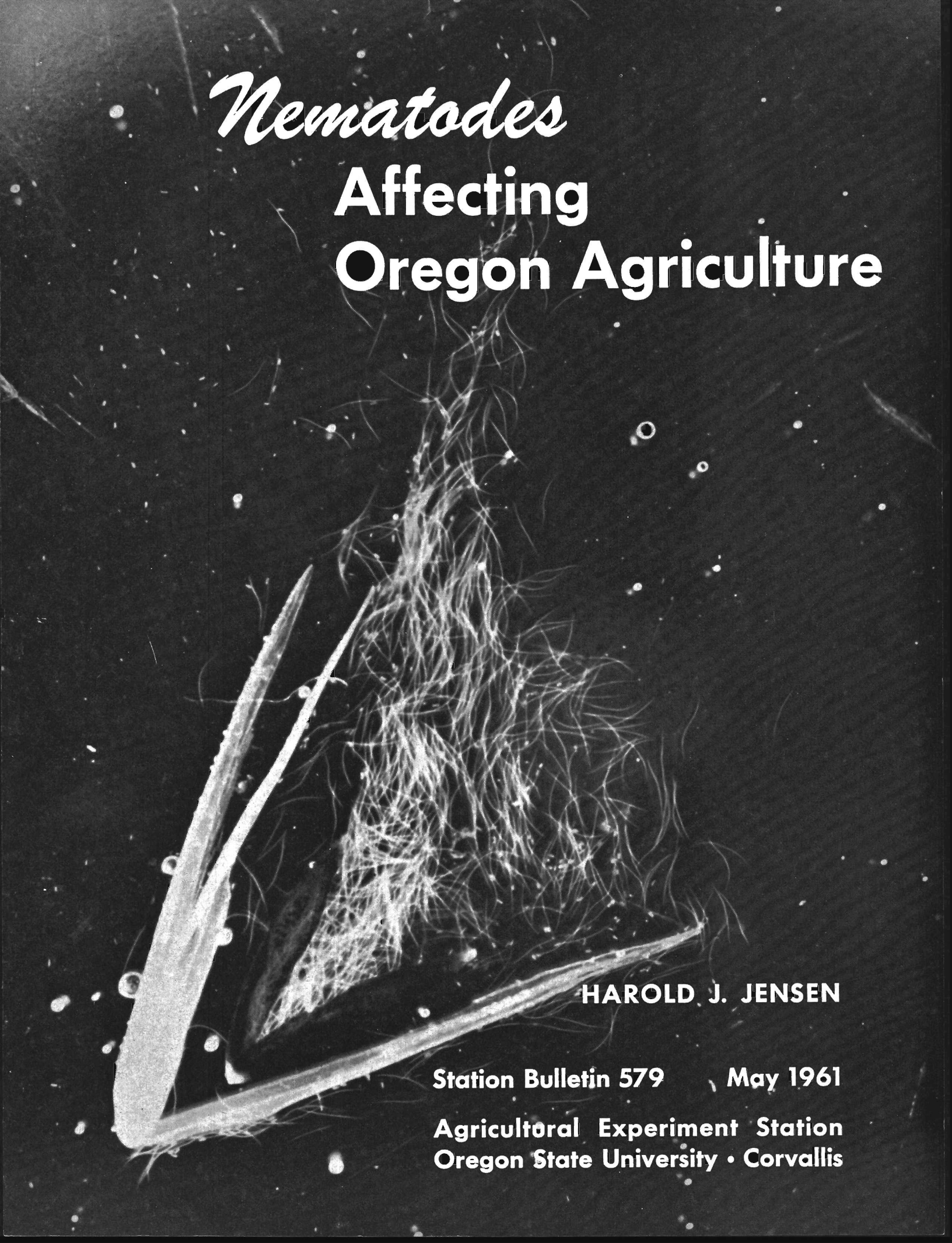
Nematodes Affecting Oregon Agriculture



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Station Bulletin 579 May 1961

Agricultural Experiment Station
Oregon State University • Corvallis

Contents

COVER: Most plantings of Astoria and Seaside bentgrass in the tideland areas of Clatsop and Columbia Counties are infected with the grass seed nematode. This nematode invades grass seed heads and transforms developing seed into nematode galls. Our cover photo shows grass seed nematodes emerging from a gall which had been kept in dry storage for seven years.

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Nematodes

Affecting Oregon Agriculture

Introduction

Most plants—cultivated and noncultivated—are injured by one or more microscopic thread or round worms called nematodes. Plant disease problems associated with nematodes attracted little attention until recently, though the first such pest was discovered more than 200 years ago. More than 140 species of nematodes are known to attack various plants and at least 40 of these are considered major crop pests. Nematodes which seriously injure Oregon crops are discussed in this bulletin.

While some parasitic nematodes are Oregon natives, many have come from distant places in soil or with plant parts used for propagation. Marketing of bare or ball-rooted plants, bulbs, cuttings, and seed is known to spread nematodes from country to country and from state to state. Once introduced, nematodes spread locally by cultivation, irrigation, floods, soil erosion, or any other action that disturbs soil and moves it from place to place. Destructive populations within a field are increased or maintained by continuous production of the same crop.

Nematodes spend most of their lives closely associated with host plants. Life cycles of nematodes are similar in that all types develop from eggs and pass through a series of larval stages and moults before becoming adults.

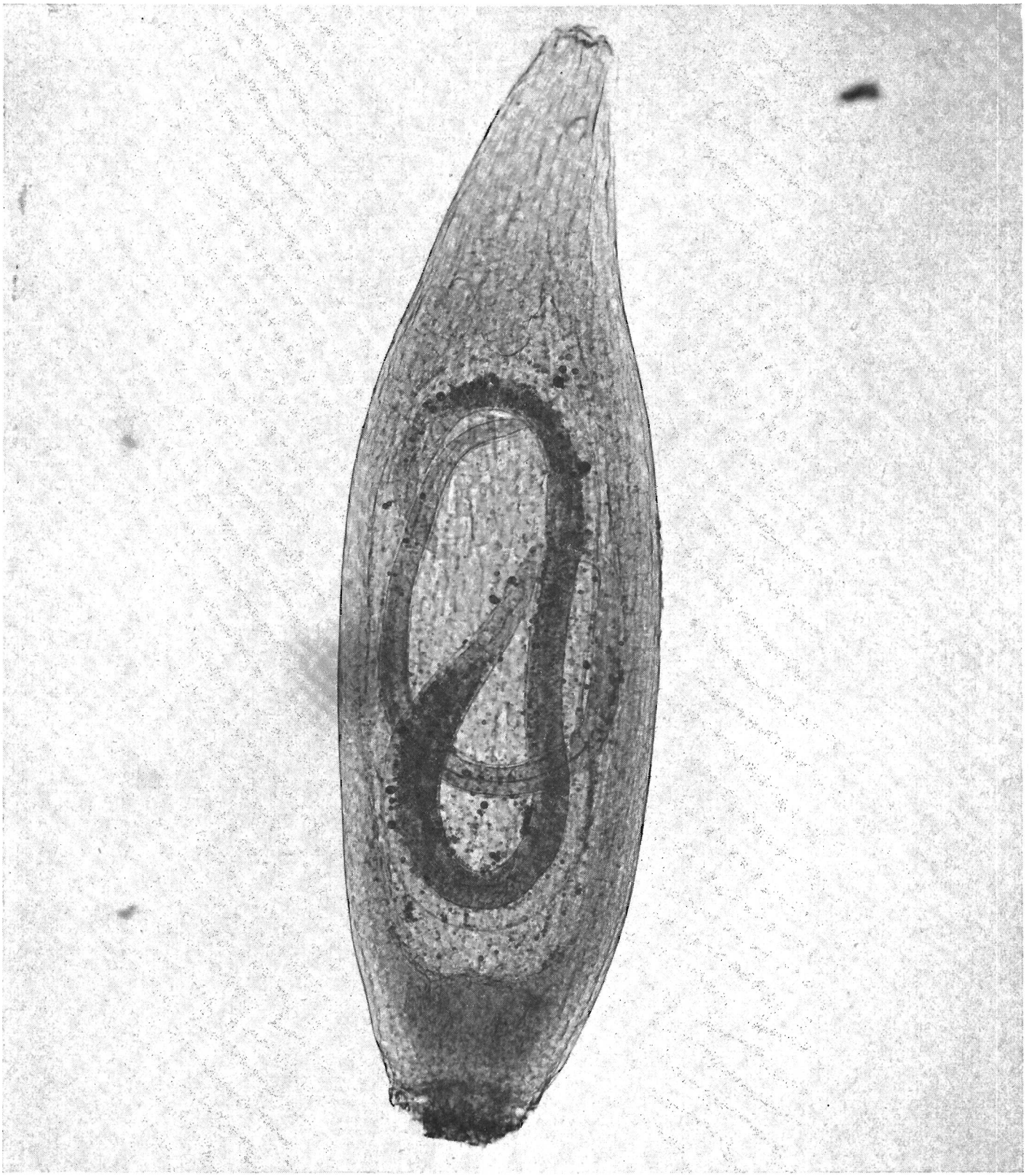
Many injurious nematodes are endoparasitic and spend their lives within plants where they remain until invaded tissues rot. Others lead an ectoparasitic existence and obtain their food through root surfaces. Unlike many other destructive organisms, nematodes usually have a wide host range and are seldom confined to a single host plant. Some species can live happily on a forest tree, a roadside weed, or a choice bulb or vegetable.

Symptoms of nematode injury to plants include malformed flowers, leaves, stems, and roots; dwarfed plants with poorly developed floral, foliar, and root structures; and other undesirable features such as dieback and chlorotic foliage. Nematodes injure plants by . . .

- Causing tissue abnormalities or malformations which result in dwarfing or distortion.
- Direct feeding which deprives the plant of water and food necessary for growth.
- Producing wounds or lesions which cause partial or complete loss of various plant structures and greatly impair vital functions necessary for growth.
- Making wounds or lesions through which other disease causing organisms may enter plants.
- Migrating beyond rotting tissues and thus spreading other organisms while invading healthy tissues.
- Destroying reproductive tissues and hindering production of flowers and seed.
- Transmitting plant viruses.

It is obvious that nematodes are destructive to crops. Many affected crops have been lost completely. Nematodes are difficult to control once they are established in soil or in plant tissue. It is best to buy plant materials from reliable sources and use precautions to prevent introduction of nematodes.

This bulletin is intended to outline existing nematode problems for Oregon growers, to aid in diagnosing presence of nematodes, and to explain how to control them. Pests and symptoms of a particular crop are listed separately under five major crop categories—forage, field, ornamental, vegetable, small fruit and specialty crops. Part 2 gives additional information on biology of specific host plants and distribution within the state. Part 3 discusses methods of control.



This gall, which contains several adult grass seed nematodes, was taken from a planting of Astoria bentgrass. Young nematodes crawl into open ends of young seeds, feed, and the seeds develop into galls instead of normal seeds. When flowers emerge from boot stage, nematodes are adult.

Part 1.

Oregon Crops Damaged by Nematodes

Forage Crops

Four nematodes are detrimental to forage and seed production in Oregon. The more pronounced effects of nematode injury are serious reduction of yield; production of substandard forage or seed; and poisoning of livestock which feed on seed screenings.

Astoria and Seaside Bentgrasses

Grass Seed Nematode (*Anguina agrostis*)

Most plantings of Astoria and Seaside bentgrass grown for seed in tideland areas of Clatsop and Columbia Counties are infected by the grass seed nematode, *Anguina agrostis*. It is a major pest often responsible for extreme reduction of grass seed yields in Oregon. This nematode invades grass seed heads, and transforms developing seed into nematode galls. Presence of this pest in field plantings results in serious complications in seed production. Pronounced decline in yields and rejection of seed for certification are two of the most important consequences of nematode injury.

Although some fields of Astoria and Seaside bentgrass may show only a trace of infection, yield in other fields is reduced 50% to 75% annually. An annual yield of 200 pounds of seed per acre was average in 1940. Now some fields are so severely infested that barely 50 pounds of seed are produced each year.

DISTRIBUTION. Bentgrass seed-producing areas of Clatsop and Columbia Counties. Infected bentgrass has also been seen as far south as Florence in Lane County.

DISSEMINATION. Anything capable of moving galls or portions of broken galls from one area to another can establish a new infection. Galls are moved with harvesting equipment, on feet of livestock, on feet or trouser cuffs of humans, by hayracks moving along fence rows or roadsides, wind, and irrigation or drainage water. Infection is also spread by planting seed which may accidentally contain galls or portions of galls.

SYMPTOMS. Nematodes transform developing bentgrass seed into galls five to eight times larger than normal seeds. The conspicuous difference in size between galls and seeds makes diagnosis of nematode infection relatively easy. Symptoms are observed as soon as the panicle —seed head—emerges. Severely infected panicles may occur on short stems and escape notice unless a critical field examination is made.

DIAGNOSIS. Best time for diagnosis is when panicles are fully developed and provide contrast between seeds and galls. Nematodes can be seen in great numbers with a microscope when a gall is broken open in water.

CONTROL. Although crop rotation and stubble burning are effective control methods in some areas of Columbia County, they cannot be regarded as universal methods. For example, the nematode cannot be controlled by crop rotation or stubble burning in some severely diseased fields in Clatsop County. Fields are in such heavy rainfall areas that elimination of vegetative and seed propagation of bentgrasses is extremely difficult; acid soil makes decomposition of organic material slow; obstructions such as fence rows, highway and railway right-of-ways, and re-

USDA PHOTO

Seed nematodes have infected the Astoria bentgrass on the right. Diseased galls are much larger than the healthy, normal bentgrass seed on the left.

maining stumpage on partly cleared fields provide protected areas from which reinfection can take place.

Thus, successful nematode control by crop rotation in Clatsop County depends on methods of harvesting, hastening organic breakdown after the field has been plowed, removal of obstructions, and destruction of volunteer bentgrass with weed spray in uncultivated areas.

- Stubble Burning. Burning of stubble is possible for some areas but many severely infected fields of Clatsop County are in heavy rainfall areas where burning may be difficult.
- Chemical Sprays. During the past few years several promising fungicides, insecticides, herbicides, and various systemic materials have been applied to infected bentgrass as drenches and foliar sprays. None of these materials gave significant results in greenhouse or field plots.
- Prevention of Seed Development. This is designed to prevent nematodes from entering young flowers where they can complete their life cycles and produce galls. Various field plot experiments show that nematode infection can be reduced to a trace by preventing bentgrass from going to seed. This is done by clipping bentgrass turf at various intervals to stimulate pasturing and by cutting silage and hay. Pasturing was more effective than other methods and reduced infection from 75% to 14%. Thus a combination of pasturing and clipping of infected bentgrass fields for one year should reduce galls.
- General Sanitation Practices. All activities leading to dissemination or reinfection should be curtailed. For example, noninfested fields or those having only a trace of nematodes should be harvested first. Volunteer bentgrass in adjacent fields should be destroyed since these plants act as reservoir hosts. Since nematode galls or parts of galls can be planted with seed, growers are advised to secure clean seed certified nematode-free.

Highland Bentgrass

Fields of Highland bentgrass infected with grass-seed nematodes have been found in Clackamas County. Symptoms and general appearance are very similar to those described in other bentgrasses. Specific host-relationships have not been fully investigated, but early research shows they are similar to those of other bentgrass hosts.

Controls have not been tested, but a program similar to that developed for Chewing's fescue should prove effective. For example, stubble burning can probably be used to good advantage since Highland bentgrass usually grows in areas where burning is practical.

Chewing's Fescue

Chewing's fescue screenings containing nematode galls are poisonous to livestock. Each year a few deaths are reported in Oregon because animals are fed screenings containing a concentration of nematode galls. Stricken animals show extreme nervous symptoms, falling, trembling of muscles, and marked lack of coordination. Autopsies performed on sheep revealed extensive lesions and hemorrhages in the large bowel and under the endocardium. Continuous pasturing of fields having a history of severe nematode infection is also likely to cause deaths among livestock. Exact nature of toxicity contained within nematode galls is not known, but probably is due to combined relationship of nematodes, bacteria, and host plant. The bacterium is not known to occur in nematode infected bentgrass, and so far as is known screenings of bentgrass are not toxic to animals.

DISTRIBUTION. Seed production areas of the Willamette Valley.

DISSEMINATION. Similar to bentgrass as any agency moving galls can spread infection.

SYMPTOMS. Grass-seed nematodes have long been serious pests of Chewing's fescue seed production in the Willamette Valley. Unfortunately, from the standpoint of diagnosis, nematode galls are not as easily distinguished in Chewing's fescue seed as in bentgrass seed. Nematode galls and Chewing's fescue seed tend to resemble each other superficially in size and shape. The galls, however, can readily be distinguished from seed in the laboratory. So far as known, the life cycle is synchronized with seed development as in bentgrass.

DIAGNOSIS. Difficulty of recognition in the field necessitates laboratory diagnosis of seed samples and a subsequent microscopic examination of galls.

CONTROL. Some control measures used against grass seed nematodes in bentgrass (except pasturing) also apply for Chewing's fescue. Since Chewing's fescue is produced in areas where stubble burning is practical, control by this method is most popular. The object of burning is to kill nematodes by heating galls which have been scattered over the stubble. Uniform distribution of straw is necessary to insure an even burn.

Orchard Grass

In May 1947, three panicles containing nematode galls were found in orchard grass near Granger, Oregon. Affected flower heads were considerably distorted.

Nematode galls of orchard grass are short and thick in comparison with the long slender galls of bentgrass. No control measures have been devised, but this occurrence illustrates importance of securing seed certified nematode-free.

Alfalfa and Clover

One of the first nematode plant diseases observed in Oregon was stem nematode injury of alfalfa. Later observations proved that other forage crops and additional nematodes were involved. When injury is confined to legume foliage, only stem nematodes are responsible. If root systems of alfalfa and clover also are damaged, the presence of nematodes belonging to the genera *Meloidogyne* and *Pratylenchus* is probable.

Bulb and Stem Nematode (*Ditylenchus dipsaci*)

Commonly called the Alfalfa Stem Nematode.

DISTRIBUTION. Occurs in alfalfa-producing areas near Hermiston and Talent, and in clover plantings in the upper Willamette Valley and Wallowa County.

DISSEMINATION. Principally by movement of infected stems in transporting hay or dispersal in irrigation and drainage ditches.

SYMPTOMS. Nematodes feed on developing stems and leaves during winter months. Evidence of disease is most conspicuous before the first cutting. Affected plants are usually stunted and have small, distorted stems. Leaves usually are small and misshapen. Visible signs of injury caused by nematodes sometimes may be confined to bud and stem branches several inches above the ground. Since infection continues year after year, plants are weakened and often succumb to injury by other organisms. Infected alfalfa stands thin out rapidly after the first season nematodes are active.

DIAGNOSIS. Nematodes in various stages of development occur abundantly in malformed stems. Diagnosis requires shredding portions of swollen stems in water and observing the contents with a microscope.

CONTROL. The search for alfalfa varieties resistant to stem nematodes has been successful. Lahontan is the most promising selection of an original import, Turkistan, which came from Turkey. Lahontan alfalfa is adaptable to Oregon conditions and is in general use in eastern Oregon. Another variety, Talent, developed from a French selection, is also resistant to nematodes. Areas where this variety can be used are limited because of its susceptibility to bacterial wilt. Talent can be grown only in western Oregon.

Control measures have not been developed for clover but growers whose plantings are in areas of infection are advised to avoid the most susceptible type—red clover. Many observations have shown that this nematode attacks strawberry, so strawberry plants can be considered a reservoir host.

Root-Knot Nematodes (*Meloidogyne hapla* and *M. incognita*)

Although alfalfa is a common host for these nematodes, serious reduction of forage and seed yields have not been reported in Oregon. Lahontan, resistant to stem nematode, is proving susceptible to root-knot nematodes and future use of this variety in Umatilla County is questionable. Alsike and Ladino clovers are highly susceptible and severely damaged in areas where root-knot nematodes are abundant.

DISTRIBUTION. Sporadic occurrence in alfalfa plantings west of the Cascades. Numerous widely scattered areas include Klamath basin, central and northeastern Oregon.

DISSEMINATION. Movement of plant debris in irrigation water and with soil.

SYMPTOMS. Root-knot nematodes are usually indicated by conspicuous swellings called "knots" or "galls" on roots and subterranean plant parts. Detection of galls on legume roots is somewhat difficult because they must be distinguished from nitrogen nodules common to these plants. Once the observer is familiar with shape and characteristics of the nodules he should have no difficulty in distinguishing galls. If the distinction is doubtful, a microscopic examination of swollen areas is necessary. Stunting, wilting, and yellowing of foliage are conditions frequently associated with diseased plants.

DIAGNOSIS. Discovery of galls and microscopic examination of shredded gall residue.

CONTROL. Most growers are reluctant to treat soil and prefer to grow less susceptible crops. Crop rotation, summer fallow, and similar control measures must be considered carefully because the nematodes have an extensive host range and they persist in soil for several months.

Root-Lesion Nematodes (*Pratylenchus* spp.)

Several species of this genus are frequently recovered from alfalfa and clover roots.

DISTRIBUTION. Species of this genus are found in nearly every cultivated area of Oregon.

DISSEMINATION. In plant roots or infested soil.

Bulb and stem nematodes have infected the alfalfa on the left. Stem on the right is healthy. Some alfalfa varieties are resistant to nematodes.

SYMPTOMS. These pests cause dead spots or lesions on roots. Presence of lesions on large roots and conspicuous reduction in feeder and secondary roots also may be caused by nematodes. Root systems frequently are damaged so severely that only a few short remnants remain. Damaged plants grow poorly and usually are stunted. Initial presence of these pests is indicated by groups of injured plants in zones or small areas in fields. Such patterns of infection are characteristics of soil inhabiting nematodes of this group.

DIAGNOSIS. Diagnosis cannot be made solely on field observations. Confirmation by a microscopic examination of root lesions is necessary.

CONTROL. Satisfactory methods for control in alfalfa and clover fields have not been developed.

Cyst Nematodes (*Heterodera trifolii*)

Although this pest occasionally is found in western Oregon on roots of various legumes, little information about it is available. Ladino clover and hairy vetch frequently are infected. Affected plantings of these hosts appear unthrifty and generally retarded. Detection is usually based on presence of females resembling miniature lemons. These are found on roots and can be seen with a little magnification. Control measures have not been developed.

Ecto-Parasitic Nematodes

These are external feeders which usually remain outside of plants and obtain food by piercing roots with well developed spears. They are often associated with diseased legumes. The genera *Longidorus, Paratylenchus, Trichodorus, Tylenchorhynchus,* and *Xiphinema* are frequent inhabitants of soil surrounding diseased plants but there is little information available regarding this relationship.

Field Crops

Nematodes have an important economic effect on the vast acreage planted to field crops. Onions, potatoes, and sugar beets often are damaged seriously by three kinds of root pests—stubby root nematodes, root-knot nematodes, and sugar beet nematodes. Bulb and stem nematodes usually appear in garlic plantings.

Garlic

Bulb or Stem Nematodes (*Ditylenchus dipsaci*)

Bulb and stem nematodes occasionally cause serious injury to garlic plantings in Oregon.

DISTRIBUTION. Benton and Washington Counties.

DISSEMINATION. Although some local spread occurs during cultivation, the most important source of infection is diseased planting stock.

SYMPTOMS. Field symptoms are patch-like areas of prematurely yellowed foliage. During harvest, basal plates of infected plants usually separate from the bulbs. Tissues of diseased cloves are usually spongy and yellowish.

DIAGNOSIS. Spongy yellowish cloves without basal plates are usually infected. Diagnosis should be confirmed by microscopic examination.

CONTROL. Crop rotation and hot water treatment of planting stock are successful control measures.

Crop rotation is a convenient and simple method of controlling this pest. Onions and similar plants probably are affected by the garlic strain of this pest and should be avoided in a crop rotation program. Elimination of volunteer plants and 2-3 years rotation with other crops are recommended to make rotation most effective.

Hot water treatment of planting stock is a good practice and kills most but not all nematodes. Garlic cloves should be separated prior to treatment which consists of a two-hour soak at 115° F. After soaking, cloves should receive a fungicidal treatment to prevent infection by organisms causing rot.

Onions

Stubby-root Nematode (*Trichodorus christiei*)

DISTRIBUTION. Found recently in the Lake Labish area.

DISSEMINATION. Since ecto-parasites rarely enter host plant tissue, they are disseminated by movement of soil during cultivation and of water during flooding.

SYMPTOMS. Infected onions are dwarfed and usually occur in irregular patches in fields. Patches of stunted onions are conspicuous during cool damp spring weather, but usually recover at least partly in warm weather. Thus differences in growth are less apparent at harvest. Diseased onions are characterized by an inferior root system consisting of a few short remnants. These remnants lose their characteristic white color, darken, and are marked

Infected onions (left) are dwarfed and usually occur in irregular patches in fields. Inferior root system is characteristic of the diseased onions.

with numerous brown lesions. This root condition is often associated with injury caused by stubby root and other ecto-parasitic nematodes.

CONTROL. Soil fumigation for nematodes in peat-type soils usually is ineffective. Trials conducted in the Lake Labish area resulted in growth improvement during the early part of the season, but no significant advantage was observed later on.

Potatoes

Root-Knot Nematodes (*Meloidogyne hapla* and *M. incognita*)

These common pests, known to most Oregon growers as potato eelworms, cause the most widespread nematode problem—on an acreage basis—in Oregon.

DISTRIBUTION. *M. incognita* is scattered widely through hundreds of acres in the Klamath Basin. Central and eastern Oregon, Hermiston, and Grand Island areas are infected with *M. hapla.*

DISSEMINATION. Infection is spread from one area to another in diseased seed potatoes. Movement of soil in various cultivation practices may lead to a minor spread, but it is much less important than infection from diseased seed.

SYMPTOMS. Infections are rarely diagnosed by observing above ground portions of potatoes though an occasional field will show a clearly defined area of dwarfed plants. Examination of tubers is necessary to detect root-knot nematodes. Severely infected potatoes have roughened skin which growers refer to as pebbly. It usually is possible to determine if tubers are infected by looking for small brownish specks in the flesh beneath this roughened peel. Though most nematodes remain just beneath the peel some have been found $\frac{1}{4}$ to $\frac{1}{3}$ of an inch beneath the surface. Initial appearance of the nematode in a tuber is a small translucent spot which becomes a brownish speck as the season progresses. The brownish color usually is due to a cork layer which surrounds the pest.

DIAGNOSIS. Although microscopic examination is necessary to identify the pest, removal of peels having a pebbly appearance usually will reveal brownish specks containing nematodes. This symptom should not be confused with tunnel-like wounds of flea beetles or wire worms.

Growers frequently wish to know if their fields are infested by this pest before planting potatoes. Common dandelions in or near the field serve as excellent indicators. Dandelions exhibit conspicuous knot-like swellings or "galls" on their roots when the pest is present. This test only indicates nematodes are present and should not be used to predict severity of future infection. Older dandelion plants should be examined because newly established ones may not have had time to become infected and form galls. Dandelions growing along irrigation and drainage ditches, fence rows, and gateways should be examined first since these sites are common infection centers.

CONTROL. Satisfactory control of this pest is difficult because the host range includes many crops and weeds. Control by one or more of the following methods has given good results. None of these methods has been entirely satisfactory when complete eradication of pests is desirable for certified seed production.

- Crop rotation. The extensive host range of this pest looms as a serious obstacle. Cereals (barley, oats, and wheat) were once considered ideal rotation crops. Unfortunately root systems of these crops are often severely damaged, although above ground portions usually show no visible effect. Galls in these crops are numerous and yet so minute they usually are overlooked. Dandelion, miner's lettuce, and black nightshade are common weed hosts. Using nonhost plants in a crop rotation program without weed control will end in disaster. Weeds will maintain or increase nematodes during the absence of potatoes. Alfalfa, crested wheat grass, and tall oat grass are probably the safest crops for this type of control program. Some growers report good results with green manure crops. Australian winter peas or rye are usually planted in the fall and plowed under in spring.

- Soil fumigation. Approximately 3,000 acres of infested soil in the Malin and Merrill areas of the Klamath Basin are fumigated each year for nematode control. Two materials most commonly used are DD (dichloropropane, dichloropropene at 20-30 gallons per acre) and EDB (ethylene dibromide at 4-7 gallons per acre). Telone (dichloropropene mixtures at 20-25 gallons per acre) has also given good control.

Sugar Beets

Oregon's sugar beet industry faces a constant threat from two nematodes, the sugar beet nematode and a root-knot nematode. Both pests frequently are present in the same field. The sugar beet nematode is better known to the industry and is considered more important.

Sugar Beet Nematode (*Heterodera schachtii*)

This pest has been a continual menace throughout sugar beet production history. Oregon has long remained free of this nematode but recent surveys show infestations now exist.

DISTRIBUTION. Several scattered fields near Milton-Freewater and Nyssa-Ontario.

DISSEMINATION. Nematode cysts (bodies of mature females containing eggs) can be spread from area to area by moving infested soil with machinery, livestock, and surface water. Dispersal of tare (dump dirt and plant debris) however, is chiefly responsible for spreading old infections and establishing new ones. For years it was common practice to return tare to fields for livestock feed or to fill low areas. Infested and noninfested soil frequently are mixed. Return of tare to fields is not recommended. Risk of spreading nematodes greatly outweighs

the little to be gained by using tare for livestock feed or for fill.

SYMPTOMS. First field symptom indicating nematodes is the appearance of small conspicuous areas where beets are stunted or missing. Later in the season areas of nematode infestation often are marked by absence of beets and presence of weed patches. In severely infested fields, areas of decline usually can be identified by excessive leaf wilting during hot weather.

Infected beets are much smaller than normal ones. Frequently they have a dense system of secondary roots, called a hairy root condition. Examination with a hand-lens usually will show numerous small white bead-like structures on rootlets and tap roots of infected plants. These structures are lemon-shaped and later become "cysts" containing eggs that develop into future generations of nematodes.

DIAGNOSIS. Dwarfed beets showing a tendency to wilt during warm weather should be pulled or examined for small, white, bead-like females. Soil intended for beet production can be examined for this pest by a simple field test. Place a teaspoonful of soil in a glass of water, stir briefly and allow debris to float to the surface. It is then possible to see and recognize any brownish cysts that adhere to the sides of the glass. Discovery of nematodes by this test will not predict severity of infestation, but will show that the field has a nematode history.

CONTROL. All preventive measures pertaining to movement of infested soil or of cysts should be employed. Once nematodes are established practical control can be achieved only by crop rotation and/or soil fumigation.

• Crop rotation is an effective method for reducing nematode population since this pest has a small host range. In addition to sugar beets, the following are hosts: mangel-wurzel, table beet, cabbage, cauliflower, brussels sprouts, broccoli, rape, turnip, rutabaga, and radish. The following weeds are hosts: dock, knotweed, lambsquarter, mustard, nightshade, purslane, saltbush, and red root. Any of these plants which survive from year to year may act as reservoirs in maintaining the pests and may counteract much of the value of crop rotation.

The following crops may be used in a short term rotation: beans, sweet clover, corn, grains, peas, potatoes, and tomatoes. Alfalfa is suitable for a long rotation period. Length of rotation period should vary with severity of nematode infection. Slight infestations may require only a 2-year program, whereas severe infestations require a 5-to 6-year interval.

• Soil fumigation is a popular method of control in intermountain production areas. This method enables growers to obtain an average crop at an approximate cost of $35-$40 an acre. Soil fumigation will not eliminate all nematodes and must be repeated each time sugar beets are grown. Dichloropropene mixtures (DD or Telone) are used at the rate of 25 gallons per acre. Many growers use a combination of crop rotation and soil fumigation.

Root-Knot Nematodes (*Meloidogyne hapla*)

Root-knot nematodes occur in all areas where sugar beets are grown. Although these pests cause serious injury in certain areas, they seldom affect production of sugar beets as severely as sugar beet nematodes.

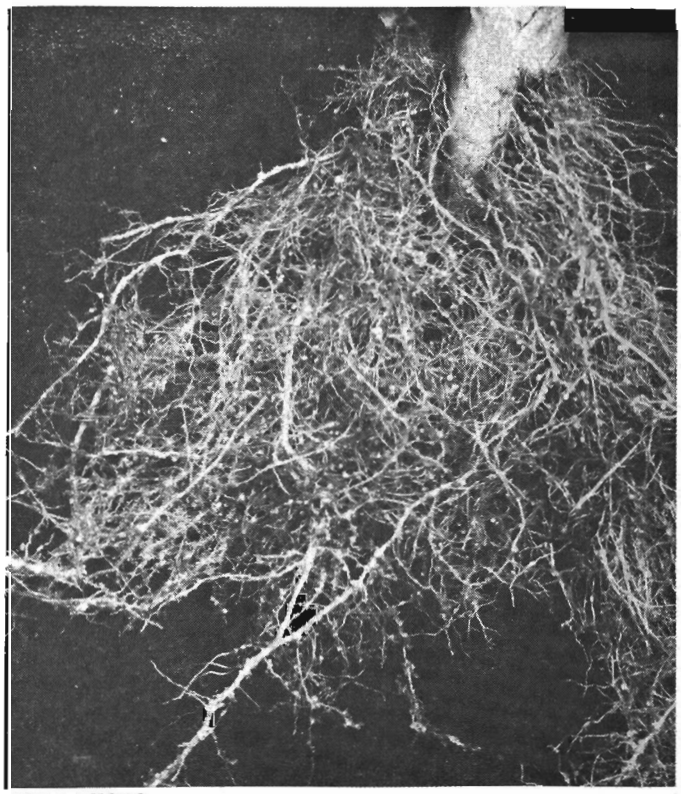
DISTRIBUTION. Scattered throughout sugar beet producing areas of Hermiston, Milton-Freewater, and Nyssa-Ontario.

DISSEMINATION. In plant debris and soil, by movement of soil in erosion, and in cultivation practices.

SYMPTOMS. Stunted beets grow in target-spot areas. Conspicuous "knots" or galls in roots usually indicate injury by root-knot nematodes. Galls may be seen on tap roots, but occur more commonly on secondary roots, where severe infections cause abnormal development and a hairy root condition. Damage is most severe in light sandy soils having a previous history of nematodes in clover, peppermint, potato, and weed hosts.

DIAGNOSIS. Galls in tap or secondary roots usually indicate root-knot nematodes.

CONTROL. Few growers regard these nematodes as serious pests of sugar beets and control measures have not been developed. Root-knot nematodes are, however, potentially serious pests capable of causing damage to sugar beets as they do to other crops. Crop rotation as a control measure is likely to be ineffective because of the tremendous host range. Soil fumigation may be satisfactory.



USDA PHOTO

Sugar beet nematodes recently have been found in Oregon. Infected beets have hairy roots covered with tiny white cysts containing nematode eggs.

Vegetable Crops

Nematodes are scattered throughout Oregon's vegetable production areas. Injury seldom affects an entire planting although some infested areas may encompass a large portion of the field. Nematodes often are serious pests in greenhouse plantings as well as those outdoors.

Field Vegetables

Root-Knot Nematodes (principally *Meloidogyne hapla*)

These are the most important vegetable nematodes in Oregon. They stunt plants and produce characteristic galls on roots. Common hosts are carrots, lettuce, onions, and parsnips.

DISTRIBUTION. A large percentage of vegetable crop land in Clackamas, Marion, Multnomah, and Washington Counties is infested with this nematode. Widely scattered infestations also occur in Douglas, Jackson, Josephine, Lane, Malheur, Umatilla, and Wasco Counties.

DISSEMINATION. Root-knot nematodes are spread by movement of infested soil or infected plant material. Transplanting infected seedlings brings about a significant number of new infections. Many growers believe nematodes were established in their fields during floods.

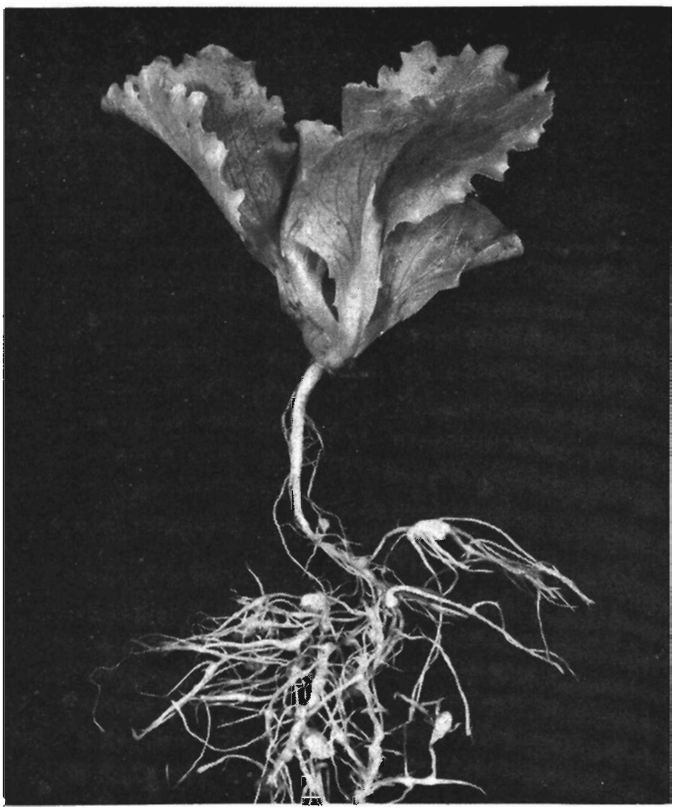
SYMPTOMS. Target-spot areas of retarded growth may indicate a serious infection of root-knot nematodes. Above ground portions of plants may not show evidence of infection unless nematodes are abundant. Plants must be removed from soil to make certain nematodes are present. Knots may occur in tap roots as well as secondary roots. Many growers believe nematodes may cause tap roots to split into two or more roots on carrots and parsnips. These nematodes do not cause galls on edible portions of lettuce and onions.

DIAGNOSIS. Knots or galls on roots or underground portions of plants usually indicate root-knot nematodes are present. Care must be taken to distinguish galls from swellings caused by bacteria, fungi, and insects.

CONTROL. Control measures consist of crop selection or rotation, and soil fumigation. The vast host range of this pest makes it difficult to grow crops which will not serve as host plants.

- Crop rotation and selection. It is possible to obtain satisfactory yields from some crops in spite of nematodes. For example, corn and many Cruciferae (cabbage, radish, rutabaga, turnip) seem to tolerate them and to produce good yields in infested areas. If susceptible plants are grown in nematode areas without soil treatment, crops such as carrots and parsnips will develop galls on edible portions and will have no market value.

- Soil fumigation. Practical control but not elimination can be achieved by soil fumigation—a specialized control prior to planting. Nematocides containing dichloropropene mixtures (25-30 gallons per acre), ethylene dibromide (5-10 gallons per acre), or dibromo-chloropropane (1-1.5 gallons per acre) have given good results. Materials containing dichloropropene are recommended in onion production.



Root-knot nematodes attack lettuce as well as many other vegetable crops grown in Oregon. Crop rotation and soil fumigation provide good control.

Greenhouse Vegetables

Vegetables grown in greenhouses usually are infected with root-knot nematodes. Movement of large quantities of mulch, soil, and other materials required for greenhouse culture provide avenues of entry for nematodes.

Root-Knot Nematodes (*Meloidogyne hapla*)

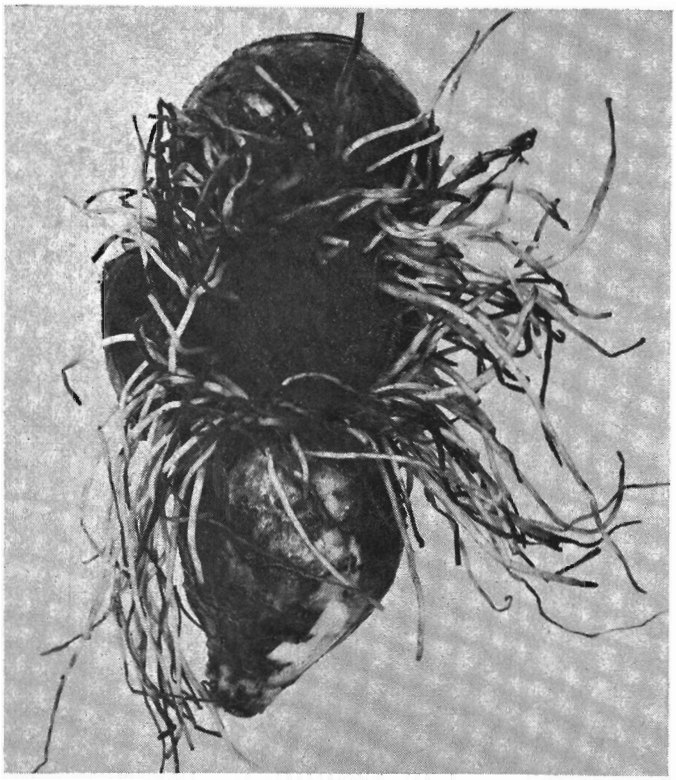
Root-knot nematodes are found everywhere and are the only known pests of Oregon vegetables grown under glass.

DISTRIBUTION. Scattered throughout Oregon in greenhouses used for cucumber and tomato production.

DISSEMINATION. These pests are usually introduced with infested soil or mulch materials and in transplants.

SYMPTOMS. Infected plants are stunted and produce little or no fruit. Conspicuous wilting occurs during warm weather. Knots or galls of infected roots are usually much larger and more numerous than those produced on the same hosts outdoors. Greenhouse environments are conducive to rapid development of serious disease problems.

DIAGNOSIS. Characteristic galls on roots of cucumbers or tomatoes indicate nematode infection.



White areas of these daffodil roots are normal. Dark areas are infected by root-lesion nematodes. Diseased bulbs mature early, are reduced in size.

CONTROL. Precautions should be taken to prevent introduction of pests. Satisfactory control, once nematodes are established, can be obtained by soil fumigation prior to planting. Fumigation is more effective if done before mulch is added. Other preventive measures include treatment of new soil prior to placement in the greenhouse and growing seedlings in treated soil to insure healthy transplants.

Ornamental Crops

The specialized nursery industry of Oregon has more than its share of nematode pests. Since this industry is so dependent upon inter- and intra-state movement of plants or plant parts, with or without soil, it is closely scrutinized by regulatory personnel because of the danger of spreading nematodes.

Bulbs

Root-Lesion Nematodes (*Pratylenchus penetrans* and *P. pratensis*)

Two kinds of root-lesion nematodes are pests of ornamental bulbs in Oregon. Of the two, *Pratylenchus penetrans* is much more important because of its general distribution and wide host range.

DISTRIBUTION. Various bulb plantings in Clackamas, Clatsop, Coos, Curry, and Multnomah Counties.

DISSEMINATION. This nematode usually is distributed by infected planting stock.

SYMPTOMS. Premature yellowing of foliage and early maturity of plants in target spot areas of a field usually indicate nematode damage. Infested areas may be difficult to find during an unusually wet season but tend to reappear in warm weather each time host crops are planted. Root systems are greatly reduced and most roots show dark lesions or dead spots. Infected plants may retain only a few stubby root remnants, the remainder having sloughed off. If plants are severely infected no roots are left on the bulbs. Since infected plants are damaged and mature early, bulb size is greatly reduced.

DIAGNOSIS. Roots with lesions should be examined microscopically for evidence of nematodes.

CONTROL. Encouraging results have been achieved by soil fumigation before planting. Ethylene dibromide (7-10 gallons per acre) and dichloropropene mixtures (30-35 gallons per acre) are in general use. Soil fumigation seldom approaches eradication, so soil must be treated yearly. Certain systemic phosphate insecticides may be useful when applied to lilies at planting time.

When infected plants are dug, root-lesion nematodes remain in roots attached to bulbs. Since many of these nematodes survive storage, planting such stock will greatly jeopardize effectiveness of treating soil before planting. Pruning roots of planting stock will eliminate 75% to 80% of the nematodes and this reduction of initial population can be a great help in the general control program. Root pruning is not necessary for daffodils because they retain few roots at planting time.

Bulb and Stem Nematodes (*Ditylenchus dipsaci*)

DISTRIBUTION. A common pest of daffodils (*Narcissus*) in Clackamas, Clatsop, Curry, and Multnomah Counties.

DISSEMINATION. Infected bulbs are mostly responsible for carrying over infestations and establishing new ones.

SYMPTOMS. Foliage of infected plants is distorted and off color, yellow to brown, depending on time of year. Sometimes zones of the planting will be severely stunted or barren areas will be left in rows. This is particularly true in plantings not dug each year—as for example, those established for cut flower production. Infected plants seldom produce satisfactory flowers and blooming may be delayed or absent. Leaves of infected plants have localized thickened areas called "spikkels." Cross sections of bulbs from infected plants will show brownish areas in the concentric rings of bulb tissue. Many infected bulbs lose their firmness, rot and disintegrate during storage.

DIAGNOSIS. Microscopic examination of "spikkels" or of brownish areas of diseased bulbs will reveal many nematodes.

CONTROL. Principal methods of controlling this pest are roguing and hot water treatment of planting stock. The following treatment is in general use to free narcissus planting stock from bulb and stem nematodes. When bulbs

are treated soon after digging, a hot water soak at 111° F. for 4 hours is recommended. One pint of formaldehyde solution (38-40% formalin) is added to each 25 gallons of water (1-200). Bulbs allowed to cure require an additional 2-hour pre-soak at 75° F. This is necessary to activate nematodes from a resting stage in which they are resistant to treatment to a stage during which they are more susceptible to treatment. Bulb surfaces are likely to be injured during treatment, so it is usually necessary to treat bulbs with a fungicide to protect them from rots. For best results bulbs must be harvested as early as the variety will allow and treated while still dormant to avoid injury. Treated bulbs should be planted as soon as possible.

Roguing of daffodil plantings is helpful in reducing injury and preventing spread if done early in the season. Roguing volunteer plants is a must in any control program. A combined program of roguing and hot water treatment is now a standard procedure for many growers.

Foliar Nematodes (*Aphelenchoides fragarie*)

DISTRIBUTION. *Aphelenchoides fragarie* is a common pest of various kinds of lilies in north and southwestern Oregon.

DISSEMINATION. Nematode infections are transferred to other areas and from one season to the next in planting stock. Transfer from one plant to another occurs in field and greenhouse plantings, especially when plants are close together.

SYMPTOMS. Bunchy-top and die-back conditions are well known to growers as symptoms of foliar nematodes. Infected leaves are blotchy and then turn yellow or brown and wither back against the stem. Terminal leaves are distorted, thickened, and point upward in various directions. Another lily symptom commonly associated with this pest is "blossom blasting." Easter lilies so affected in field and greenhouse cultures are referred to as "blind." Nematodes thrive in young flower buds—often injuring them so that blooming is retarded or the flowers destroyed. Infected plants often show more than one of these symptoms at the same time.

Bunchy-top, die-back, and blossom blasting are common symptoms of many infected Easter and other garden lilies. A notable exception is in the Rubrum lily. Infected garden lily leaves show purplish areas before turning brown and wilting back to the stem. Symptoms usually appear during late summer in all garden lilies except Easter lilies when they appear in late spring. Infection from this nematode moves along the row and seldom causes a target-spot like pattern.

DIAGNOSIS. A microscopic examination of diseased leaf tissue should be conducted for confirmation.

CONTROL. Infected bulblets are successfully treated by using a hot water bath of 111° F. (43.5°C) for 1 hour. Formaldehyde solution (38-40% formalin) is added to the hot water bath at 1 part per 200 parts of water, or one pint to 25 gallons of water. This treatment is best applied to bulblets only to reduce volume handled and to avoid plant injury which often follows treatment of larger bulbs. After treatment, bulbs should receive a fungicide dip for protection against rot.

Roguing lily planting for foliar nematodes is a common practice. Since it is difficult to detect infection at an early stage, roguing must be repeated several times during the season.

Dahlias

Potato-Rot Nematode (*Ditylenchus destructor*)

This pest, usually associated with potatoes, recently has been found to cause rot-like symptoms on dahlia roots (formerly called tubers).

DISTRIBUTION. A few dahlia plantings of northwestern Oregon.

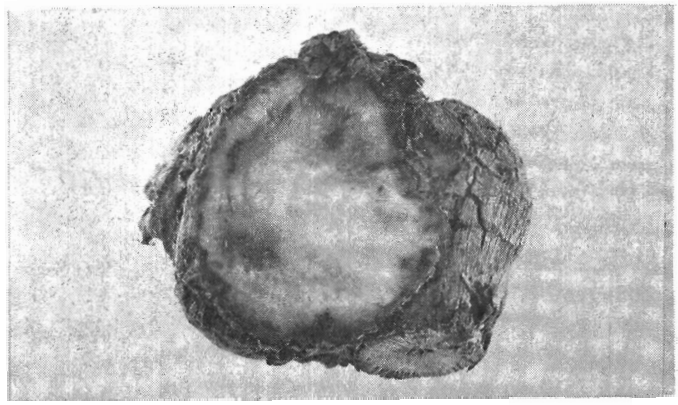
DISSEMINATION. Infected dahlia roots.

SYMPTOMS. Lack of characteristic foliage and root symptoms seriously handicaps detection of infected plants during the growing season.

Nematodes usually are found in shallow lesions on roots with abnormal transverse cracking accompanied by flaking or sloughing of bark. Advanced stages of infection seem to resemble symptoms produced by the same nematode on potatoes. Subsequent rot is a dry breakdown with a granular-like appearance followed by shrinking and cracking of the surface. Infections continue to develop in storage.

DIAGNOSIS. Confirmation of infection must be made by microscopic examination because symptoms are not specific and this nematode is extremely difficult to identify.

CONTROL. This problem is new to Oregon and control measures are still in experimental stages.



Dahlia roots recently have been found to be infected with the potato-rot nematode. Darkened areas in this root are characteristic of diseased "tubers."

Woody Nursery Crops

Root-Lesion Nematodes (*Pratylenchus* spp.)

Three kinds of root-lesion nematodes are pests in Oregon nurseries. *Pratylenchus penetrans*, the most injurious, is a common pest of apple, cherry, peach, and pear seedlings. Many kinds of evergreens and shrubs are injured by this pest. *P. pratensis*, another common species, oc-

casionally is recovered from various seedlings and ornamentals. *P. vulnus* sometimes is found in roots of various kinds of boxwood.

DISTRIBUTION. Upper Willamette Valley—principally Clackamas, Marion, Multnomah, and Washington Counties. Some infestations occur in Jackson and Umatilla Counties.

DISSEMINATION. Movement of infested soil and various kinds of infected propagation stocks probably account for establishing *P. penetrans* and *P. vulnus*. This also applies to *P. pratensis* although there is evidence this species is native.

SYMPTOMS. First indication of these pests is a conspicuous dwarfing of plants which may or may not be accompanied by off-colored foliage. Infection areas usually take the shape of circular or target-spot zones with most plants in the area affected though a few may remain normal. Primary damage occurs in young root systems which remain poorly developed. In severe infections secondary roots fail to form or are so girdled that only short, stubby remnants remain. Symptoms are difficult to observe in light infections.

DIAGNOSIS. Nematodes are found in root tissue by microscopic examination though sometimes it is necessary to stain tissue for best results.

CONTROL. Soil fumigation with 25-30 gallons of a dichloropropene nematocide is recommended as the principal control measure. Crop rotation recommendations are not available because the host range is not completely known. Many growers prefer to rotate with a cover crop, such as Sudan grass, which is rarely invaded by these nematodes. Most legume crops, principally clover and vetch, should not be used as cover crops because they are susceptible to root-lesion nematodes. Investigations of various therapeutic measures have and are being conducted to find ways to eliminate nematodes from valuable nursery stocks.

Root-Knot Nematodes (usually *Meloidogyne hapla*)

DISTRIBUTION. Nursery crop areas of western Oregon.

DISSEMINATION. In infected planting stock.

SYMPTOMS. Galls are found on roots of various nursery plants during digging. Infections usually are rather mild and fail to result in noticeable above ground symptoms during the growing season. Many infected plants such as roses, show abnormal developments of secondary roots near galls. Root-knot nematodes probably are most destructive in light or sandy soils.

DIAGNOSIS. Root-knot nematode infection rarely can be diagnosed by above ground growth alone. Galls also may result from bacteria, insects, or natural subterranean plant structures. Verification by microscopic examination is necessary.

CONTROL. The most practical control measure is a preplanting soil fumigation treatment with one of many nematocides which do not have a detrimental effect on future crops.

Spiral Nematodes (*Helicotylenchus nannus*)

Vast numbers of spiral nematodes recently were recovered from soil surrounding declining gardenia plants. Numerous nematodes also were seen feeding on gardenia roots.

DISTRIBUTION. Greenhouse, Eugene area.

DISSEMINATION. Probably via infested soil.

SYMPTOMS. Gardenia plants, greenhouse grown for commercial flower production, developed decline symptoms which include stunting of plants to half the size of others planted at the same time; yellowing and premature dropping of leaves; failure to form flower buds; premature dropping of buds; eventual death.

Declining gardenias have fewer feeder roots and much more sloughing of root cortex than normal plants. Colonies of spiral nematodes feed on roots. Points of initial infection develop small brown circular areas which grow together and contribute to sloughing of root cortex. In one instance a gallon of soil taken from root areas of declining plants yielded more than 20,000 spiral nematodes.

DIAGNOSIS. Examination of roots and surrounding soil of declining gardenia plants will reveal vast numbers of spiral nematodes.

CONTROL. Control measures are being investigated.

Flowers

Foliar Nematodes (*Aphelenchoides fragarie* and *A. ritzema-bosi*)

Two species are greenhouse pests of many plants including Begonia, Chrysanthemum, Birdnest Fern, Gloxinia, Easter lily, Pepperomia, and African violet. *A. ritzema-bosi* is the more common greenhouse pest. *A. fragarie* rarely is found in any host other than lily.

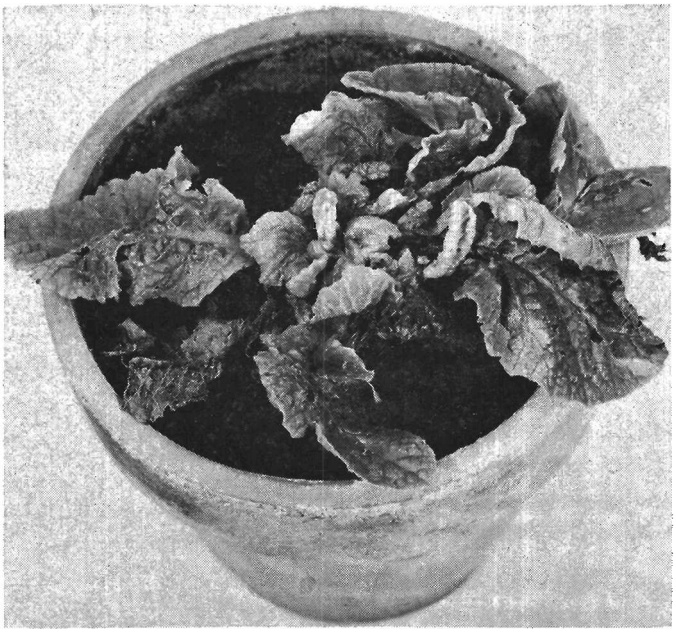
DISTRIBUTION. Common pest in many greenhouses throughout Oregon.

DISSEMINATION. Nematodes are spread from one place to another with diseased propagation material or contaminated plant debris.

SYMPTOMS. Diseased plants such as Christmas Begonia, Chrysanthemum, Gloxinia, Easter lily, and African violet usually produce few or no flowers. Invaded plants develop unsightly foliage. Leaves are distorted, discolored, and are extended abnormally from stems or crowns. Infected leaves show dark water-soaked spots at first. These areas and the entire leaf later turn brown, shrivel, and then fold back against stems or drop.

DIAGNOSIS. Nematodes are concentrated near stomatal openings at first but later can be recovered from nearly any part of the leaf. Soaking or shredding diseased leaves in water will enable some nematodes to leave tissue so they can be observed microscopically.

CONTROL. Since infected propagation stocks and contaminated soils introduce these pests, growers should obtain materials from reliable sources. Crowded conditions in greenhouses contribute to a rapid spread of nematodes —especially when plants touch each other. Adequate spac-



Distored leaves of this primrose are one indication that it is infected with bulb or stem nematodes. These pests are common in some greenhouses.

ing is essential to prevent infections reaching epidemic proportions. Splashing from overhead irrigation also may spread pests from one plant to another. Vegetative propagation from diseased leaves or cuttings will establish or reestablish infections. Isolation of unthrifty plants from crowded plantings—even though such plants show no specific symptoms—is an excellent precautionary measure.

Some growers obtain satisfactory results with phosphate insecticides used as foliar sprays. Applications are repeated at 7-10 day intervals until symptoms vanish. This interval is necessary to eliminate newly hatched larvae which survived in the egg stage. Dosages vary according to material and percentage of active ingredients in formulations. These are hazardous materials and application should be made according to instructions on the label.

Bulb and Stem Nematodes (*Ditylenchus dipsaci*)

D. dipsaci is a common pest of many herbaceous flowering plants such as phlox and primrose.

DISTRIBUTION. Sporadic in greenhouses and ornamental plantings throughout Oregon.

DISSEMINATION. Bulb and stem nematodes usually are established in new sites through movement of infected propagation stock.

SYMPTOMS. Stunting and distortion of stems and leaves are common symptoms of this pest. Some plants show characteristic symptoms only in early spring and little evidence of infection during warm dry weather. Distorted areas often are thickened abnormally. Infected plants may fail to bloom and usually are ragged and unattractive.

DIAGNOSIS. Nematodes usually are found by shredding infected tissue in water.

CONTROL. Roguing of infected plants and removal of all diseased plant material and chaff from seed will do much to check infection. Systemic phosphate insecticides give satisfactory results when applied periodically as foliar sprays.

Root-Knot Nematodes (*Meloidogyne hapla* and *Meloidogyne* spp.)

Flowering ornamental plants whether grown in greenhouses, gardens, pots, or window-boxes often are infected with root-knot nematodes. Clematis, coleus, cyclamen, peony, snapdragon, African violet, are examples of plants frequently injured.

DISTRIBUTION. Root-knot infections occur in greenhouse and ornamental garden plantings throughout Oregon.

DISSEMINATION. Infections are established by movement of infected propagation stocks—cuttings, roots, transplants, tubers—and of contaminated soil.

SYMPTOMS. Characteristic foliage symptoms are lacking but stunted plants which produce few or no flowers and wilt excessively during warm weather may harbor these pests in their roots. If stunting is caused by root-knot nematodes, roots will show galls. Secondary roots near galls may be so numerous that a hairy-root condition develops.

DIAGNOSIS. Evidence of root-knot nematodes can be determined by carefully breaking up galls and searching the residue for pear-shaped females.

CONTROL. All precautions which prevent movement of contaminated soil or plant debris into established plantings are good control measures. Growing sites such as bench or ground beds, cans, flats, and pots must be properly sterilized if there is a history of infection. Most potting soils can be treated by heat or by one of several nematocides to insure freedom from pests. Once infections are established, infested soil and diseased plants should be removed immediately to prevent spread.

Small Fruits and Specialty Crops

Most nematode diseases of Oregon-grown small fruits occur in strawberries but blueberries and gooseberries are sometimes affected. Commercial peppermint is the major speciality crop injured by nematodes.

Strawberries

Three major nematodes attack Oregon strawberries. A fourth pest is occasionally found on planting stock received from other states.

Spring Dwarf Nematode (*Aphelenchoides fragarie*)

Commercial Oregon strawberry plantings are not known to be infested with this pest, though occasional infections have been observed on experimental plantings of imported stocks in controlled areas.

DISTRIBUTION. Linn County.

DISSEMINATION. Infected planting stock.

SYMPTOMS. In spring symptoms include absence of blossoms, retardation of fruiting stalks, and distorted leaves. Infected plants are ragged, leaf stems are distended and plants often are called "spider-legged." While some fruiting may occur, development of new leaves conceals characteristic symptoms.

DIAGNOSIS. Large numbers of nematodes are found in the crown or in fruiting stalks. Microscopic examination of infected tissue will reveal spring dwarf nematodes.

CONTROL. Since infected strawberry plants come to Oregon from other areas, growers obtaining planting stock from out-of-state sources should insist on protection by certification. Once spring dwarf nematodes are established in plantings control involves roguing or, if pests are widespread, destruction of the entire planting. Treatment of runners by hot-water and certain chemicals is possible.

Strawberries planted where infected red clover was grown often are damaged by bulb and stem nematodes. Abnormal stems are characteristic.

Bulb and Stem Nematodes (*Ditylenchus dipsaci*)

Strawberries planted in fields where infected red clover was grown often are damaged by bulb and stem nematodes.

DISTRIBUTION. This nematode appears sporadically in upper Willamette Valley—Clackamas, Columbia, Marion, Multnomah, and Washington Counties.

DISSEMINATION. Nematodes usually are established by infected plants or by infected red clover.

SYMPTOMS. Field plantings show areas of poor growth where dwarfed plants develop abnormal foliage. Short thickened leaf and fruiting stalks are characteristic symptoms. Leaf distortion may or may not be evidence of nematode injury. Most injury is done in winter while foliage and fruit buds are developing in the crown. Symptoms are most noticeable early in the season, less noticeable at picking time, and concealed after harvest, but yield is nevertheless reduced. Damage is apt to be most severe during late spring months in years of heavy rainfall.

DIAGNOSIS. Bulb and stem nematodes are recovered from infected leaf or fruiting stalks by shredding tissue in water. Confirmation by microscopic examination is required.

CONTROL. Specific control measures have not been developed for this nematode. Growers are advised to obtain plants from certified sources and to avoid planting in areas having a history of infected strawberries or red clover.

Root-Knot Nematodes (*Meloidogyne hapla*)

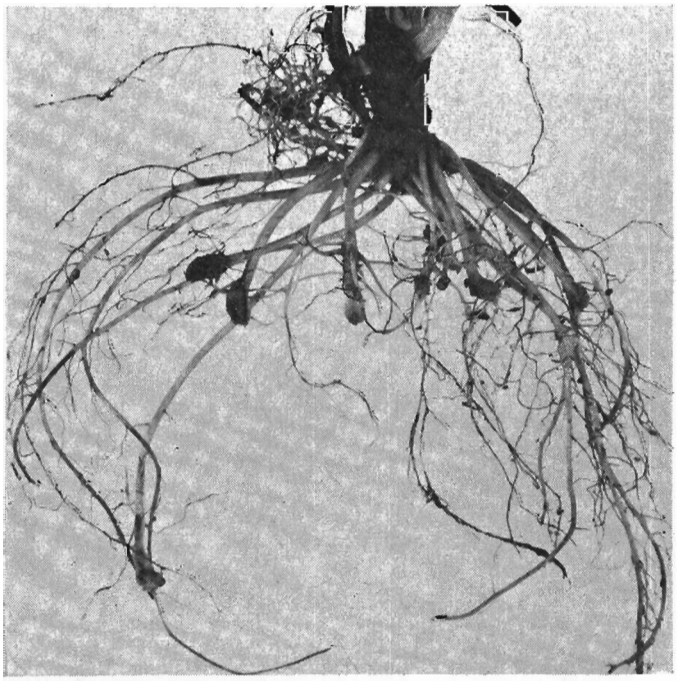
Several varieties of one-crop and everbearing strawberries are infected by this pest. Blueberry and gooseberry occasionally are invaded.

DISTRIBUTION. Most injury has been reported from Clackamas, Jackson, Marion, and Multnomah Counties.

DISSEMINATION. Although contaminated soil is of some importance, movement of infected plants is responsible for establishing most new infestations.

SYMPTOMS. Foliage symptoms are of little diagnostic value when plants are infected by root-knot nematodes. Injury causes root galls. Considerable variation exists in gall size on strawberry roots. Smallest galls, frequently overlooked, may contain a single nematode while larger galls contain several. While a hairy-root condition often is seen when infections are severe, this condition is not always associated with nematodes.

Although reduction in yield and plant vigor is inconspicuous, these nematodes present a serious problem for growers of certified plants. Nematodes are spread to new areas in diseased plants and certification standards are designed to prevent this means of dissemination. Infected plantings cannot be certified.



This strawberry plant is infected with root-knot nematodes. These pests also attack blueberry and gooseberry plantings in certain Oregon areas.

DIAGNOSIS. Nematodes can be removed from root galls by laboratory techniques.

CONTROL. Certified plants will not be diseased, but once a planting has become infected little can be done. When infection has been diagnosed and the plantings have declined beyond an economic return, soil should be worked into seed bed condition and fumigated if strawberries or other susceptible crops are to be planted. Planting strawberries after strawberries is not recommended if previous berry crops have failed.

Root-Lesion Nematodes (*Pratylenchus penetrans* and *P. pratensis*)

Strawberry roots frequently are infected with both species of pests. Caneberry roots also occasionally are invaded. Of the two species *P. pratensis* seems to be more common in strawberry roots.

DISTRIBUTION. Root-lesion nematodes occur in many western Oregon plantings.

DISSEMINATION. Soil may be a minor factor although infected transplants are likely to establish new infections.

SYMPTOMS. Strawberries seldom are damaged so severly that characteristic target-spot areas of poor growth are noticeable in a field. Although root-lesion nematodes probably are detrimental to strawberries, information is lacking regarding their effect on Oregon berry production. These nematodes are believed to be an integral part of root-rot complexes involving fungi. Thus the so-called "black root-rot" of strawberries may be a disease of this type.

Tissues die near points where nematodes invade roots. Infected roots washed free of soil may exhibit lesions caused by nematodes.

DIAGNOSIS. Microscopic examination.

CONTROL. Recommendations are not available for control, but soil fumigation studies are in progress. A careful inspection of planting stock and selection of future planting sites with no history of nematodes are considered good precautionary measures.

Peppermint

Two pests affect peppermint in Oregon, but others may occur as mint production expands.

Root-Knot Nematodes (*Meloidogyne hapla*)

Meloidogyne hapla is the most common and widespread pest of commercial peppermint in Oregon, but data on yield reduction caused by this pest are lacking.

DISTRIBUTION. Root-knot nematodes were believed to occur only in peppermint plantings near Hermiston and Grants Pass. Recently they have been found in all areas, though some individual plantings appear free. Root-knot nematodes also are common pests of spearmint.

DISSEMINATION. Spread from one area to another is usually caused by moving infected planting stock. Local spread within fields is due to various cultivation practices such as leveling land, and by movement of water as in irrigation.

SYMPTOMS. Characteristic foliage symptoms are lacking although delay in regrowth following harvest has been observed. Root system galls are conspicuous and often are accompanied by a matted or hairy root condition resulting from excessive formation of secondary roots near the swelling.

DIAGNOSIS. Nematodes can be seen in root galls by microscopic examination.

CONTROL. Best procedure is to avoid establishing an infection by planting rhizomes which are free of nematodes. Since root-knot nematodes invade many crops, growers are advised to avoid land having a history of nematode infection. Infections are seldom diagnosed before mint plantings have been established. Fumigation is not recommended in established peppermint plantings because of difficulties in application and because most nematocides are harmful to growing plants.

Mint Nematode (*Longidorus menthasolanus*)

The mint nematode does not enter host tissue to feed. Instead, this nematode remains in the soil and penetrates the host tissue with a spear. This pest is the largest plant parasitic nematode known.

DISTRIBUTION. Mint nematodes commonly occur in peppermint plantings of flood areas near the Santiam River in Linn and Marion Counties.

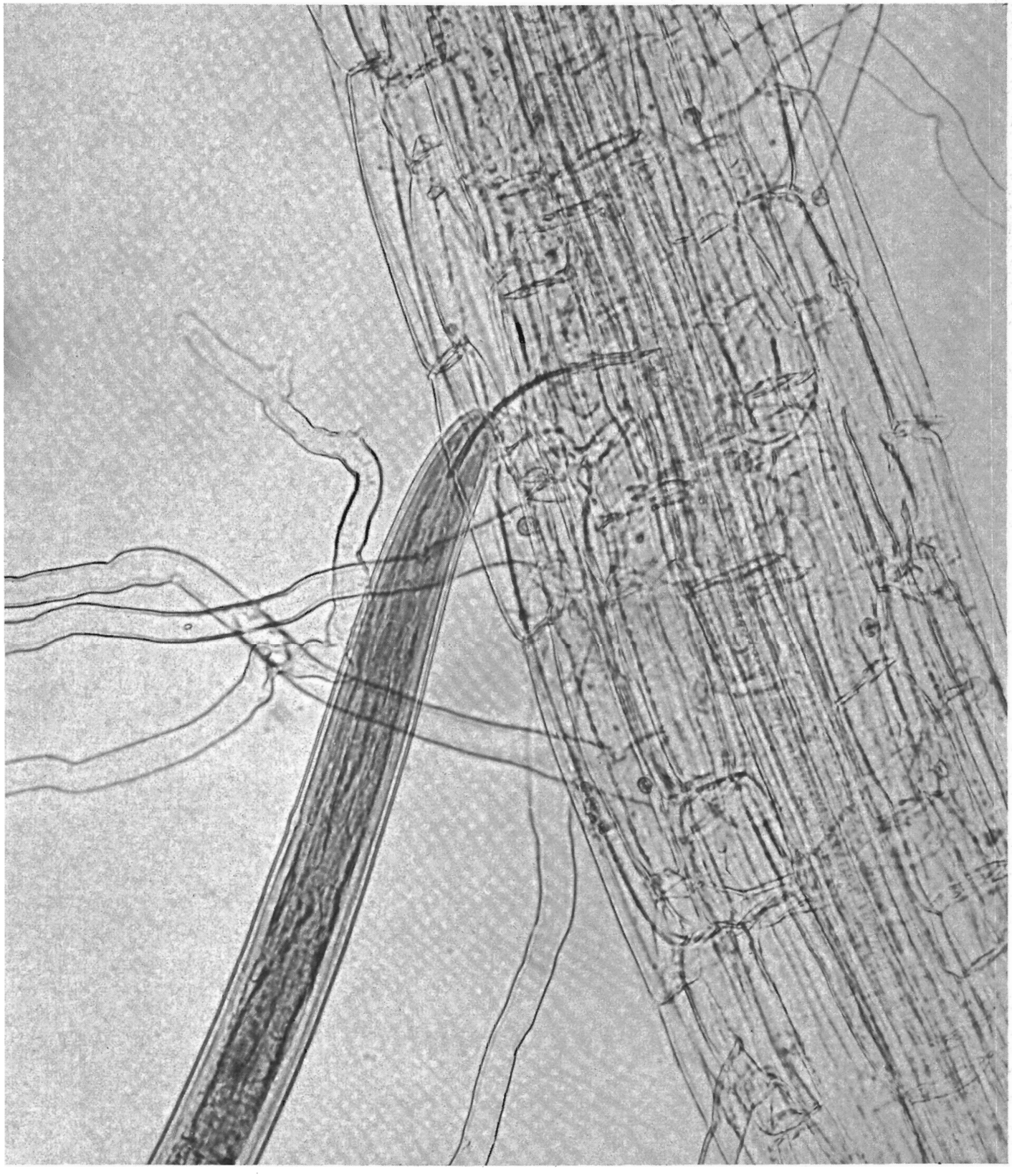
DISSEMINATION. Spread probably is due to erosion and soil movement which takes place during flooding.

SYMPTOMS. Barren areas of fields where the mint stand is sparse and surviving plants have a reddish color indicate nematode damage. These conditions are most conspicuous during cold damp spring weather before mint begins rapid growth. Symphylids may produce similar field symptoms so accurate diagnosis is necessary, especially since both pests often inhabit the same area. Fortunately these nematodes are so large a microscope is not necessary to see them in soil or on roots.

Root systems of surviving mint plants in barren areas usually are poorly developed and retain only a few stubby roots. Nematodes are often so thickly coiled around damaged roots that they resemble small tufts of cotton. These nematodes seem to prefer a cool moist environment as symptoms are most severe in years having a prolonged damp spring. Although mint plants surviving in barren areas show severe symptoms in early spring, many such plants attain average growth during warm and dry seasons.

DIAGNOSIS. Nematodes can be seen by visual inspection of damaged roots or surrounding soil.

CONTROL. Several soil fumigation experiments indicate a substantial yield increase can be obtained by pre-planting treatment. One gallon of technical dibromochloropropane applied by injection gives excellent results. Other materials are being investigated for control efficiency. Very little information is available on host preference for this pest, but a rotation program of nonsusceptible crops should prove effective.



This dagger nematode, with its spear plunged into the center of a root, is feeding on Chewing's fescue. These nematodes, which future research may prove to be the most destructive pests in the country, are widely distributed in root areas of most trees, flowers, and other plants.

Part 2.

Biology, Host Range, and Life Cycle

Nematodes are among the most abundant groups of animals. They are found wherever life exists and probably are best known to us as parasites of plants and animals. Man himself is a choice food supply for more than 32 types of nematodes.

Only a few of the vast numbers which inhabit seas, lakes, streams, and soil are known to science. Researchers estimate that there are 300 to 600 million nematodes per acre a foot deep in the soil. A single gall of infected wheat contains 90,000. Nearly 1,000 were counted in a small dog, and more than 5,000 pin worms have been found in a man.

Sometimes nematodes are called "eelworms"—probably a more satisfactory term as it describes their shape and movement. Most nematodes move in a snake-like fashion but some scarcely move at all. Some depart from the conventional eel-like shape to resemble miniature beans, lemons, and pears. The vast majority are so small that microscopes are necessary to see them. A few can be seen without magnification. The largest one known to science—found in the placenta of a whale—is reported to be 25 feet long. Most nematodes have a size range of 1/50th to 1/5th of an inch.

Active life for most nematodes begins within jelly-bean shaped eggs, though others are born as active young —in either case they are called larvae. Eggs produced by a single female vary from a few for some species to several thousand for others. Eggs are deposited within the host plant or animal or in soil or water. Larvae generally resemble their parents except they are much smaller and lack some adult structures such as reproductive organs. In order to complete their development, most forms undergo a type of metamorphosis which involves a series of four moults and four larval stages. A complete life cycle from egg to egg may last only a short time—3 to 5 days for some species—but others reach the ripe old age of a year or more.

Though nematodes are small in size, they are complex in structure, possessing essential mechanisms necessary for development, survival, and reproduction. While most nematodes are blind (except numerous marine forms) and possess no known circulatory or respiratory organs, they do have well developed digestive, excretory, muscular, nervous, and reproductive systems. Their exterior covering, which furnishes great protection, is called the cuticle. Adverse conditions such as high or low temperatures and excessive or limited moisture are easily tolerated by many species.

Though nematodes have been intensively studied as parasites, their contributions to nature's general plan have been overlooked. They provide food for higher animals and plants and also help with the breakdown of decaying organic materials. As parasites of various insects and other forms of animal life they help maintain a balance in nature.

Seed Nematodes

Anguina agrostis

The most important seed nematode in Oregon is *Anguina agrostis,* the grass seed nematode. This pest continually harasses Oregon's grass seed industry by causing serious damage to Chewing's fescue and bentgrasses. A second species may be involved, since natural or artificial infections do not occur between the two principal hosts.

Oregon Host Range	*Distribution*
Astoria Bentgrass. *Agrostis tenuis* Sibth.	Clatsop, Columbia, and Lane Counties
Seaside Bentgrass. *Agrostis palustris* Huds.	Clatsop, Columbia Counties
Highland Bentgrass. *Agrostis tenuis* Sibth.	Clackamas County
Chewing's Fescue. *Festuca rubra* v. *cummutata* Gawd.	Willamette Valley (scattered)
Creeping Red Fescue. *Festuca rubra* L.	Experimental Host Range

Life Cycle and Biology. Galls containing thousands of larvae usually fall to the ground about harvest time. They remain in stubble until fall and winter rains soften the hardened exterior and free young nematodes. Larvae move about in the film of moisture on surfaces of soil and existing vegetation. Eventually some larvae make their way into stems and growth tissues of host plants. A few find their way to sites of developing flowers where they remain until future seeds start to develop in the boot stage. Then they crawl into open ends of young seeds and begin to feed. As they feed, young seeds develop into galls instead of normal seeds. When flowers emerge from the boot stage nematodes are usually adults. As host plants mature, nematodes continue to feed, mature, mate, and produce thousands of eggs during gall development. Then as flowers mature for harvest, eggs hatch and release

thousands of new larvae coiled within the gall and ready to begin another cycle.

Usually one male and one female—sometimes several—are recovered from each gall after panicles have emerged from the boot stage. If only one sex invades a developing ovule, galls will be smaller than usual. Seed hulls will be enlarged like those of an average gall.

Ability of second-stage larvae to survive in dried galls for 10 to 15 years following harvest is an amazing example of nematode survival in extremely adverse conditions. All food for this inactive period, as well as for first and second stage development, is provided in the egg. Survival in galls accidentally included in seed used as planting stock makes this nematode a constant threat to bentgrass production.

Foliar Nematodes

Foliar nematodes of the genus *Aphelenchoides* are pests of greenhouse and outdoor ornamental plantings. Two species of this genus occur in Oregon. They are the "spring dwarf" or "crimp" nematode, *Aphelenchoides fragarie;* and the "chrysanthemum leaf" nematode, *A. ritzema-bosi.*

Aphelenchoides fragarie

This foliar or leaf pest has several common names in addition to those mentioned. Two of the most common terms are "bud and leaf" nematode (Easter lilies) and "spring dwarf" nematode (strawberries). This nematode also has been found in sword fern along coastal regions of southwestern Oregon. Easter lily growers are occasionally concerned over possible spread of this pest from sword fern to lilies. Neither field observations nor laboratory tests indicate this is possible. Primary importance of this nematode to Oregon agriculture is damage to lily plantings. Conditions called "dieback" and "bunchytop" are well known to Oregon lily growers.

Oregon Host Range	*Distribution*
Bellingham Hybrid Lily	Benton County
Easter (Croft) Lily	Coos, Curry, and Clackamas Counties
Strawberry	Linn County
Sword Fern	Coos and Curry Counties

Aphelenchoides ritzema-bosi

"Chrysanthemum leaf" nematodes are common greenhouse pests, though outdoor plantings are occasionally affected. The greenhouse host range includes many plants—African violet, Bird's nest fern, and Pepperomia—which usually make up the home owner's collection, but nematodes rarely are found on these hosts in Oregon. The life-cycle is very similar to other species of the genus.

Oregon Host Range	*Distribution*
Chrysanthemum	Occurs sporadically in greenhouses near cities
Begonia	"
Gloxinia	"
Phlox	"

Life Cycle and Biology. Most researchers conclude that a life cycle from egg to egg can be completed in a minimum of 14 days. Poor conditions such as temperature, moisture, development of host plant, and so forth, may prolong time in which a life cycle is completed.

Foliar nematodes tend to establish both endo- and ecto-parasitic relationships with host plants. As endo-parasites—inside the plant—they usually enter host plant tissue through stomata—small natural openings—although direct penetration can be made through the cuticle. As ecto-parasites—outside the plant—they usually travel on surfaces of host plants in a film of moisture. They are easily spread from one host plant to another during an ecto-parasitic relationship. Once nematodes are established, it is possible to find eggs, larvae, and adults in tissue next to stomata.

Aphelenchoides are active, frequently moving so fast that they remain near the surface of water in an examining dish. They also become inactive and survive in dried leaf tissue and other infected plant debris for 3 to 5 years. Their ability to live as ecto-parasites and to survive for years in infected host tissue necessitates certain horticultural sanitation practices.

Easter lilies frequently are victims of the bud and leaf nematode. Greenhouse and other outdoor ornamental plantings often are attacked.

Bulb or Stem Nematodes

These nematodes usually attack bulb or stem portions of plants, though flowers and leaves also are injured occasionally. Two species of this group (of the genus *Ditylenchus*) are pests in Oregon. *Ditylenchus destructor*, ("potato-rot" nematode) has been found only on bulbous iris and dahlia. Another species, *Ditylenchus dispsaci* ("bulb or stem" nematode), is a common pest in several Oregon crops. Many researchers believe this species is a composite of several related nematodes. This may be, since several instances exist where a population from one host will fail to produce symptoms or survive on another reported host plant.

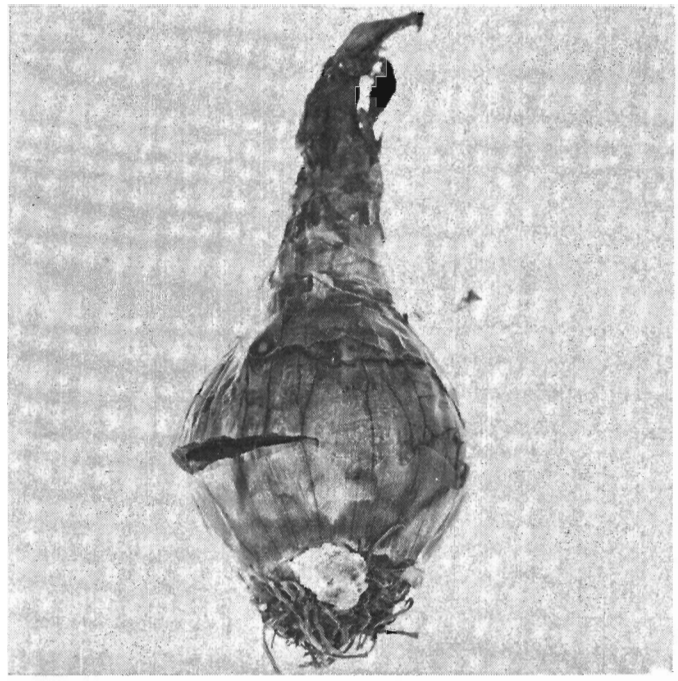
Ditylenchus dipsaci

Commonly known as the "bulb or stem" nematode, "teasel" nematode, or "alfalfa stem" nematode, this pest is distributed over much of Oregon and occurs in several crops and weed hosts. Evidence of damage or injury is most noticeable in spring.

Oregon Host Range	*Distribution*
Alfalfa	Rogue River Valley, Blue Mountain area near Enterprise, and Hermiston
Alpine Carnation	Nurseries, Portland area
Clover, Red	Willamette Valley, Hillsboro area, spotted in Multnomah and Clackamas Counties
Daffodil	Greenhouses, Clatsop, Multnomah, Clackamas, Marion and Curry Counties
Garlic	Benton and Washington Counties
Phlox	Greenhouses, Portland area
Primrose	Nurseries, Portland area
Strawberry	Willamette Valley, sporadically in Clackamas and Multnomah Counties
Teasel	Clackamas County

Weed Hosts	*Distribution*
Cow Poison, Larkspur *Delphinium trolliifolium* Gray	Benton County
Hairy Cat's Ear *Hypochoeris* radicata L.	Coastal areas
English Plantain *Plantago lanceolata* L.	Coastal areas
Sea Plantain *Plantago maritima* L.	Coastal areas
Silver Weed *Potentilla anserina* L.	Coastal areas
Sand Strawberry *Frageria chilensis* (L.) Duch.	Coastal areas

Life Cycle and Biology. Time to complete a life cycle from egg to egg has not been determined, although some researchers have estimated 21-30 days for best conditions. Poor conditions may extend this period many times. Considerable overlap exists in various developmental stages since there is no spontaneous sequence from one generation to another. This is evident by observing eggs, larvae, and adults in diseased tissue.



A common symptom of bulb or stem nematodes is the "nematode wool" shown at the base of this daffodil bulb. Flowers also are injured.

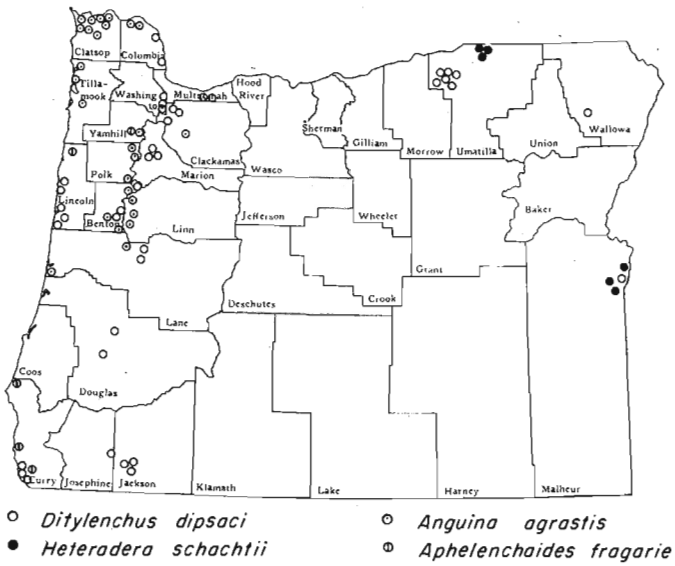
Bulb and stem nematodes usually are parasites of stem tissue, though leaves and flowers also are damaged. Although above ground plant symptoms are conspicuous and easy to see, bulbs or infected underground portions require examination. Invasion of the host plant usually takes place through natural openings, but these nematodes also provide their own avenue of entry. Once established, pests move through tissues of host plants, break down cell walls, and feed on cell contents.

Sometimes bulb or stem nematodes gather together in tight clusters which resemble tufts of cotton and are called "nematode wool." This frequently occurs on outsides of daffodil bulbs near the basal plate. Nematodes in these situations will withstand highly adverse conditions, such as dryness, long exposure to hot water, and sub-zero temperatures. Like many plant parasites these nematodes can remain alive in infected plant tissue for at least nine years. Infected plant tissue must remain dry or activity is resumed.

Ditylenchus destructor

Until 1945 this nematode was regarded as a "potato strain" of *Ditylenchus dipsaci*. New research shows that nematodes in potatoes and iris are identical. Though this nematode once attacked Oregon iris, recent reports of its occurrence have not been received. *D. destructor* was found recently in major Oregon dahlia plantings.

Oregon Host Range	*Distribution*
Several Varieties of Dahlias	Clackamas, Marion and Multnomah Counties
Several Varieties of Iris	Multnomah County



Locations of certain species of nematodes in Oregon.

Life History and Biology. Biology of this pest is similar to that of bulb or stem nematodes. Potato-rot nematodes are most active during late fall and early winter when symptoms are most apparent on dahlias and iris. During winter months, when these crops are in storage, larvae, eggs, and adults can be found in infected tissue. Thus generations tend to overlap. In mushrooms, another host not known to be infected in Oregon, activity is continuous.

Root-Lesion Nematodes

Other common names for this group are "meadow" and "migratory" nematodes. The most injurious nematodes in Oregon belong to this group. At least five species occur in Oregon, but only three (*Pratylenchus penetrans*, *P. pratensis*, and *P. vulnus*) are regarded as major pests. Most serious is *P. penetrans*, a constant threat to the nursery and ornamental industry.

Root-lesion nematodes produce dead spots or lesions on roots. Injury is probably most severe on small feeder roots which may be completely girdled. These pests injure their host plants . . .

- By direct feeding which deprives plants of water and food.
- By producing lesions which cause partial or complete loss of plant structures and impair vital functions necessary for growth.
- By producing wounds or lesions through which other organisms may enter plant tissue.
- By migrating ahead of rotting tissues and spreading other organisms into healthy tissues.

Pratylenchus penetrans

An extensive host range of many valuable crops and wide distribution in most agricultural lands west of the Cascades make this pest most dangerous of Oregon nematodes. *P. penetrans* is able to tolerate a wide range of environmental conditions, for within this geographic area occur many variations in temperature, moisture, plants, and soil conditions.

Life History and Biology. Time required for a life cycle from egg to egg has not been accurately determined for Oregon conditions. Observations elsewhere indicate a life cycle can be completed in 45 to 65 days. In Oregon this nematode is active throughout the year—though it may be difficult to find during summer dry spells. Adults, larvae (which resemble adults except in size) and eggs are found in tissue. Males usually are as numerous as females. Jelly-bean shaped eggs are deposited—singly or in groups of three or four—in host tissue along migration paths of adults. Unlike other common nematodes which produce hundreds of eggs, root lesion nematodes lay only 10 to 20.

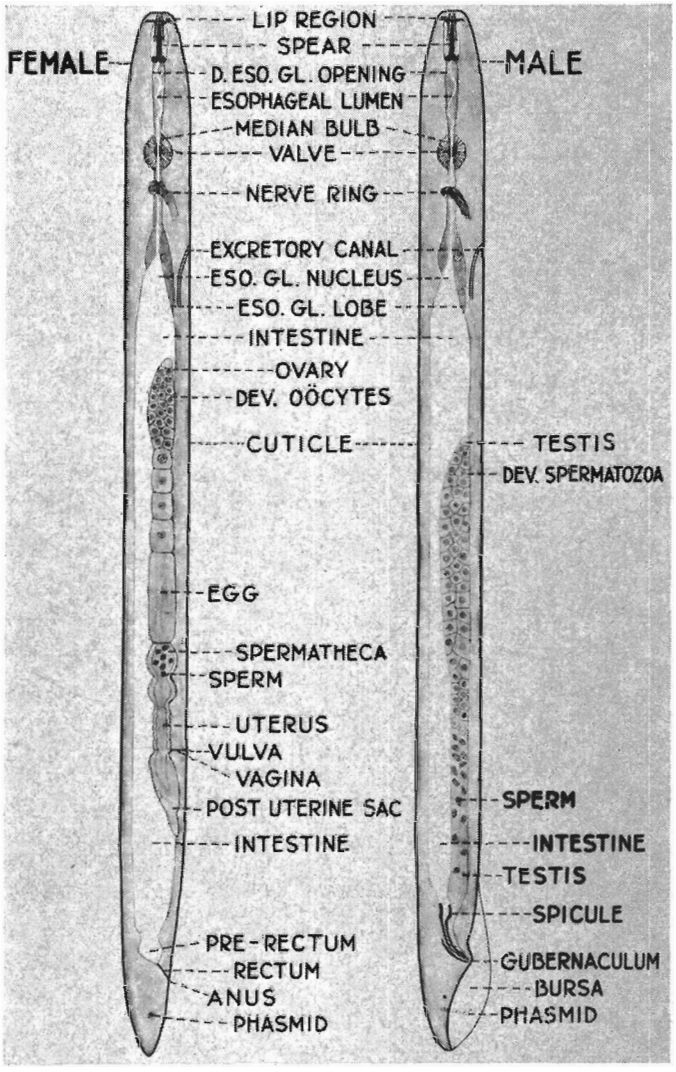
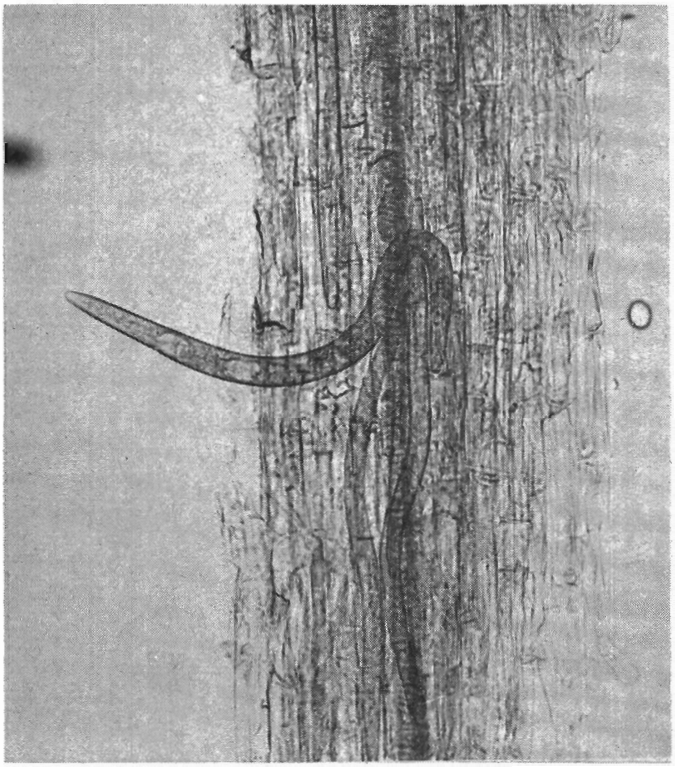


DIAGRAM OF ROOT-LESION NEMATODES SHOWING INTERNAL ANATOMY
The most injurious nematodes in Oregon belong to the root-lesion group. These pests produce dead spots, lesions, and damage small feeder roots.

Root lesions caused by these nematodes are also invaded by secondary organisms. Root-lesion nematodes are seldom found in large numbers in tissues occupied by secondary fungi and bacteria but tend to migrate to marginal areas of lesions—hence the common name "migratory." Root-lesion nematodes frequently travel from one area to another in the same root, from root to root, or from plant to plant.

These nematodes can survive in soil, without a host plant, longer than a year. In plant tissue, usually roots, they can survive most storage and transportation conditions. Once established in host tissue, they withstand some of the most adverse conditions devised by man. Thus far no treatment of infected plants by heat or chemicals has been developed which will eliminate these nematodes without injuring plants.

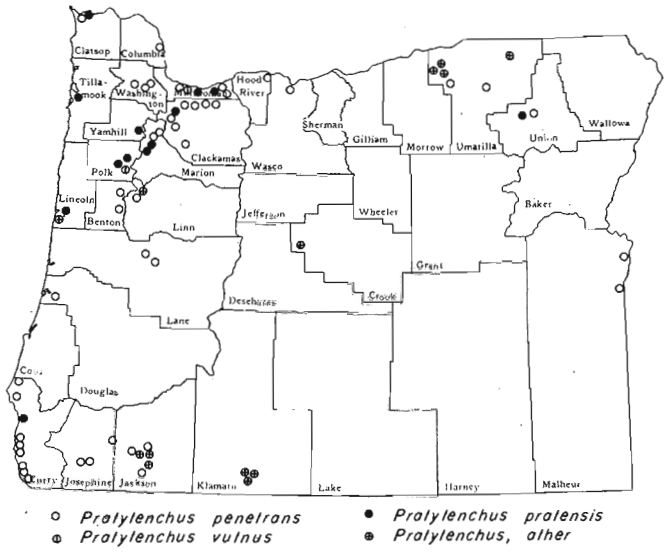


Root-lesion nematodes are shown feeding on a narcissus root. This direct feeding deprives plants of water, food, and does other serious damage.

Pratylenchus pratensis

This species of root-lesion nematode probably has a greater distribution in Oregon soils than *P. penetrans*, but Oregon's host range of economic plants for this pest is more limited.

Life History and Biology. Life history of this nematode is similar to species already discussed. Before 1940, root-lesion nematodes were considered one species, *P. pratensis*. A population with more than 10% males is rare. These nematodes are seldom abundant in host tissues. Discovery of *P. pratensis* in areas far from agriculture indicate this species is native to Oregon.



Locations of root-lesion nematodes found in Oregon.

Pratylenchus vulnus

This nematode is less common than *P. penetrans* and *P. pratensis*. Only a few ornamental plants have been injured. Though *P. vulnus* is not currently a serious Oregon pest, damage done in other states makes it a potential threat to agriculture.

Pratylenchus penetrans is distributed widely in agricultural areas of western Oregon, and is found on a great variety of crops—ornamental, forage, and greenhouse plantings. *P. pratensis*, occurs in widely scattered areas throughout Oregon and has a lengthy host range. So far this nematode has become a serious pest of Easter lilies and occasionally strawberries. *Pratylenchus vulnus* has been recovered from a few ornamental plants in the Willamette Valley.

Root Lesion Nematode Host Range of Oregon Crops

Andromeda	1	Lily, Bellingham hybrid	1
Arborvitae, Golden	1	Lily, Easter	1, 2
Ash, Mountain	1	Lily, Regal	1
Astilbe	1	Lily, Speciosum	1
Azalea, Mollis	1	Maple	1
Boxwood, Dwarf	1, 3	Narcissus	1
Cherry, Mazzard	1, 2	Oak	1
Cherry, Mahaleb	1, 2	Peach	1
Chrysanthemum	1	Plum, Flowering	1
Clover, Red	1, 2	Pyrmidallis Arborvitae	1
Clover, Subterranean	2,	Rose, Christmas	1
Cypress, Lawson	1	Snapdragon	1, 2
Dahlia	1	Spruce, Norway	1
Juniper, Hetyi	1, 2	Strawberry	1, 2
Juniper, Pfitizer	1	Vetch, Hairy	1, 2
Laurel, English	1	Yew, Irish	1

P. penetrans = 1 *P. pratensis* = 2 *P. vulnus* = 3

Root-Knot Nematodes

Knot-like swellings or "galls" on roots of various crops are familiar to most agriculturalists. Root-knot nematodes, one of the first groups of nematodes recognized in Oregon, belong to the genus *Meloidogyne*. Nine species and six varieties of root-knot nematodes are now recognized. Three of these (*Meliodogyne hapla, M. incognita,* var. *acrita,* and *M. arenaria* var. *thamesi*) occur in Oregon.

Meloidogyne hapla

This nematode is the most common root-knot species in Oregon. Host range includes many common forage, greenhouse, ornamental, and vegetable plants. These pests are widely distributed over most cultivated areas.

Oregon Host Range	*Distribution*
Carrot	Clackamas, Grants Pass, Keizer, Parkrose
Celery	Lake Labish, Salem
Clematis (Greenhouse and Nursery)	Portland
Clover, Alsike	Cave Junction, Grants Pass, Klamath Falls, Redmond
Clover, Red	Cloverdale
Coleus (Greenhouse)	Lebanon
Cyclamen (Greenhouse)	Lebanon
Gladiolus	Grants Pass
Lettuce, Miners	Madras
Pansy	Hood River
Parsnip	Clackamas, Keizer, Parkrose
Peony	Hermiston, Milton-Freewater
Peppermint	Echo, Hermiston, Madras, Ontario, Stanfield, Talbot
Potato	Grand Island, Madras
Snapdragon (Greenhouse)	Hermiston, Lakeview
Spearmint	Hermiston
Strawberries	Canby, Central Point, Gresham, Keizer
Tomato (Greenhouse)	Eugene, Gresham, Milton-Freewater
Tomato	The Dalles
Violet, African (Greenhouse)	Portland

Meloidogyne incognita var. acrita

This nematode is most common east of the Cascade Mountains but occasionally is found in western Oregon. In most respects it resembles and has the same life history as others in the genus.

Oregon Host Range	*Distribution*
Clover, Ladino	Alsea
Dandelion	Adrian, Bonanza, Klamath Falls, Malin, and Powell Butte
Potato	Adrian, Bonanza, Klamath Falls, Lakeview, Malin, and Powell Butte
Tomato (Greenhouse)	Eugene, Milton-Freewater, and Portland area
Violet, African (Greenhouse)	Portland

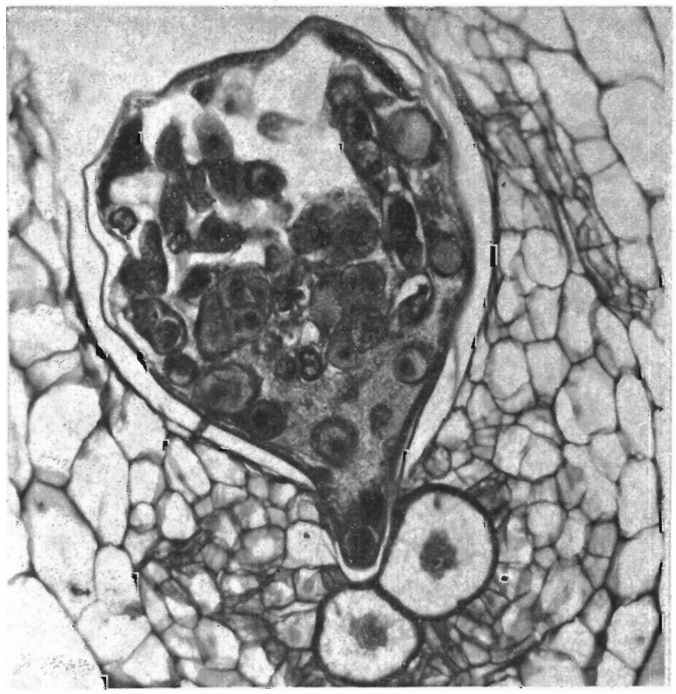
Meloidogyne arenaria var. thamesi

Little information is available regarding distribution of this nematode in Oregon. It has been found in dandelion roots and potato tubers in the Klamath basin area.

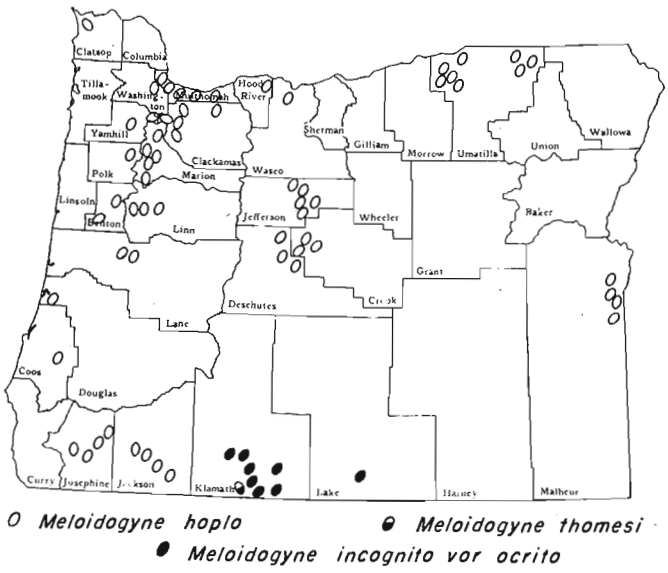
Life History and Biology. Root-knot nematodes are similar in structure and behavior. Once they are established in a field, sources of subsequent infection include established and volunteer biennial or perennial crops or weeds and infested soil. Two full generations and a partial third per year occur in most outdoor plantings in Oregon. Development in greenhouse plantings is continuous. Nematodes are most active during warm weather and least active during cold months.

Recent research shows that first-stage larvae, formerly thought of as the infective stage, develop and remain in eggs. Thus root-knot nematodes enter host plants as second-stage larvae. These larvae enter host plants near root tips. Heads usually are perpendicular to central portion of roots. When feeding begins both invaded tissues and nematodes expand and swell. Maturing nematodes go through three stages—from eel-shaped second-stage larvae to sausage-shaped third-stage, and finally to pear-shaped adult females. Males are not as abundant as females. Male development is somewhat different in that they regain their original eel-like shape as adults.

Each female may produce 300-600 eggs. These are deposited in a gelatinous egg mass, Nematode posteriors usually protrude through the surface of galls so egg masses can be deposited outside of roots. Exceptions include dahlia roots and potato tubers where egg masses are usually found far beneath the surface. There may be one



This pear-shaped female root-knot nematode is feeding on potato tissue. Giant cell formation at nematode's head usually is caused by this pest.



Locations of root-knot nematodes found in Oregon.

or more egg masses on exterior surfaces of host tissue depending on numbers of females in a gall. Galls result from giant cell formation. Small galls may contain only one female while large galls contain several. Some galls may contain nematodes in various stages of development.

Males tend to be rare in some varieties of nematodes which attack tomatoes but common in those which attack strawberries. When males are rare these nematodes can produce subsequent generations without fertilization of eggs.

Time required to complete a life cycle is variable and dependent on temperature, moisture, and development of host plants. Under optimum conditions (semi-tropical) a life cycle may be completed in 21 days. With cold, wet, heavy soils and a slow-growing host plant, only one generation may develop in a year. Damage sustained by many host plants in Oregon is seasonal. During fall, winter, and early spring, the environment is usually unfavorable for rapid development of nematodes and of many host plants. A greenhouse usually provides these pests with optimum conditions and serious plant injury may occur any time.

Cyst Nematodes

Heterodera or cyst-forming nematodes are so named because the lemon shaped bodies of dead females become a protective container for eggs and larvae. This phenomenon increases difficulty of control. The protective cyst-like containers enable eggs and larvae to withstand long periods of adverse conditions such as rotation, summer fallow, cold weather, and transit of plants.

Several species of *Heterodera* injure agricultural crops. Distribution of some species is limited while others are found the world over. Golden nematodes (*Heterodera rostochiensis*), common pests of potatoes, belong to this group. Though frequent surveys have been conducted in Oregon's potato growing areas, this pest has not been found. Sugar beet nematodes (*Heterodera schachtii*) were discovered in Oregon a few years ago. Numerous soil samples taken from western Oregon indicate that "clover-root" nematodes (*Heterodera trifolii*) are common pests.

Heterodera schachtii

This nematode is one of the most destructive pests of sugar beets, and can be blamed for the rise and decline of the sugar beet industry in Germany between 1830 and 1890. Since then, these pests have threatened the industry in western United States—especially in the intermountain region where vast acreages of sugar beets have been lost. This nematode has been found recently in two major sugar beet areas of Oregon. Probably it was introduced from adjacent areas on machinery or in "tare" dirt.

Biology and Life History. Some larvae may emerge, periodically, from the same cyst for as long as eight years. First generation of a season usually emerges as soil warms up in spring and as host plants become active.

Like most parasitic nematodes this species passes through four larval stages before reaching adulthood. First stage larvae and first moults occur within eggs. Second stage larvae (the infective stage) hatch from eggs. Once larvae emerge from cysts they are attracted to root areas of a developing host plant. Penetration usually is made just behind the root cap. Shortly after penetration, larvae establish themselves in tissues and begin to feed. As nematodes continue to develop, they lose their worm-like shape, become greatly enlarged, and resemble miniature sausages. This association with the host plant usually results in conspicuously swollen areas of invaded roots. Larvae continue their development and pass through necessary moults and larval states—a total of four each—to become adults.

Development of males differs from that of females. Males (not known for *Heterodera trifolii*) regain their slender shape during the fourth moult, leave root tissue, but remain near roots in search of females. Female larvae continue to expand while developing. As their size increases they break through the root cortex but remain attached to roots by their head and neck region. As females reach maturity a gelatinous mass may be deposited about the posterior. Females deposit a number of eggs—which soon become active larvae—into this mass. Not all eggs, however, are deposited in this mass. Most are retained within bodies of females. After death, the lemon-shaped body of each female becomes a cyst which changes from white to dark brown.

Known host range of this pest in Oregon includes only sugar beets—they are infected in Milton-Freewater and Nyssa-Ontario areas. Information concerning possible weed hosts is not available.

Heterodera trifolii

Although *Heterodera trifolii* has been repeatedly recovered from soil samples in northwestern Oregon, little information exists about injury to crops. Partial crop failure has been observed in stands of Ladino clover. Host

range of this pest includes other Oregon legumes such as hairy vetch.

Biology of this pest is similar to the sugar beet nematode but has one exception. Males have not been found, and larvae hatch from unfertilized eggs. Since this species is found in noncultivated areas near the summit of coastal mountains, clover-root nematodes probably are native to Oregon.

Ladino clover and hairy vetch are known host plants for this pest, but future investigations probably will reveal more hosts among legumes. Clover-root nematodes have been found only in northwest Oregon.

Ecto-Parasitic Nematodes

Ecto-parasitic nematodes do not enter root tissue but still cause unsatisfactory plant growth.

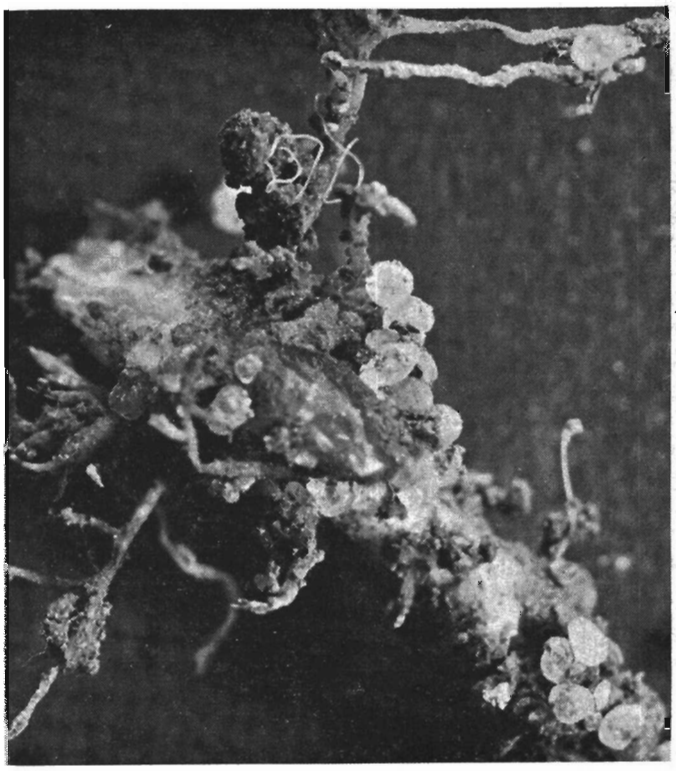
Root systems of infected plants usually are poorly developed and show various evidences of deterioration such as lack of small feeder roots, short, thickened root remnants, and conspicuous discolored areas or lesions. These symptoms are described as a "stubby root" condition. This poor root development is often associated with nonspecific above ground conditions such as stunting, chlorotic foliage, and a tendency of affected plants to wilt on hot days. Like other nematodes living in soil, ecto-parasites are usually distributed so that plant injury occurs in target-spot areas in fields.

Ecto-parasitic nematodes remain in soil near roots, where they use a well-developed spear to feed on tissues beneath the surface. Each time a nematode feeds, it makes separate minute punctures which open the way for invasion by bacteria, fungi, and other nematodes. Ecto-parasites also act as carriers for certain virus diseases.

Diagnosis of these pests is more complicated than that of endo-parasites because they rarely are found attached to host plants. Evidence of parasitism depends on removal of pests from soil surrounding infected plants and duplication of symptoms under controlled conditions. The following genera of ecto-parasitic nematodes have been found in Oregon soils where crop production was inferior; *Helicotylenchus, Hemicycliophora, Longidorus, Paratylenchus, Rotylenchus, Tylenchorhynchus, Trichodorus,* and *Xiphinema.*

Spiral Nematodes—Helicotylenchus spp.

Enormous populations of *H. nannus* occasionally are associated with various ornamental plants showing symptoms of stunting. This pest recently was associated with a general decline in an Oregon greenhouse planting of gardenias. Microscopic observations frequently reveal nematodes partly embedded in the root bark. Sometimes colonies of nematodes in all stages of development occur beneath sloughing cortex. Males have not been observed. Very little information is available concerning the ecology of this pest. Formation of a coil or spiral figuration in death is a characteristic feature of this and closely related genera.



Mint nematodes are the largest plant parasitic species and can be seen as spaghetti-like loops around mint root in top center of the above photo.

Sheath Nematodes—Hemicycliophora spp.

Distribution of this genus in Oregon is confined to a single species *H. gracilis* found in enormous numbers in Josephine County gladiolus fields. Their association with poorly developed root systems of dwarfed plants in zone-like areas in the field indicates a potential disease problem. A well developed spear and the double cuticle are characteristic features of this genus. Males have not been found.

Mint Nematode—Longidorus menthasolanus

This particular nematode, the largest plant parasitic species, is a common pest of mint in flood areas of Linn, Marion, and Polk Counties. It can be seen without a microscope because of its large size. Mint nematodes are easily found in spring when they usually congregate in large numbers on or around roots of host plants. Preliminary observations have revealed a few additional host plants such as table beet, Marion bluegrass, and tomato. Populations of this pest seem to attain their highest level in June. After harvest or during dry weather, mint nematodes become inactive and tend to coil like small springs singly or in clusters. Populations of this pest are largely composed of females and larvae. Males are found rarely. The long spear and large size are prominent features of the genus.

Pin Nematodes—Paratylenchus spp.

These nematodes are rather small but possess exceptionally large spears. They are so widely distributed that most soil samples contain a few specimens of at least one of the several species found in Oregon. Large populations of pin nematodes often are found in soil samples obtained from root zones of plants making poor growth. Though root systems are favorite targets of these pests, they also have been seen in leaf and stem tissue of mint rhizomes. Untreated greenhouse soils also may contain large numbers of these pests. For example, 7,000 pin nematodes were recovered from a single pint of soil in a bench bed where snapdragons were severely stunted and failed to bloom.

Spiral Nematodes—Rotylenchus spp. and
Stunt Nematodes—Tylenchorhynchus spp.

Although these genera are considered plant pests elsewhere, they are not known to cause serious crop losses in Oregon. Data from hundreds of soil samples indicate several species from each genus are widespread here. Stunt nematodes are found in most soil samples and are most abundant in soil used for ornamental crops (azaleas and rhododendrons). Enormous populations of this group also are found in greenhouse beds, vegetable areas (onion), and in sagebrush areas of eastern Oregon.

Spiral nematodes belonging to the genus *Rotylenchus* are more restricted in their distribution and are largely confined to nursery and greenhouse soils of western Oregon.

Stubby Root Nematodes—Trichodorus christiei

Stubby root nematodes were first among ecto-parasites proved to be plant pests. They belong to a genus having abnormally thickened cuticles which become wrinkled as the nematodes move about, and they also possess a peculiar feeding apparatus found in no other group. *Trichodorus* spp. move rather sluggishly and are usually found in small numbers in most soil samples taken in western Oregon. Their distribution in western Oregon includes isolated noncultivated areas in coastal mountains. Thus, it is evident that some species are native. Enormous populations of *Trichodorus christiei* associated with dwarfed onions in peat beaver dam soil at Lake Labish indicate this species can be a serious crop pest. Largest populations of nematodes and conspicuous plant symptoms occur during cool damp springs.

Dagger Nematodes—Xiphinema spp.

Dagger nematodes are closely related to *Longidorus* and possess well developed spears. Since ecology of dagger nematodes has not been adequately studied, there is little information concerning the biology of this group. The principal species generally distributed in Oregon soils is *Xiphinema americanum,* but at least one other species is present though sporadically distributed.

Dagger nematodes recently became major plant pests when one species was discovered to cause galls or tumor-like growths on rose roots, and another proved to be the long sought carrier of the virus responsible for "fan leaf" disease of grapes.

Soil fumigation, if properly done, is an effective control measure against many types of nematodes. Soil structure, moisture, and temperature all influence efficiency of this control. Infested areas larger than one-half acre usually require a power driven applicator for effective fumigation.

Part 3.

Nematode Control

Soil Fumigation

Soil fumigation consists of adding certain volatile chemicals to soil for pest control. Chemicals developed for nematode control by soil fumigation are called "nematocides." Objective of fumigation (as it applies to nematode control) is to place chemicals in the soil where they can effectively volatilize into a gas which will spread through spaces between soil particles and kill the nematodes.

Soil fumigation is an effective control measure if properly done. Soil structure, moisture, and temperature influence efficiency of soil fumigation for nematode control. Effects of these conditions on control are only partly understood.

Soil Condition

Structure. Amount of pore space and organic content in soil are important when computing how much nematocide to apply. Size of soil particles and their arrangement in various soils has a direct influence on amount of pore space which must be filled with gas at a concentration lethal to nematodes. Although spaces between particles of a sandy soil are large, the total volume of pore space is barely one-third as great as that in clay or peat soil. Inorganic content of soil also effects dispersion of the gas by adsorption or absorption upon the soil particles. Dispersion area of a given amount of nematocide is small in an organic soil and much greater in a porous mineral soil.

Moisture. Soil is usually at the proper moisture level for fumigation when it barely retains its shape after being squeezed in the palm of the hand. Most recommendations call for a soil moisture content slightly below field capacity in sandy soils, and between 50% and 75% of field capacity in heavier soils.

Amount of water or air contained within the soil pore space is inversely proportional. Thus as moisture increases, air decreases. Pore space of a saturated or "waterlogged" soil would be completely occupied by water, and gas would not be able to spread through a soil in this condition.

Temperature. The best range of soil temperature for nematocide application in Oregon is between 55° and 70° F.

Change of a nematocide from a liquid to a vapor and its diffusion throughout soil is dependent on soil temperature. A high temperature (above 85° F.) is not desirable because it results in too rapid volatilization and evaporation of the liquid for effective control. At a low temperature (below 45° F.) the nematocide may only partly volatilize and result in limited diffusion. Most manufacturers recommend their materials for a wide range of temperature (40° F. to 85° F.) at the application depth.

Preparation. Proper soil preparation is vital to successful soil fumigation. Soil should be in a seedbed condition, relatively free from clods and unrotted organic crop refuse. Most nematocides are not effective below an established plow sole, thus the soil should be tilled to the depth of desired penetration. Improper preparation of soil jeopardizes control because gases cannot diffuse readily into large clods and unrotted plant refuse. Large amounts of unrotted organic material definitely hinder application of nematocides because they obstruct injection nozzles and blade edges of chisel points.

Post Fumigation Treatment. The first two inches below the surface is one of the most difficult zones in which to achieve control with volatile nematocides. This is because exposure to rapid surface evaporation and to air currents prevents the gas, as it rises from the injection level, from building up the necessary lethal concentration. Thus a temporary "surface seal" is desirable to delay rapid evaporation and to encourage dispersion so the nematocide can reach a lethal concentration in this area.

Packing the soil or sprinkling it with water makes an effective seal. A drag—plank, iron rail, chain, frame harrow, or roller—is frequently attached to the rear of power applicators in order to fill in uncovered furrows and pack the soil. Some growers pack soil immediately following treatment with a cultipacker attached to another tractor. Sometimes it is possible to follow soil firming with a "water seal" by sprinkling the surface with one-half inch of water. A water seal is usually applied in small areas such as a home garden, greenhouse, or nursery. Soil is then left untilled until sufficient time has elapsed to safely plant the areas without plant injury.

Application

Though soil fumigation has many pitfalls and cannot be guaranteed unconditionally, it has become an annual practice in many states where thousands of acres are effectively treated to control nematodes. An infested area may involve a field of several acres or may be confined to a localized spot in the family garden. Selection of a suitable method of application must be decided after considering several factors including:

- Crop involved.

Decide if net return per acre is enough to warrant added cost of soil fumigation.

Check manufacturer's instructions for information about possible crop injury.

- Area infested.

Consider approximate size of the area to be treated before obtaining an applicator or material. Determine if the entire area should be treated or if applications should be confined to localized spots or row treatments.

Consider various soil conditions—especially soil preparation.

- Application equipment.

Type of equipment needed depends upon size of infested area. A small area—a home garden, or greenhouse —can be treated with hand applicators.

Infested areas larger than one-half acre usually require a power driven applicator.

- Nematocide used (refer to table on page 32).

Consider latest recommendations of specific materials for pests involved.

Standard applicators are designed to apply liquid nematocides. Some materials are now absorbed on a granular carrier and marketed as solids. These require a drill or similar equipment for application. Some manufacturers add emulsifiers to materials intended for sprays or for use in the irrigation system.

Consider availability, deterioration, and storage requirements for materials used.

Before opening nematocide containers or attempting to apply the contents, growers and operators should carefully read manufacturer's recommendations on the label. Many nematocides are injurious if accidentally spilled on skin or clothing. Feet are particularly vulnerable because shoes restrict movement of air. Prolonged breathing of vapors indoors is especially irritating. Read instructions carefully and be sure to take all recommended precautions.

Most nematocides are toxic to plants and application should be made several days before planting. Manufacturers usually recommend a 10-14 day interval between treatment and planting. If necessary, this period can be shortened by aerating the soil by discing or harrowing one week before planting. Growers occasionally report poor seed germination following soil treatment. This usually happens because time between treatment and planting was too short. This interval must be extended if application was made during a period of low soil temperature or high moisture condition. Additional time should be allowed if a heavy rain—more than ½ inch—occurs within four days after application.

Methods

The following methods and equipment have been devised for treatment of infested areas of less than one-half acre. They require standard packing of soil after treatment. Addition of a "water-seal"—soaking the upper half-inch of soil with a garden hose—will insure a more effective treatment.

- Some materials can be sprinkled from a fruit-jar or other device into a shallow trench which is immediately covered with soil.

- Certain nematocides are marketed in an emulsifiable form or absorbed on a carrier. Application is made by spraying or broadcasting materials on the surface and working them into the soil with a rototiller or similar device.

- Application can also be made by pouring a specific amount or placing capsules of material into holes (6 to 10 inches deep), punched into the soil. The usual procedure is to mark the soil in grid-fashion (6" X 6" - - - 12" X 12" square) before treatment to insure uniform and complete coverage.

- Most small scale treatments are made with a hand operated device resembling a giant hypodermic needle. Treatment with hand operated applicators insures greater uniformity in amount of material applied at injection depth than methods previously mentioned. Soil is marked off in grids to aid injection of materials at proper intervals for uniform coverage.

Multi-purpose fumigants such as methyl-bromide recently have become popular because they are effective against nematodes, fungi, insects, and also weed seeds. Application is made beneath a plastic tarp with the aid of a special dispenser. Chief advantage of this is that planting can occur within a few hours after treatment, and a wide variety of pests and diseases can be controlled.

Large scale treatments for infested areas of more than ½ acre are made by one of the following methods with power-drawn equipment.

Blanket or broadcast application involves treatment of an entire area or field. This method is used when a preplanting treatment is desired or when crops yielding high returns per acre are involved.

Chisel applicators are probably the most common devices used for large-scale fumigation. Nematocides are applied behind chisels spaced 8 to 12 inches apart through a fluid system pressured by a gear driven pump or compressed air. The pump is usually driven by the power take-off on the tractor, but may be powered by an independent unit. Application depth is usually 8 inches.

Plow-sole applicators are designed to place nematocides in the bottom of the furrow just ahead of the plow, where they are immediately covered with soil. The fluid system is relatively simple, consisting of a delivery tube which leads from the supply tank to a quick shut-off valve, then to a position just ahead of the plow. Most plow-sole applicators rely on gravity flow to move the nematocide through the fluid system. Use of a constant flow tank will greatly increase accuracy of amount of material used per acre. Some plow-sole applicators are equipped with a pressure injection system consisting of a gear-driven pump connected to the tractor's power take-off.

Blade applicator was developed at Oregon State University to apply nematocides in a more effective injection pattern than is obtained by plow-sole or chisel applicators. The nematocide is applied as a continuous sheet at injection level instead of the narrow band-like pattern of other applicators. This eliminates most difficulties encountered in obtaining efficient lateral diffusion.

Application rates for most power applicators can be controlled by: (a) tractor speed, (b) spacing between orifices, (c) size of orifice, (d) pressure at orifice, or (e) by addition of a diluent.

Surface application of granular materials (nematocides absorbed upon vermiculite or clay particles) with some type of a fertilizer applicator has been recommended for some areas. Immediately after application, the material is worked into the soil by plowing, discing, or rototilling. The granular materials also can be incorporated into soil with a fertilizer or seed drill. Before applying these materials in the field, equipment should be calibrated and tested to insure proper rate of application.

Two recent developments in the manufacture of nematocides include incorporation of emulsifiers into the material and production of water soluble materials. This enables growers to apply materials to the soil with their irrigation systems (usually with a sprinkler system, although applications have been made in a rill system). Another method used is to spray materials on soil surface with a boom-type sprayer. Then the material is worked into soil. Research shows these two methods are not effective in Oregon.

Spot or Row Treatment. It is not always necessary to treat the entire area to produce a profitable crop in nematode infested soil. Treatment can be confined to the immediate area where plants are grown. For some plants treatments can be made before planting or later as a side-dressing operation. Spot treatment is useful for plants that are widely spaced such as fruit trees and various melons. Row treatments are used for cotton, lilies, tobacco, and tomatoes. Very few plants will tolerate applications of nematocides after planting, thus growers are advised to read labels to learn if their established crops can be safely treated without plant injury.

Sampling Soil and Plants

Specific information about nematodes is becoming increasingly important to Oregon growers in maintaining and improving crop production. Detection of nematodes in soil or plants has become a standard laboratory procedure, although special facilities and personnel are required. It is possible to remove most nematodes from soil and plant tissue samples and thus determine types present and accurately estimate their abundance. Value of the entire procedure is not limited by standard laboratory analysis, but by difficulty of obtaining representative samples.

No satisfactory methods are known for taking samples which will show a representative population distribution of nematodes within an area. In spite of this drawback many growers submit soil and plant samples for nematode diagnosis. Results obtained from samples help growers select crops, plan future cropping programs, and determine whether or not soil fumigation is required. Thus field sampling, in spite of its drawbacks, can give some knowledge of the nematode situation on which the success of a farming future depends.

Samples

Soil. A sample containing one quart of soil is desirable. Sample contents should be a composite obtained from at least 20 locations within the area to be sampled. The objective is to obtain, as nearly as possible, a sample that will represent the nematode population within a given area. Various trowels and shovels are usable as sampling tools, but a soil tube $\frac{7}{8}$ by 12 inches is more desirable. Subsamples should contain a profile of the first 12 to 18 inches of soil. If plants of the damaged crop are available, some roots and surrounding soil should be included in the sample. Plastic bags tied firmly and tagged on the outside make desirable containers.

Plants. Injured plant roots, along with soil that surrounds them, contain enough nematodes to determine if they are the cause of the symptoms. The collector must assume the responsibility that roots in the sample are those of the plant mentioned on the label. If the area does not contain plants of the injured crop it may be possible to include roots of an alternate host plant. For example, root-lesion nematodes are usually present in the roots of legumes (vetch and clover). Additional samples may be needed if a comparison for nematode population levels between areas of normal and poor growth are desired.

Labels. Inadequately labeled samples have little or no value. Satisfactory labels must contain the following information:

Date
Growers' name
Growers' address
Location and size of area or field
Name and variety of crop
Collector's name
Type of information desired.

Samples can be sent to the Oregon State University plant clinic, Department of Botany and Plant Pathology, Corvallis. A small fee is charged for this service.

Results and Interpretation of Findings

Results are given as the number of various plant pests found in a quart of soil or a gram of root-tissue. Each situation or problem usually requires individual attention. Since certain populations of nematodes have different effects on various plants, interpretations cannot be generalized.

A short-lived plant probably is less likely to show injury than a perennial plant which is subject to nematode feeding for a much longer time. Also, plants which normally have few roots are less able to withstand a large population of nematodes than plants which possess a root system of numerous fibrous roots. An annual plant with a fibrous root system could tolerate a certain population level that plants with different characteristics could not. Thus it is possible to suggest various procedures if a certain nematode population level is present. Questions may be addressed to your County Agent or to the OSU plant clinic.

SUMMARY OF MANUFACTURERS' RECOMMENDATIONS FOR NEMATOCIDES

Trade name	Chemical composition*	Soil temperature	Soil moisture	Types of formulation	Interval between treatment & planting**	Dosage
D D	1, 3, Dichloropropene 1, 2, Dichloropropane	40-80° F.	Enough for seed germination	100% con. 31% emul.	14 days	25-30 gals.
Vidden-D	1, 3, Dichloropropene 1, 2, Dichloropropane	40-80° F.	Enough for seed germination	100% con.	14 days	25-30 gals.
Telone	Technical Dichloropropenes	40-80° F.	½ field capacity or less	100% con.	14 days	20-24 gals.
Nemagon	1, 2-Dibromo-3-Chloropropane	50-80° F.	Enough for seed germination	47-100% con. 47-80% emul. 2-50% gran.	2-3 weeks	1-2½ gals.
Fumazone	1, 2-Dibromo-3-Chloropropane	50-80° F.	Medium	70% emul. 25% con. 10% gran.	2-3 weeks	1-3 gals. 10 gals.
Dowfume W-85 EDB	Ethylene Dibromide	50-95° F.	High up to field capacity	83% con.	7-14 days	7-10 gals.
Dowfume MC-2	98% Methyl Bromide 2% Chloropicrin	40-90° F.	High up but not above field capacity	100% con.	2-5 days	1-2 lbs./100 sq. feet

* Some materials are injurious to certain crops; refer to labels for instructions.
** In case of heavy rains this period must be extended; refer to labels for instructions.

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* Pages in dark type are principal references.