cannot be assumed that they account for plant damage. This assumption would be as false as accusing honey bees of causing stunting because they are observed in flowers. All types of nematodes are attracted to plant roots especially if some type of decay has been started. The most harmful plant parasites, on the other hand, are somewhat repelled by decay. This emphasizes the need for diagnosis when the diseases are in early stages and definite identification of the parasite by an experienced nematologist.

Nematodes usually occur in spots or patches within cultivated fields. Location of these spots is generally the same from one year to the next. Thus, nematode damage is nearly always "spotty", for reasons which are as yet unexplained.

Fig. 6 — "Hairy root" (left) and excessive root branching (right) caused by nematodes in carrots.

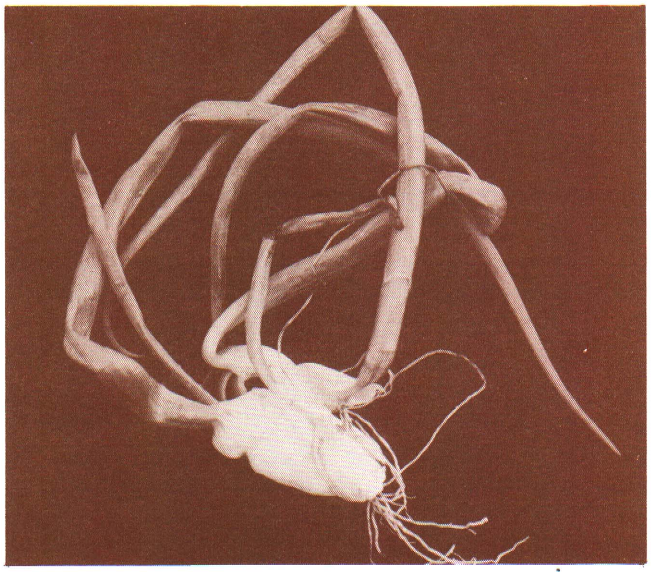

Fig. 8 — Distortion and twisting of onion caused by nematodes attacking above-ground plant parts.

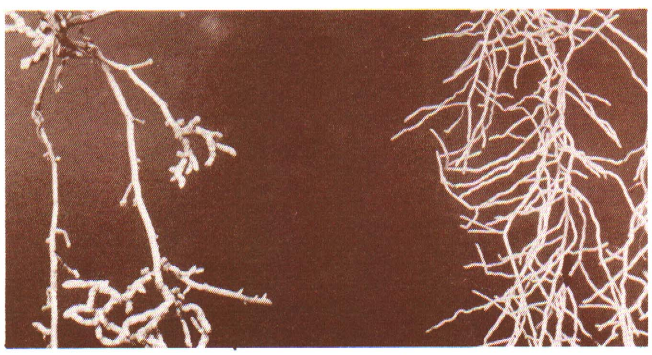

Fig. 7 — De-vitalized root tips caused by nematodes feeding near the root tip (left); normal root tips (right).

DETERMINING NEMATODE PRESENCE

An examination of plant roots and soil taken from around the roots can help determine whether or not nematodes are wholly or partially responsible for poor plant growth. When collecting or sending samples for laboratory examination, follow these procedures to increase reliability:

Collecting Samples

Parasitic nematodes are rarely found in dead plant parts, regardless of what may have killed the plant. Soil and root samples should be taken from nearby plants, preferably those that show symptoms of nematode damage, but are not yet severely affected.

TURFGRASSES AND ORNAMENTALS

When sampling turfgrass and ornamental areas, take samples from around the edge of damaged areas where the plants are still alive. *DO NOT take samples from areas where plants are dead.* Samples should not be taken at a depth greater than the root systems extend for both turfgrasses and ornamentals. Samples should include both roots and accompanying soil. Do not submit separate samples for each portion of a home lawn: (i.e., side lawn, front lawn, back lawn, etc.). A good procedure is to sample several spots representative of the area, mix the samples thoroughly, and take a composite sample of the resulting mixture. A one pint soil sample is generally adequate for analysis.

FALLOW FIELDS

When sampling fallow fields, take samples from areas where poor growth was noted during previous seasons and nematodes were suspected. If samples are taken immediately after harvest, they should be obtained from the plant row. Collect several soil samples 8-10 inches deep from such areas and combine into one composite 1-pint sample.

WOODY PLANTS

Samples collected from woody plants (i.e., fruit trees, grapevines, forest trees, etc.) should be taken far enough from the main stem or trunk to include young roots. Samples may have to be taken as deep as two feet. Include both feeder roots and associated soil in a sample. Take samples from several locations around a tree.

Do not allow samples to become dry or heated. Laboratory procedures for removing nematodes from samples are effective only when the nematodes are alive and active. Dead or inactive nematodes are likely to escape detection.

Plan ahead! Collect samples for nematode analysis well in advance of anticipated planting dates. In most cases, nematicides are toxic to plants and require a waiting period between application and planting to allow the chemical to escape from the soil. Michigan's soil and climatic conditions usually dictates a fall treatment preceding spring planting.

Submitting Samples

Place the root and soil sample in a moisture-proof container as soon as possible to prevent them from drying-out. Small polyethylene sacks (freezer bags, etc.) are suitable. Samples should not be left in the sun or in a closed automobile on a hot day. Heat kills nematodes!

All samples for nematode analysis must be submitted through the county extension office. Each sample must be accompanied with a correctly completed form, available at the agent's office. To make an accurate nematode control recommendation, it is necessary to know the host, symptoms associated with the damage, environmental conditions preceding the damage, (rainfall, temperature, etc.), cultural practices (herbicides, fertilizers, etc.), prevalence and location of the problem. Major plant parasitic nematodes encountered in Michigan are summarized in Table 1.

NEMATODE CONTROL

Nematode control is not simple, whether by legislation, biotic agents, cultural practices, resistant plant varieties, physical factors or chemicals. The control chosen will depend upon the value of the crop, whether the crop is annual or perennial, greenhouse, or field grown. Nematode control also requires positive identification of the nematode species involved in each situation, as well as any plant damage. For accurate diagnosis and recommendation, symptoms, environmental conditions, cultural practices, and the occurence of particular nematode species must be considered.

Legislative Control

Legislative control of nematodes through passage and enforcement of quarantines is designed to prevent the spread of particular nematodes into areas known to be free of these species. Means of quarantine include embargoes, certification at point of origin, disinfection, and inspections at destinaton. Many countries have laws prohibiting the importation of particular nematodes from abroad. Several countries have passed domestic quarantines that regulate movement within the country and restrict internal spread of a particular pest. State and Federal quarantines prohibit movement of the golden nematode of potatoes *(Heterodera rostochiensis)* and the soybean cyst nematode *(H. glycines)*, which are known to occur in at least two of Michigan's neighboring states. Quarantines are effective only when the biology of the organism is understood and the regulations are enforceable.

Cultural Practices

Several cultural practices help suppress populations of plant parasitic nematodes. However, time required to reduce nematode populations in this manner, particularly on higher value land, is usually not economical. Control by crop rotation is based on the fact that some nematode species are able to feed and multiply on certain crop plants (host plants) but not on others (non-host plants). For this reason, rotations that include resistant or non-host plants can be effective in reducing damage incited by several nematode species.

Another method, summer flooding of fields is possible in areas with adequate sources of available water and equipment necessary for critical control of the water table level. Alternate flooding, with periods of drying, appears to be of greater value than continuous flooding or drying for both sand and organic soils. Tests with much soil have shown that one month of flooding followed by one month of drying and another month of flooding greatly reduces nematode population. However, flooding for nematode control is generally not practical in Michigan.

Reduction of nematode populations during fallow periods is probably caused by starvation, heat and dessiccation. But, clean summer fallow tends to deplete organic matter and encourage soil erosion.

Natural Enemies

Nematodes have a large variety and number of natural enemies. Nemataphagous fungi are abundant throughout the world. Many soil-inhabiting protozoans

Table 1. Summary of the Major Plant Parasitic Nematodes Most Frequently Encountered in Michigan*

Nematode	Mode of Parasitism	Symptoms and/or Signs of Damage	Major Michigan Hosts
Root-lesion nematodes (**Pratylenchus** spp.)	Migratory Endoparasitic	Small dark lesions generally enlarge resulting in extensive root rot.	Alfalfa, beans, potato, grape, peach, cherry, strawberry, and many ornamentals.
Root-knot nematodes (**Meloidogyne** spp.)	Sedentary Endoparasitic	Root galls or excessive root formation.	Tomatoes, carrots, celery, lettuce, strawberry, and many ornamentals.
Cyst nematodes (**Heterodera** spp.)	Sedentary Endoparasitic	Stunting and chlorosis of foliage. White cysts on roots.	Sugar beets, red beets, cabbage, cauliflower, turnips, lambsquarters and pigweed.
Stubby-root nematodes (**Trichodorus** spp.)	Ectoparasitic	Devitalized root tips, resulting in short, stubby, clustered roots.	Onions, corn, celery, grasses, blueberry, cherry, peach, and grape.
Dagger nematodes (**Xiphinema** spp.)	Ectoparasitic	Stunted growth, root galls occasionally. Transmits plant viruses.	Grapes, roses, peaches, cherries, strawberries, brambles, blueberries and tomatoes.
Pin nematodes (**Paratylenchus** spp.)	Ectoparasitic	Reduced root system, reddish lesions on roots.	Celery.
Stunt nematodes (**Tylenchorhynchus** spp.)	Ectoparasitic	Roots stunted and sparsely developed, but gall, lesions or root decay **do not** usually develop.	Turfgrasses, ornamentals.
Spiral nematodes (**Helicotylenchus** spp.) and Lance nematodes (**Hoplolaimus** spp.)	Ectoparasitic or semi-endoparasitic	Reduction in feeder roots, associated root decay.	Ornamentals, turfgrasses, corn.
Ring nematodes (**Criconemoides** spp.)	Ectoparasitic or semi-endoparasitic	Stunting of feeder roots, general unthriftyness of plant.	Peaches, roses.
Bulb and Stem nematodes (**Ditylenchus** spp.)	Migratory Endoparasitic	Distortion and twisting of leaves, thickening and stunting of stems, softening of bulbs.	Alfalfa, onions, flower bulbs.
Bud and Leaf nematodes (**Aphelenchoides** spp.)	Migratory Endoparasitic	Angular leaf spots and defoliation, newly unfolded leaves crimped.	Chrysanthemums, strawberries, narcissus, phlox, African violets.

*Many other nematodes damage plants, however, most of these are not known to cause significant damage in Michigan.

appear to utilize nematodes as a food source. And, some nematodes are effective natural enemies of other soil inhabiting nematodes. Viruses, bacteria, tardegrades, flat-worms and soil insects also depress nematode populations. The use of trap crops (plants that can be penetrated by nematodes, but which do not allow nematodes to reach maturity) for nematode control is intriguing, but is generally inefficient, costly, and risky.

Antagonistic plants produce materials in their roots that are toxic to nematodes. The best known of these are asparagus and certain marigolds (*Tagetes* spp). Some research indicates that interplanting selected marigold species and lesion-nematode susceptible plants decreases the number of lesion nematodes in the soil and the roots of the susceptible crops. Unfortunately, some agricultural magazines and newspapers have taken such information and inferred that the use of marigolds will solve all nematode problems. Marigolds should not be considered a cure-all since some nematodes parasitize marigolds. More must be learned about marigolds and their interactions with various nematodes and crops before they can be used as a control.

Resistant Varieties

The use of crop varieties resistant to nematode attack offers a promising control method. Most programs to select resistant varieties, however, have been aimed at solving a particular nematode-plant interaction. Thus, released resistant varieties are resistant only to a specific nematode and are usually susceptible to attack by other nematodes, even within the same genus.

Physical Factors

The application of heat is the most important of the various physical factors used in nematode control. Time of exposure at a specific temperature is critical with this method. For every temperature, a minimum exposure time is required for the heat to produce a particular effect on an organism.

Disinfestation of soil by moist heat is suitable for greenhouses or plant-bed production. Basically, this method involves exposure of the soil to moist heat for 30 minutes at 100°C. Various methods, such as tank steaming, buried pipes and inverted pans are used to dispense the steam through the soil. Dry heat, such as used on flash-flame soil pasteurizers, will successfully sterilize soil, but, its use on large volumes of soil has been limited, due to high operation costs.

The basic principle of disinfection is to heat the infested plant material so that the nematodes are killed, but plant tissue undamaged. This margin is usually small, requiring accurate control of both duration and temperature. These lethal time/temperature combinations vary with the nematode species as well as the host plant. Other physical factors, such as electricity, irradiation, ultrasonics or plasmolysis are harmful or lethal to nematodes, but their potential for effective nematode control is questionable.

Chemical

Chemical soil treatment offers the most promising means of nematode control at this time. Nematode-toxic chemicals can be brought into contact with the nematodes by mechanical disposal through the infested soil, percolation in water or a gaseous diffusion of a nematicidal fumigant through the pore spaces of the soil. To kill nematodes, chemicals must enter their bodies. This penetration may occur through the cuticle, through body openings or by ingestion during nematode feeding. However, several of the new nematicides apparently reduce nematode activity by suppressing their feeding and/or reproduction rather than actively killing them.

Complete eradication of soil-borne plant parasitic nematodes through soil application of nematicides is impractical for field conditions. The objective of such treatments is to reduce nematode populations to a level where serious crop damage will not result. Complete eradication is obtainable, however, on limited volumes of soils, such as in greenhouses and seedling production.

Nematicides are generally used as a preventive measure. By the time nematode damage becomes apparent, the infested crops are usually injured so severely that control measures are ineffective in increasing yields. Therefore, control procedures are normally based on pre-plant or time-of-planting application.

WHAT TO USE

Selecting the correct nematicide depends upon the following factors: 1) time of year applied; 2) availability of application equipment; 3) level of nematicidal residues allowed for specified crops at the time of harvest or sale; 4) toxicity of nematicide to the crop; 5) whether the crop is used as food or for other purposes; 6) whether crops grown in the rotation plan are sensitive to residues persisting in the soil (i.e., bromide residues inhibit onion growth for two years after application); 8) the kinds of soil-borne pests (weeds, fungi, soil insects and/or nematodes) needing control; and 9) the amount of money that should be spent on the control operation.

Several chemicals are available for nematode control (Table 2, p. 13). Some are effective only against nematodes; others are multipurpose and effective against a wide range of soil organisms. Most fumigant nematicides are very toxic to plants and must be applied several weeks before planting to allow sufficient time for exposure to the soil and soil aeration.

Some new nematicides are relatively non-toxic to plants when applied at suggested rates and can be used either prior to or after planting. Your county agricultural agent can help you determine the best nematicide and application method.

SOIL PREPARATION

Proper soil preparation prior to nematicide application is essential for maximum effectiveness. The soil should be kept moist and cultivated often for several weeks to guarantee thorough decomposition of previous crop debris. Undecayed plant residues harbor nematodes, protect them from nematicide contact and interfere with movement of fumigation equipment. The soil should be in excellent seedbed tilth and soil moisture should approach that desirable for seeding. Fumigants escape too rapidly if the soil is too dry. Dispersion of nematicides in excessively wet soil is poor. Soil temperatures should be between 50° and 80°F for good fumigation. 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. Generally, spring fumigation is not practical in Michigan. Spring planting dates are usually delayed too much by waiting for warm soil temperatures and the required aeration period. Non-fumigant nematicides do not require as exacting temperature and moisture conditions. These contact nematicides can be applied whenever conditions favor nematode activity.

Methods of Treatment

FUMIGANT NEMATICIDES

Broadcast Soil Treatment consists of applying nematicides evenly to the entire field. Fumigants are injected from chisels or shanks spaced 8 to 12 inches apart and 6 to 10 inches deep. Most chemicals diffuse at least five to ten inches from the point of injection, giving complete coverage. Chisels work best when the shanks are staggered on the tool bar so that adjacent chisels are several inches apart from the front to back (Figure 9). Staggering the chisels helps prevent clogging. A pressure-type applicator provides an even distribution of chemicals using this system.

The moldboard plow is also used for broadcast application (Figure 10). Delivery tubes attached to the rear of the plows discharge chemicals into the bottom of the open furrow where it is covered immediately. Since the chemical must be covered immediately, there should not be an outlet tube behind the last plow. Both pressure and gravity-flow applicators can be used.

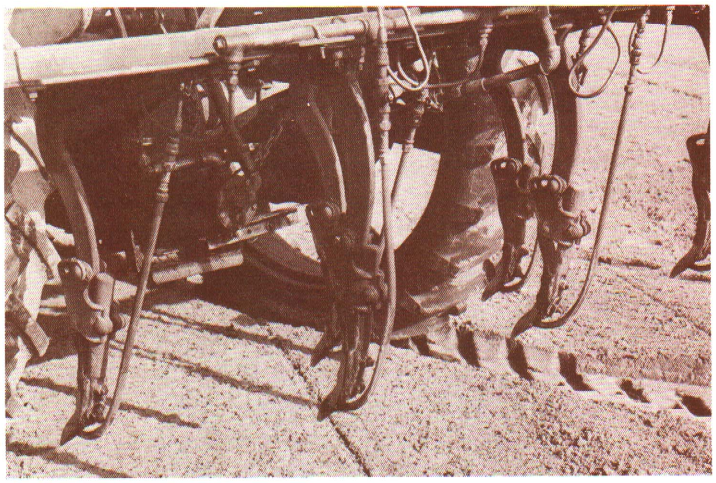

Fig. 9 — Stagger the placement of adjacent chisels along the tool bar for best fumigation results (courtesy H. L. Rhoades, University of Florida).

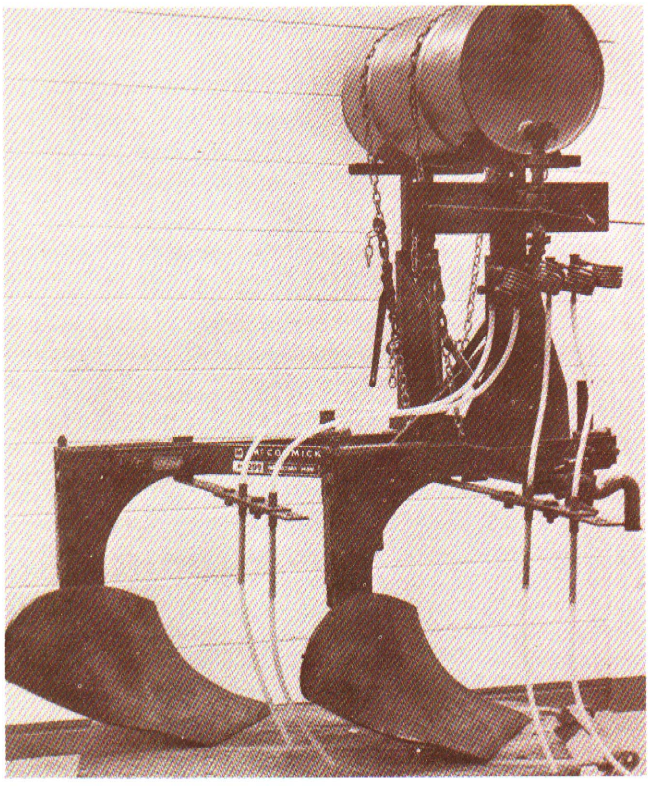

Fig. 10 — The moldboard plow can be adapted for fumigant application (courtesy Lorbeer, Sherf, Cornell Extension Bulletin 1133, 1964).

Blade applicators have been used to insure an even more effective injection pattern than can be obtained by the plow — sole or injector applicators (Figure 11). With these applicators, the fumigant is sprayed as a continuous "sheet", avoiding some of the difficulties encountered in obtaining lateral diffusion. The injection boom, adapted with fan type nozzle, is mounted in a protected recess beneath the blade and sprays the entire width of the soil as it flows over the rear edge of the blade. The soil must be in excellent tilth and free of trash for proper operation. Pressure equipment should be used.

Regardless of the equipment used for broadcast application, the fumigant should be injected at least 6 to 10 inches deep. Smooth the soil with a drag or culti-packer immediately after application to prevent chemicals from escaping.

Row application, the most commonly used control in row crop production, is less expensive than broadcast. Either pressure or gravity-flow equipment can be used. In row application, the chemical is placed six to eight inches deep, then covered with a listed bed of soil formed by two disc plows mounted behind the fumigation shanks. Listed bed rows are used to seal volatile fumigants in the soil, except when the chemical is applied during planting.

After treatment, the bed is left undisturbed for 7 to 21 days, depending on the type of nematicide used, weather, and soil conditions. The bed can be leveled for planting with a V-shaped blade, built-up sweep, or opening plow and shovels which move the untreated top portion of the bed into the furrow.

Some fumigants can be applied in the row at planting time. When such chemicals are used, they should be placed at a minimum depth of six inches and at least two inches beneath the seed. This minimizes the possibility of injury to germinating seed and young seedlings.

NON-FUMIGANT NEMATICIDES

Contact nematicides are not fumigants, and will not give satisfactory results if applied by fumigant methods. Non-fumigant nematicides must be applied, mixed into, and/or carried by water into contact with the nematodes.

Effective application rates vary with the area of soil to be treated (band, row, or broadcast), soil type, and pest to be controlled. In general, the treatment band should cover at least 12". Non-fumigant nematicides should be applied uniformly over the area with a granular or fertilizer distributor and mixed into the top 4 to 6 inches of soil immediately. This can be accomplished with a rotary tiller, rotary hoe, disc harrow, cultivator, or two sets of disc tillers. Irrigation, especially in combination with natural rainfall, also helps work these applications into the soil. Liquid formulations of non-fumigant nematicides may be used as soil drenches and bare root dips.

Non-fumigant nematicides may be applied either pre-plant or/and at time of planting. When such chemicals are used, care must be taken to plant the seeds in the treated portion of the soil. Possibility of injury to germinating seeds and seedlings is usually minimal when these materials are used correctly.

Equipment Calibration

Before application equipment can be used properly in the field, the volume of material it delivers under a specified set of operating conditions must be determined. Several factors can cause variation in the application rate, including:

- Area of the metering orifices
- Speed of the agitator or amount of pressure
- Ground speed of the applicator
- Nature and size of granules or viscosity of liquid
- Roughness of the field
- Relative humidity and temperature

Several factors determine the type of equipment used for applying nematicides: soil condition, method of treatment (row or broadcast), adaptability of equipment, size of area being treated, and formulation of chemical (liquid or granule).

Pressure applicators are commonly used for broad-

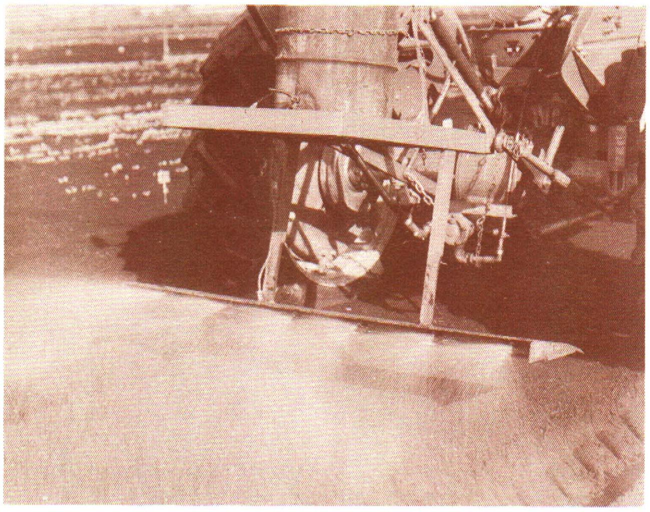

Fig. 11 — Blade applicators apply fumigants as a continuous "sheet" 6 to 8 inches beneath the soil surface, avoiding some lateral diffusion difficulties (photo courtesy of H. L. Rhoades).

cast application of liquid fumigants (Figure 12). Basically, these include a pump (driven by power take-off, independent gasoline engine, or a ground wheel), tank for chemical, metering device, delivery tubes, injection and smoothing drag. The chemical is pumped from the tank through the metering device into delivery tubes, which are attached to chisel or plows mounted on a cultivator frame or tool bar. The chemical flows into the furrow behind the injector. This applicator is easy to calibrate. The pump is set according to calibration charts for a desired rate so that application rate will be uniform regardless of tractor speed. With a good flow divider, discs are not needed to regulate delivery rate.

Gravity-flow applicators can be inserted into any drum with a threaded opening (Figure 13). Valves, orifices, and coils regulate the chemical as it flows from the container, through the tube, and into the soil. Because no pump is used with this system, tractor speed is very important with gravity flow rigs, and can cause great variations if rate of delivery is not kept constant.

Gravity-flow applicators are calibrated as follows:

1. Determine the linear feet of row space in an acre according to your row width, or, in case of broadcast application, the linear feet that one outlet would include in one acre.

2. Determine, in pints, the amount of fumigant you plan to use and divide this figure into linear feet or row space to determine how far a pint will go.

3. Measure off and mark this distance on the field.

4. Run the tractor across this distance with all the equipment in the soil and at the speed you plan to run when applying the fumigant.

5. Having determined this time, blank out all but one outlet and keep checking or changing orifice disc until a pint runs out over the measured distance.

6. All individual outlets should have the same output.

Table 3 lists recommended application rates for soil fumigants at various tractor speeds and the amount of fumigant delivered from each outlet, both per minute, and per 100 feet. Equipment manufacturers supply such charts or graphs for use with their chemicals. Application rates are based on gallons per acre of formulated materials. Remember, DBCP rates are based on gallons of active ingredient per acre and additional computations will have to be made. At low rates (up to 5 gallons per acre), accurate calibration is extremely difficult.

Granular insecticide or fertilizer applicators are used for applying granular nematicides (Figure 14). However, there is a tendency to apply fumigant nematicides too shallow with this equipment. The material should be placed at least four to six inches deep in the row, regardless of the depth of fertilizer placement. Using the applicator, you can apply fertilizer, plant, and fumigate all in one operation. Generally, more effective nematode control is obtained when granular nematicides are applied in bands and the granules incorporated with a power driven rotary tiller the same width as the band. However, this should be done before fertilizer application.

Fig. 12 — A pressure-type applicator using a wheel-driven pump for broadcast treatment.

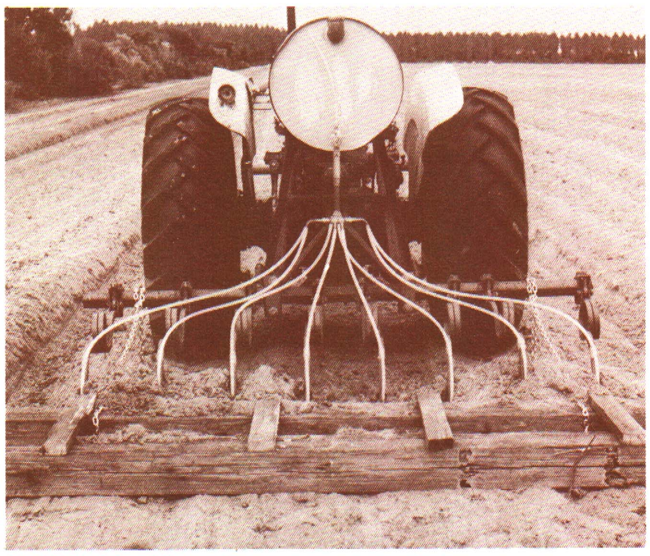

Fig. 13 — A gravity-flow applicator with heavy drag to seal the soil surface.

To calibrate granular applicators:

1. Adjust delivery openings on applicator unit at approximate settings and fill hopper with granules to be applied.

2. Set tractor speed as it will be operated in the field.

3. Operate the units over a measured distance of several hundred feet in a freshly prepared seedbed. Collect the granules discharged over this course with containers under the delivery opening.

4. Weigh the amount of chemical delivered by each outlet: adjust each unit to deliver identical amounts.

5. Calculate area treated.

6. Calculate the amount of granules applied per acre as follows:

$$\text{Pounds/A} = \frac{43560 \times \text{pounds granular applied}}{\text{area of treated land in square feet}}$$

7. The amount of active ingredient applied is determined as follows:

$$\text{Pounds/A (active)} = \frac{\text{lbs/A granules} \times \%\ \text{active ingredient}}{100}$$

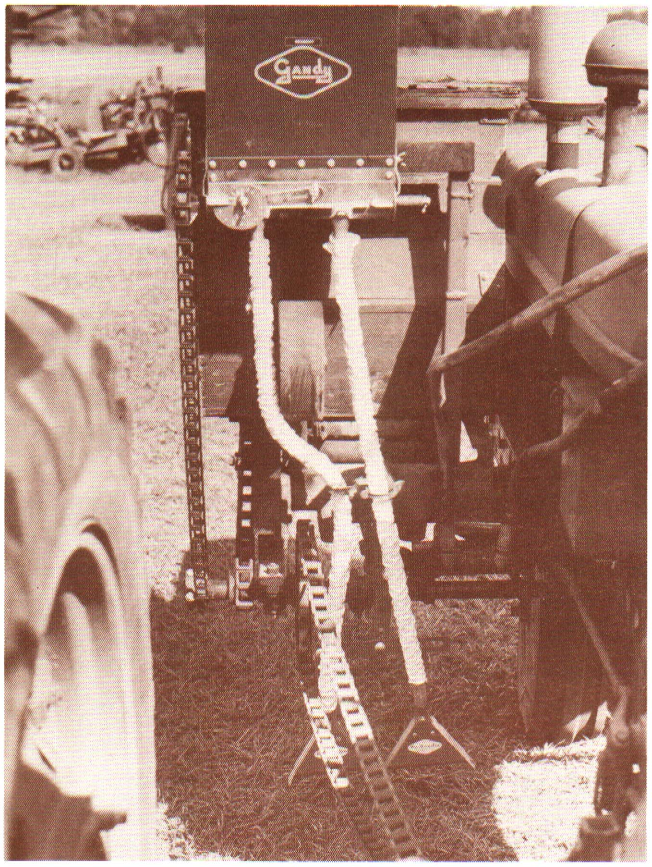

Fig. 14 — Granular insecticide or fertilizer applicators are suitable for applying granular nematicides.

Table 3. Calibration Data for Fumigation Application at Varying Tractor Speeds.

Application Rate	Tractor Speed		Discharge from each outlet (12-inch spacing)			
			Per 100 ft		Per Minute	
(gal/A)	(mile/hr)	(ft/min)	(ml)	(oz)	(ml)	(oz)
1	2.0	176	9	0.3	15	0.5
1	3.0	264	9	0.3	24	0.8
5	2.0	176	45	1.6	80	2.8
5	3.0	264	45	1.6	115	4.1
10	2.0	176	90	3.1	155	5.5
10	3.0	264	90	3.1	230	8.1
15	2.0	176	130	4.7	235	8.2
15	3.0	264	130	4.7	315	12.2
20	2.0	176	180	6.2	310	10.9
20	3.0	264	180	6.2	460	16.2
30	2.0	176	260	9.3	465	16.4
30	3.0	264	260	9.3	700	24.7
40	2.0	176	360	12.3	615	21.7
40	3.0	264	360	12.3	925	32.6

Table 2. Characteristics of Nematicides Registered for Use in Michigan.

Trade Names	Active Ingredients	HAZARDS TO MAMMALS[1]		EFFECTIVE AGAINST			
		Oral	Dermal	Nematodes	Soil Insects	Soil Fungi	Weed Seeds
Brozone Brom-O-Sol	methyl bromide (68.6%) chloropicrin (1.4%)	serious inhalation hazard		★	★	★	★
Chloropicrin Picfume Larvicide Chlor-O-Pic	trichloronitromethane (99%)	serious inhalation hazard		★	★	★	★
DBCP Nemagon Fumazone	1,2-dibromo-3-chloropropane and other halogenated C_3 compounds	low	low	★			
D-D Mixtures D-D Vidden D	1,3-dichloropropene-1,2-dichloropropane and related chlorinated hydrocarbons	moderate	low	★	★		
Dasanit	0,0-diethyl-0-p[methyl sulfinyl] phenyl phosphorothioate	high	high	★	★		
Diazinon Sarolex	0,0-diethyl-0-p[2-isopropyl-4-methyl-6-pyrimidyl] thiophosphate	moderate	moderate	★	★		
Dorlone	ethylene dibromide (18.9%) 1,3-dichloropropenes and related C_3 hydrocarbons (79.9%)	moderate	moderate	★			
DowFume MC-2 Brom-O-Gas	methyl bromide (98%) and chloropicrin (2%)	serious inhalation hazard		★	★	★	★
DowFume MC-33 Terr-O-Gas	methyl bromide (67%) and chloropicrin (33%)	serious inhalation hazard		★	★	★	★
Ethylene Dibromide DowFume W-85 Soilbrom-85	1,2-dibromoethane	moderate	moderate	★	★		
Mocap	0-ethyl, S,S-dipropyl phosphorodithioate	high	high	★	★		
Telone	1,3-dichloropropene and related chlorinated hydrocarbons (100%)	moderate	moderate	★	★		
Vapam VPM	sodium methyl dithiocarbamate (32.7%)	low	moderate	★	★	★	★
Vorlex	methyl isothiocyanate and chlorinated C_3 hydrocarbons (80%)	moderate	moderate	★	★	★	★
Terr-O-Cide 15 Terr-O-Cide 30	1,2-dibromoethane (40%) and chloropicrin (15%) —or— 1,2-dibromoethane (36%) and chloropicrin (30%)	moderate	moderate	★	★	★	
Terr-O-Cide 15-D Terr-O-Cide 30-D	1,3-dichloropropene-1,2 dichloropropane and other halogenated C_3 compounds (85%) and chloropicrin (15%) —or— 1,3-dichloropropene-1,2 dichloropropane and other halogenated C_3 compounds (70%) and chloropicrin (30%)	moderate	low	★	★		

[1]Most fumigants are vesicants, which cause severe burns when in contact with skin or mucous membranes. Avoid direct contact and INHALATION of these materials. (See section on "Safety in Handling Nematicides" for additional information).

SAFETY IN HANDLING NEMATICIDES

Nematicides are poisonous to man, livestock, pets, birds, poultry, fish and sometimes plants. A poisonous or toxic compound becomes dangerous when it is improperly or carelessly used. Poisonous compounds may be used safely by following recommended concentrations, application rates, and methods.

Follow these steps:

1. Properly identify the pest problem and determine the best pesticide and rate for your conditions.

2. Apply the recommended material at the correct time and in the correct manner.

3. Store pesticides in their original labeled containers — out of the reach of children, pets and livestock.

4. Dispose of empty containers promptly and safely.

Special Precautions

Some nematicides are extremely toxic and may be fatal if swallowed, inhaled, or absorbed through the skin. These highly toxic materials should be applied only by a person thoroughly familiar with the hazards, who will assume full responsibility of safe use and comply with all the precautions on the label. Special precautions warrant special mention, when using toxic materials.

1. Read the manufacturer's label carefully and completely, paying particular attention to precautions and antidotes.

2. Use granular formulations of highly toxic nonfumigant nematicides when effectiveness warrants.

3. When mixing and applying these materials, use a chemical cartridge respirator approved for the specific pesticide, and wear protective clothing, long sleeves, a washable rain hat, and *natural* rubber boots and gloves.

4. Start with clean clothing each day, and change if garments become wet with spray. If a liquid formulation is spilled on garments, remove them at once and take a bath. Take a thorough bath as soon as the work day is finished.

5. Look ahead. Have soap, water, and clean clothes on hand in the field in case of accidental spillage of the nematicides.

6. Make a habit of washing your hands frequently. Be sure to wash your hands before eating, drinking or smoking.

7. Avoid ingestion, inhalation and dermal contact with nematicides.

8. Always mix and load pesticides in an open area where ventilation is adequate; never mix pesticides in an enclosed area.

9. Use only recommended materials according to recommended rates and methods of application.

10. Never use applicators with leaking hoses or connections.

11. Never use your mouth to siphon nematicides from one container to another or to blow out nozzles or clogged lines on equipment.

12. Wash spray equipment daily to avoid hazardous accumulations.

13. Store pesticides in the original labeled containers away from food, feed or medicine, and out of reach of children, pets, and livestock.

14. Never guess at what is in the pesticide container. If the label has been damaged or removed, discard the entire container with its contents.

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