Field and Vegetable Crops

wide ranges of crops and climatic conditions in California necessitate development of several diverse control programs

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Nematodes of greatest economic importance are the several species of root-knot nematodes—*Meloidogyne* spp.—but pests such as the sugar-beet nematode—*Heterodera schachtii*—and the stem and bulb nematode—*Ditylenchus dipsaci*—are of major concern on specific crops.

Cotton is a host to only one root-knot nematode—*Meloidogyne incognita acrita*—which occurs in all the major cotton producing areas of California. Injury to cotton has been observed in the San Joaquin, Coachella, and Palo Verde valleys. The largest areas of infestation are in the coarse textured soils of the San Joaquin Valley. The repeated planting of cotton and other susceptible crops on these soils has resulted in a build-up of root-knot nematode populations to a point where serious reductions in yield occur unless control measures are undertaken. Injury to cotton by root-knot nematodes is not observed as often in fine textured loam and clay loam soils as on other soil types.

Root-knot nematode infestation on cotton roots causes the production of galls, killing of feeder roots, and interference with the normal development of the taproot. This root injury can result in marked reduction in yield.

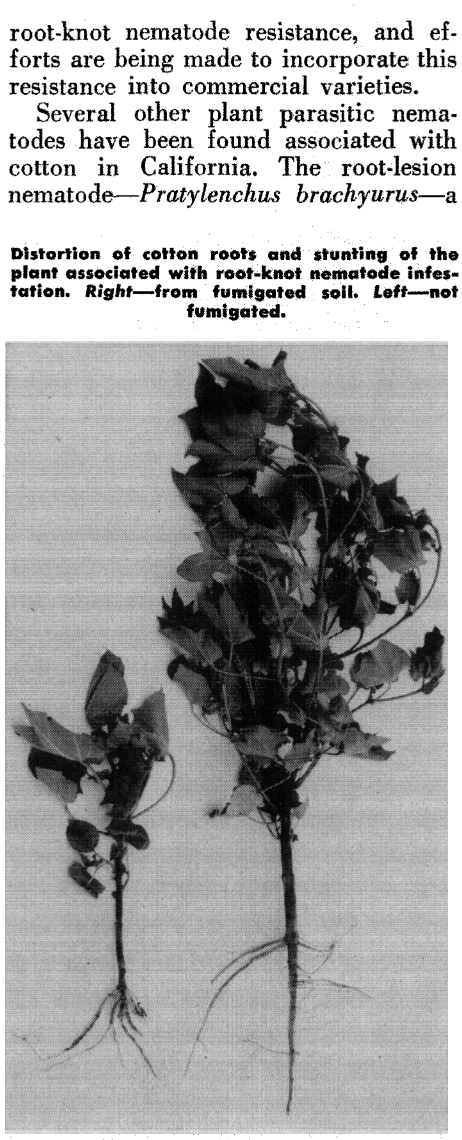
Extensive field testing has demonstrated that satisfactory nematode control in cotton can be obtained by soil fumigation. Increases in yields of lint cotton have often ranged from 0.5 to 1.5 bales per acre. Yield increases have normally been most striking on poor yielding fields, but in some fields producing 2.5 bales per acre yields have been increased 0.8 bale per acre by soil fumigation.

Rotating cotton with alfalfa has resulted in satisfactory nematode control and increased cotton yields in some areas of the San Joaquin Valley. Summer fallow accompanied by tillage operations to dry out the soil can also reduce root-knot populations and improve cotton yields.

Acala 4-42, the cotton variety most widely grown in California, is moderately susceptible to root-knot nematode. Deltapine 15, a variety becoming increasingly popular in the desert valleys of southern California, appears to be much more susceptible. Some breeding lines of cotton have shown considerable root-knot nematode resistance, and efforts are being made to incorporate this resistance into commercial varieties.

Several other plant parasitic nematodes have been found associated with cotton in California. The root-lesion nematode—*Pratylenchus brachyurus*—a serious pest of peanuts and other crops in the southeastern United States, has been recovered from cotton roots in one location each at Shafter, Indio, and Blythe. Although greenhouse tests have shown that this root-lesion nematode will reproduce on cotton and produce lesions on the roots, field populations of this nematode have remained at a relatively low level in plots in which cotton only has been grown for seven years.

Distortion of cotton roots and stunting of the plant associated with root-knot nematode infestation. *Right*—from fumigated soil. *Left*—not fumigated.



The stubby-root nematode—*Trichodorus christiei*—is widely distributed in the coarse textured soils of the desert valleys. Greenhouse tests have shown that this nematode can injure the root system and cause a reduction in the growth of cotton. The feeding of this nematode at the root tips stops the growth of those roots and results in a stunted, open root system lacking lateral feeder roots. Experimental evidence concerning the effect of the stubby-root nematode on cotton yields is not available; however, populations of this species have remained at a low level during seven years of continuous cotton culture.

Alfalfa in California is subject to attacks of economic importance by several genera of plant parasitic nematodes.

Although limited in its distribution and dependent on favorable climatic conditions for severe outbreaks, the stem and bulb nematode can be very injurious to alfalfa. In years having cool, wet springs this nematode has damaged alfalfa stands in the Antelope and Santa Maria valleys, in the coastal areas of Orange and Ventura counties, in the Salinas Valley and in some areas of the San Joaquin and Sacramento valleys. The stem and bulb nematode is most severe in areas where alfalfa is grown in the same fields for long periods. Rotation with nonhost crops gives satisfactory control, but does not always fit into local farming operations.

The stem and bulb nematode differs from the other nematodes discussed in that it attacks the aboveground parts of the plant rather than the roots. Shortening of the internodes, swelling of the nodes, and distortion of the leaf tissue are common symptoms. Under conditions that favor the nematode, crown buds are often attacked, and heavily attacked plants may be killed.

The alfalfa variety Lahonton, developed by the United States Department of Agriculture, is resistant to stem and bulb nematode and has been planted in some areas.

The stem and bulb nematode has been successfully controlled in laboratory tests by applications of organic phosphate insecticides, such as Systox. However, these materials have not been used to control the nematode in the field.

Root-knot nematodes occur on alfalfa in all major producing areas. The northern root-knot nematode—*M. hapla*—and the Javanese root-knot nematode—*M. javanica javanica*—appear to be the species of greatest importance. The only known root-knot nematode attacking cotton—*M. incognita acrita*—is also found on alfalfa. Severe infection in new plantings can cause stunting, poor stands, poor taproot development and loss of lateral feeders. Galls on alfalfa, particularly those caused by *M. hapla*, may be quite inconspicuous and easily overlooked because they are small and occur on the feeder roots. The presence of root-knot nematode on alfalfa is important not only from the standpoint of direct injury to the alfalfa but also because alfalfa is a crop long favored in control rotations with other susceptible host plants. Recent work has done much to determine the susceptibility of various alfalfa varieties to the different root-knot nematode species.

In a number of fields in southern California poor growth of alfalfa has been associated with the stubby-root nematode. Pathogenicity tests carried out in the greenhouse showed that this nematode could severely injure alfalfa roots and reduce the production of forage.

Ladino clover was found infested by the northern root-knot nematode and a root-lesion nematode in a limited survey of commercial plantings in Glenn County. Soil fumigation improved the growth of the clover in soil infested with the northern root-knot nematode.

White clover has been reported infested by the clover cyst nematode—*Heterodera trifolii*—in Ventura and Glenn counties.

Sugar beets in California are seriously infested by two species of root-knot nematodes and by the sugar-beet nematode.

The sugar-beet nematode is distributed throughout most of the beet-growing sections of the state, with the possible exception of the southern part of the San Joaquin Valley. Evidences of sugar-beet nematode infestation are best seen on the roots, where the very small lemon-shaped individuals—white females or brown cysts—occur. A hairy-root condition often seen is caused by excessive proliferation of small roots. Aboveground symptoms are poor growth and stunting of the plant and wilting of foliage during hot periods of the day.

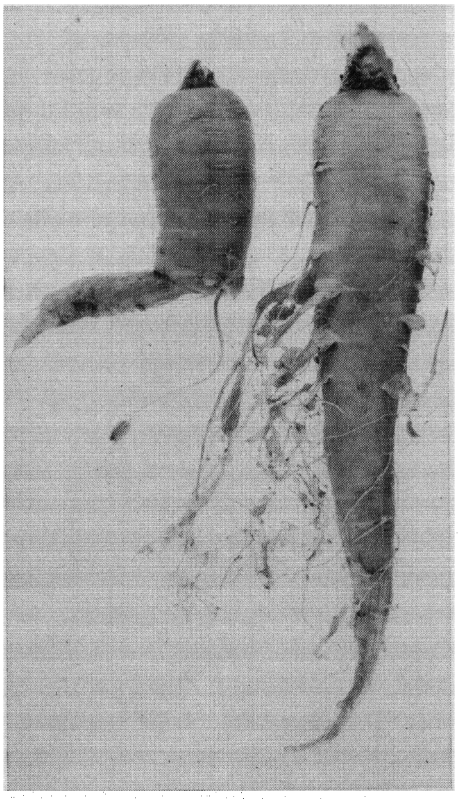
The most successful control measures for the sugar-beet nematode have been early planting and crop rotations. Soil fumigation has not been successful in most cases and is not used except occasionally on sandy loam soils.

Early planting in cool soil enables the beets to become established before nematodes are active. Research has shown that soil temperatures must be at least 60°F before the sugar-beet nematode is active, and in most areas beets planted in December and January have produced fair crops in spite of the presence of nematodes.

Proper crop rotation programs, in which only one beet crop is grown every four years, have usually resulted in satisfactory production. Crops which should be avoided in the rotation program include table beets and spinach and all of the cruciferous crops—including Brussels sprouts, cabbage, radish, and cauliflower. Clean cultivation also should be practiced because certain weeds—such as pigweed, curly dock, shepherd's purse, nettleleaf goosefoot, and mustard—are host plants.

The root-knot nematodes cause severe losses to sugar beets, especially in the coarse textured soils. Foliage symptoms are similar to those seen on sugar-beet nematode infested fields. The roots are typically galled, sometimes forming massive distortions. If severely galled, the entire root may be broken down at the end of the growing season by the action of other soil organisms.

Root-knot nematode, *Meloidogyne incognita acrita*, galls on carrot roots. Note the galling and distortion of taproot.



Chemical control of root-knot nematodes attacking sugar beets has been successful in most cases, and considerable soil fumigation is done commercially. Broadcast applications of nematocides have proved more effective than row placement. Crop rotation with small grains as alternate crops has given good control in combination with a fallow period. However, the widespread susceptibility of many crops to root-knot nematodes limits the selection for rotation purposes.

The large dry lima bean crop grown in the south coastal area of California was one of the first crops to benefit from soil fumigation. Soil treatment with EDB—ethylene dibromide—gave control of wireworms and the root-knot nematode and resulted in marked increases in yield. Repeated treatment of infested soils with various nematocides and the use of hydrocarbon insecticides has reduced both wireworms and root-knot nematodes to relatively low levels in most areas where large dry lima beans are grown.

For the small dry lima bean, breeding programs have resulted in the development of the Westan variety, a root-knot nematode resistant bean adapted to the west side of the San Joaquin Valley.

Other nematodes associated with dry lima beans in southern California are a root-lesion nematode — *Pratylenchus scribneri*; a stylet-bearing nematode—*Tylenchorhynchus clarus*; the stubby-root nematode—*Trichodorus christiei*; and a pin nematode—*Paratylenchus* sp. Stubby-root nematodes have reproduced on lima beans in greenhouse tests, but little is known regarding the amount of injury these parasites do to limas in the field.

Blackeye bean varieties resistant to one root-knot nematode—*M. incognita acrita*—are seriously injured by another root-knot nematode—*M. javanica javanica*—in the Chino Valley of southern California. Greenhouse and field tests have further shown that when infestations of root-knot nematodes are present, blackeye bean varieties are more severely injured by Fusarium wilt. In field trials, soil fumigation with 0.5 gallon per acre of Nemagon or Fumazone—1,2-dibromo-3-chloropropane—gave control of the nematode, reduced the severity of Fusarium wilt, and increased yields of dry beans.

Fresh market and canning tomato production in California encounters a serious problem with the root-knot nematodes. There are tomatoes growing in some area of the state at all times of the year. When climatic conditions are satisfactory for the growth of the tomato they are also favorable for the development of root-knot nematodes.

All root-knot nematodes known to occur in California attack tomato. *M. incognita acrita* is found most commonly, but *M. javanica javanica* occurs in all producing areas and is particularly prevalent in southern California.

The nematodes may be present in the fields or they may be introduced in infested transplants, or by other means. Recently a large planting of winter tomatoes in the Imperial Valley was found to be infested by root-knot nematodes. The area had just been cleared from the desert and the tomatoes were the first

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crop. A close inspection revealed that the nematodes had probably been introduced in the steer manure placed in a furrow underneath the planting row.

To make sure that the millions of tomato transplants shipped from southern California to the Sacramento and San Joaquin valleys are free of root-knot nematodes, strict soil fumigation practices have been initiated. Recently methyl bromide has been injected into the soil and the soil surface covered with polyethylene tarps. This type of treatment controls root-knot nematodes as well as other pests.

Both row and area treatments with nematocides have given satisfactory control of the root-knot nematodes under most conditions. Because nematodes are capable of moving themselves only a relatively short distance through the soil during one growing season, row fumigation has given good results and reduced the cost of the treatment at least 50%.

A study of the influence of soil temperature on reproduction of several species indicated that *M. javanica javanica* and *M. incognita acrita* are capable of some reproduction at a constant soil temperature of 95°F, although the optimum temperature is at 85°F. The maximum constant temperature at which *M. hapla* reproduces is 91°F.

Although other plant parasitic nematodes have been associated with tomatoes in the field, little is known concerning their pathogenicity.

Root Crops

Irish potatoes, sweet potatoes, carrots, table beets, and parsnips are hosts to the root-knot nematodes, and the market quality of those crops—as well as the total yield—can be severely reduced by the nematodes. Furthermore, both Irish and sweet potatoes are propagated vegetatively, and fields may be infested through the planting of infested propagating stocks.

The early crop of Irish potatoes grown in the southern San Joaquin Valley and in areas of Riverside and San Bernardino counties normally matures and is harvested before economic damage is inflicted on the crop, even in root-knot nematode infested soil. Soil temperatures during the development of the early crop are below the level at which rapid development of the nematodes can take place. Midsummer or fall harvested potatoes can be injured by root-knot nematodes. Attacks result in small to large warts or pimples on the surface of the tubers and necrotic lesions in the flesh at the site of nematode development.

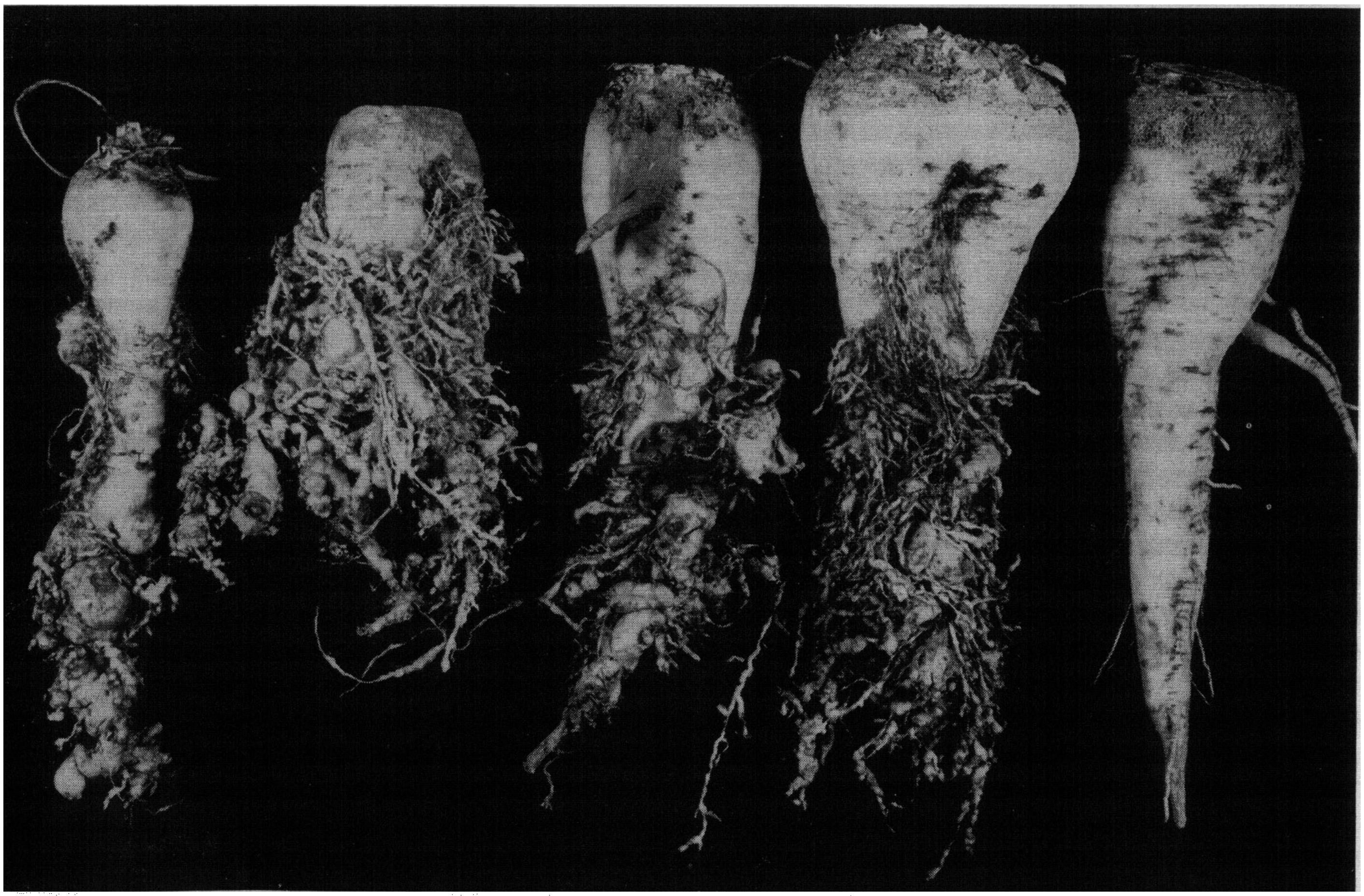
Control of nematodes in potato plantings for market has been obtained with the nematocides containing dichloropropene. Soil treatment with ethylene dibromide for root-knot nematode control plus methyl bromide fumigation for tuber moth in harvested potatoes can result in bromide residues in the potatoes that exceed the established tolerance. Neither Nemagon nor Fumazone should be used as a preplanting treatment for potato soils because of phytotoxicity. Control of root-knot nematodes in land producing seed potatoes is extremely important.

Severe infestation of sweet potatoes by root-knot nematodes causes a cracking and corking of the surface and results in reduced grade or culls. Selection of seed stocks free from nematodes, fumigation of the propagating beds, and preplanting fumigation of the soil in fields have resulted in satisfactory control of this pest. Soil fumigation tests have resulted in large increases in crop yield and quality.

Vegetable Crops

Garlic and onions are attacked by a race of the stem and bulb nematode which causes extensive damage to both

Root-knot nematode injury to sugar beets. Beet on right from soil treated with a nematocide.



these crops in the major growing areas of Santa Clara and San Benito counties and occasionally in other areas. Symptoms are thickening of the basal portion of the bulb and stem and longitudinal splitting of the outer scales, caused by swelling of the inner scales of the bulb. In onion there is twisting and rolling of leaves, eventually followed by rotting. Sometimes pustules or open lesions on stem and leaves—referred to as spikkles—are formed. The disease in onions has been referred to as bloat because of the puffy, swollen appearance, especially of the bulb. In garlic, the rotting causes the root plate to become separated from the bulb when it is pulled.

The stem and bulb nematode has been found occasionally invading the seed and sets of onions and garlic cloves. In garlic, where no true seed is produced, propagating the crop vegetatively has spread the nematode throughout the producing areas.

As no successful treatment for infested onion sets or garlic cloves has been developed, careful selection is desirable. Considerable effort is being directed toward the development of a source of nematode-free garlic for planting.

Crop rotations have been reported successful in the control of the stem and bulb nematode on both garlic and onions. It is especially important that onions not follow garlic; severe losses have been encountered recently in Kern County, where this rotation is sometimes followed. Early garlic appears to be damaged less often than late garlic. However, even early garlic has been severely damaged where heavy infestations of this nematode occur.

Good control of the stem and bulb nematode by soil fumigation has been obtained experimentally by making split-applications of dichloropropene fumigants. Applications of 40–50 gallons per acre of these materials have been made, with the total amount of chemical split into two equal amounts, applied one week apart. Plowing the field before the second application deposits cull garlic and litter infested with nematodes—along with the surface soil where fumigation is least effective—deeper in the soil where the litter is exposed to the action of the chemicals.

Cantaloupes, cucumbers, squash, and watermelons are susceptible to the root-knot nematodes, and injury has been observed in all major producing areas. The summer crop is most likely to suffer severe injury, but early melons and squash grown in the desert valleys can be injured on heavily infested soil.

The wide row spacing used with most cucurbits makes row placement fumigation a satisfactory practice.

Green beans—including the snap beans and green limas—are attacked by root-knot nematodes and infestations can be serious problems in green limas grown for freezing, because uniform crop maturity is essential. Nematode infestations in the fields are seldom uniform, resulting in irregular amounts of plant injury and an irregular rate of crop maturity. Preplanting soil fumigation has controlled root-knot nematodes on both snap beans and green limas.

Sweet corn has been injured by the stubby-root nematode in the Chino Valley. In one year, the planting of two crops of sweet corn on a sandy loam soil resulted in an increase of the nematode population to a point where the second crop was injured. The feeding of the nematode at the root tips caused stunting of the roots, proliferation of numerous lateral roots—subsequently injured—and some swelling of the root tips.

Cabbage, broccoli, cauliflower, and Brussels sprouts are hosts to root-knot nematodes and to the sugar-beet nematode. The crucifers are seldom seriously damaged by either of these nematodes, as they are grown during the winter or in areas with mild summer temperatures.

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White cyst of sugar-beet nematode, *Heterodera schachtii*, on sugar beet.

Stubby-root nematode, *Trichodorus christiei*, injury to sweet corn. From Chino Valley. Note stunting of lateral feeder roots. Arrow points to swelling at root tips.

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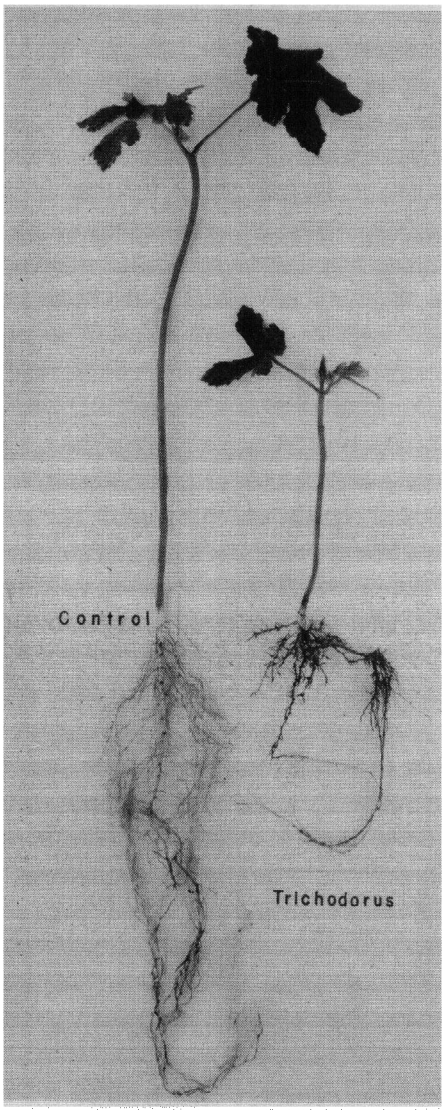
However, severe injury has been observed in cases where these crops were grown on heavily infested soils during periods when soil temperatures were warm enough for rapid nematode development.

Stubby-root nematode injury to okra. Greenhouse test.



The crucifers are particularly important as hosts of the sugar-beet nematode in that they should not be included in rotations designed to control that nematode.

The cabbage cyst nematode—*Heterodera cruciferae*—has been reported from a number of fields in the Half Moon Bay area, but little is known concerning the economic importance of this pest.

Pepper and eggplant also are injured by one or more of the species of root-knot nematodes.

Okra is extremely susceptible to root-knot nematodes and can be severely stunted or killed on infested soil. Okra is also attacked by the stubby-root nematode, and crop injury has been observed in the Coachella Valley.

Celery grown during the winter months usually escapes severe injury by root-knot, but the nematodes must be controlled if the crop is to be grown on infested fields during the summer. Use of nematode-free celery transplants is important.

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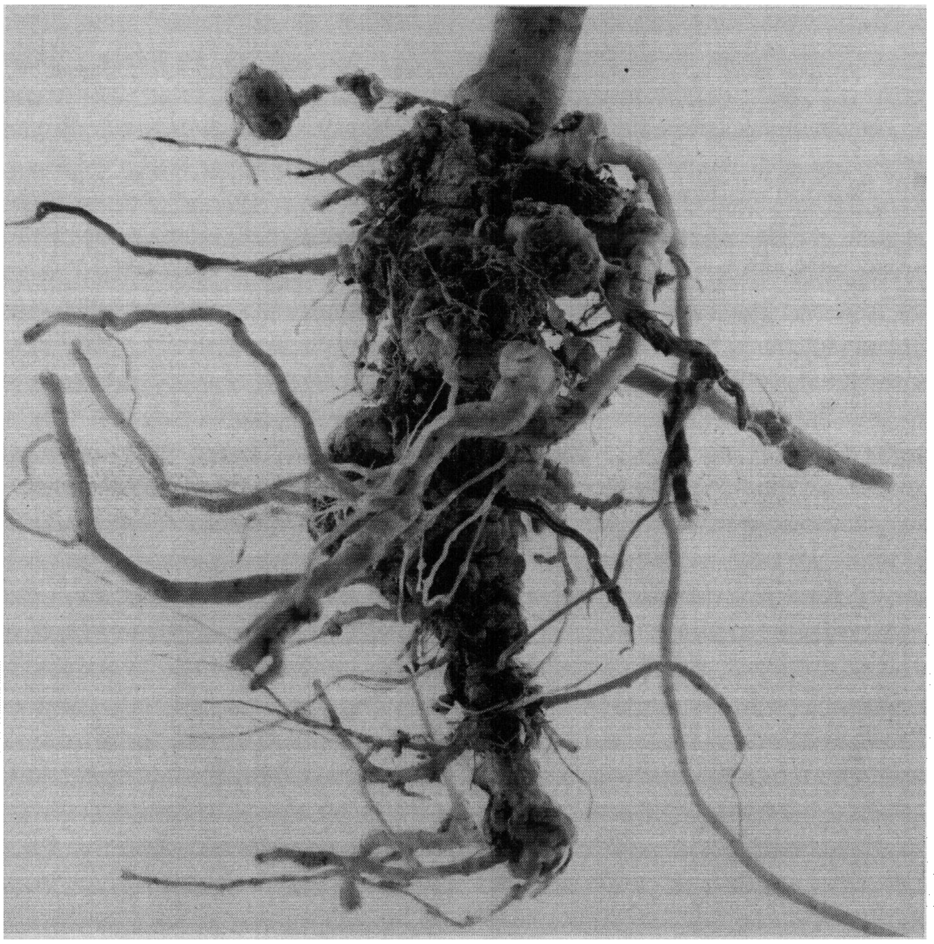
Root-knot nematode, *Meloidogyne javanica*, galling on watermelon roots.



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nomena eggs within the cyst can remain viable in the soil for many years.

Endoparasitic sessile and gall forming nematodes include the most widely known and important root-knot nematode genus, *Meloidogyne*. Superficially the species in this group have a life cycle very similar to the cyst forming *Heterodera* and differ mainly by the absence of cyst production. As with *Heterodera*, only the second stage infective larvae and males are found free in the soil. All other stages are restricted to and develop in the roots of plants. In addition to not forming a cyst the adult females differ from *Heterodera* in that they are usually completely enclosed within the root, and eggs are always deposited in a gelatinous egg sac. All of the root-knot nematodes incite the formation of root galls in the process of feeding upon host tissues.

When females are in small galls the eggs are deposited on the surface of the root in a gelatinous egg sac that is an effective mechanism against egg desiccation. In large galls both females and their egg sacs may be completely inside the gall. The second stage larvae are not well adapted to withstand desiccation and they die rather quickly under conditions of low moisture. This lack of ability to withstand desiccation as second stage larvae does not interfere with larval survival under conditions of favorable moisture and temperature. Second stage larvae, under such conditions, and in the absence of a host, can remain viable in the soil for at least three years.

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