THE ROOT-KNOT NEMATODE

BY L. B. THROWER *

Nematodes, or eelworms, are a group of semi-microscopic animals, some of which are parasitic on plants or other animals, others may be free-living. The eelworms which are parasitic on plants may be either sedentary or migratory, the latter group including those that are active within the roots of the host as well as those that feed upon the outer tissues. Root-knot nematodes are sedentary and spend the greater part of their life cycle within the tissue of the host. Until recently, these nematodes were thought to belong to a single species, *Heterodera marioni*, but they are now considered to belong to the genus *Meloidogyne*, of which several species have been described.

Although the root-knot eelworm has a distribution extending from temperate to tropical climates, it is particularly favoured by the warmer climate of the tropics where the absence of a cold season permits ten or more generations to be passed in twelve months.

Since the roots are the only parts to be directly affected, damage caused by *Meloidogyne* spp. is often overlooked during the early stages of the disease.

Hosts of the root-knot nematode

More than 1,500 species of plants have been recorded as hosts of the root-knot nematode throughout the world. The table lists some of the plants, grown in the Territory, which are susceptible to root-knot. Those marked with an asterisk have been recorded as hosts of the root-knot nematode in Papua and New Guinea.

TABLE 1.—Plants Susceptible to Root-knot

Vegetables	Ornamentals	Commercial crops
* Beetroot	* Dahlia	Banana
* Carrot	Marigold	*Centrosema pubescens*
* Chilli pepper	* Ornamental Hibiscus	Cinchona
* Cucumber	* Zinnia	Coffee
* Eggplant	....	* Kenaf
French bean	....	* *Leucaena glauca*
Lettuce	....	* *Mimosa invisa*
* Okra	....	* Papaw
Potato	....	* *Phaseolus calcaratus*
* Pumpkin	....	* *Phaseolus mungo*
* Tomato	....	* *Tephrosia candida*
* Tree Tomato	....	Tea
		Tung (*Aleurites* spp.)

* Recorded hosts.

Most of the above records refer only to the northern part of the Gazelle Peninsula. However, natural infection of *Leucaena* has been recorded at Popondetta and in the Markham Valley. There is strong evidence that a marked decline in vigour results if *Leucaena glauca* is attacked during the first year of growth. However, mature *L. glauca* is affected to a much lesser degree. Among the cover crops, both *Phaseolus mungo* (mungo bean) and *P. calcaratus* are particularly susceptible, but *Crotalaria* spp. seems to be very resistant and *Pueraria phaseoloides* (kudzu) is also resistant.

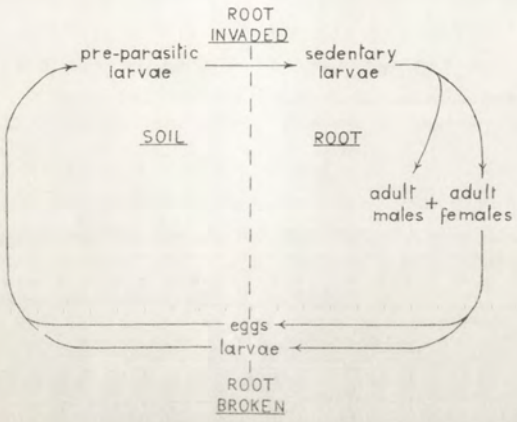
* Mr. L. B. Thrower was Pathologist, Lowlands Agricultural Experiment Station, Keravat, his present address is Department of Botany, University of Melbourne.

Description and life-history

Most plant-parasitic eelworms are less than one millimetre long, and so are practically invisible to the naked eye. Typically, the body is elongate and slender and the mouth has a stylet with which the cells of the host may be punctured. However, the form of the egglaying female of the root-knot nematode differs from that of many other eelworms.

The life-cycle of *Meloidogyne* spp. is illustrated in Fig. I. Eggs hatch in the soil and give rise to the preparasitic larvae (Plates 1 and 2) which move through the soil to the roots of a suitable host. A root is penetrated until the larva reaches a layer close to the conducting tissue. At this stage the male and female worms are indistinguishable, but thereafter their development is quite different. Normally, females greatly outnumber the males and parthenogenesis (development of eggs without fertilization) may occur in densely-parasitized roots.

Fig. I.



The female eelworm injects a substance into the surrounding cells which causes them to swell. From these giant cells the worm absorbs its food. Simultaneously, the female nematode begins to swell until it becomes a pear-shaped object which is just visible to the naked eye (Plate 3). Eggs are produced, usually about 500 per female, and deposited in a mucilaginous substance secreted by the worm. When the root rots, or is broken, these masses of eggs, or the larvae that have developed from them, are liberated into the soil so that a new cycle of infection is begun. The larval nematode is very susceptible to unfavourable conditions, but the egg is an extremely resistant structure.

PLATE 1. A group of five nematode eggs.

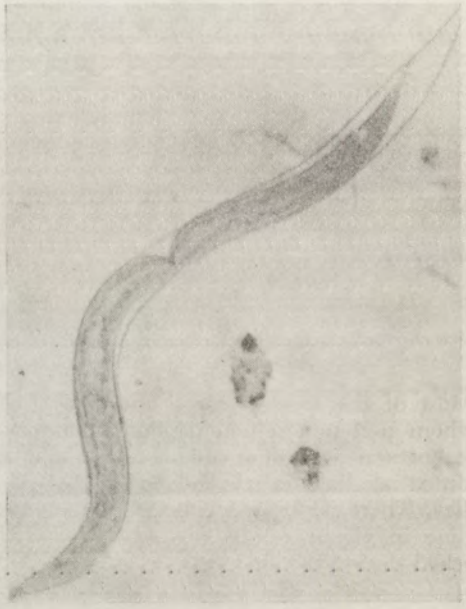


PLATE 2. Larva of root-knot nematode. (x 260)

Recognition

As a result of invasion by root-knot nematodes, galls or "knots" are formed on the roots of susceptible plants (Plates 4 and 5). These galls may vary in size from a small structure to three inches in diameter. Young

PLATE 3. Mature female of root-knot nematode.

plants may be killed outright, although this is a comparatively rare occurrence. In less severe cases, unsatisfactory growth and reduced yields result, due both to removal of food by the parasites and interference with the conducting system of the roots.

Although the formation of knots is the characteristic and most spectacular symptom of attack by this nematode, such structures are not always produced. Instead the surface of the roots may be damaged so that fungi and bacteria may gain entry and rot the tissues.

When a knot is cut across with a sharp knife, the egg-laying females can often be distinguished as minute spots having a different colour from the surrounding tissue ; they can be seen quite clearly with the aid of a hand lens. If the gall is pressed, the females and masses of eggs may be squeezed out from the cut surface.

Root knots and nodules

Some of the leguminous plants that are used as cover crops are susceptible to attack by the root-knot nematode. The peculiar feature of many legumes is that nodules are formed on their roots by a group of bacteria named *Rhizobium*. In this situation, the bacteria are able to "fix" atmospheric nitrogen so that this plant nutrient becomes available to the plant from a source other than the nitrogenous compounds in the soil. The process of nitrogen fixation may thus result in improved growth of the leguminous plant.

Small knots on the roots of leguminous plants may be mistaken for nodules. The appearance of the nodules is illustrated in Plate 6, and this should be compared with the root knots shown in Plates 4 and 5. In addition, some features of root knots and nodules are compared in Table II.

Control

Before discussing the specific measures that may be used to control the root-knot eelworm, some factors that influence the distribution and establishment of the nematode will be considered.

Normally, nematodes travel slowly through the soil, although eggs may be carried by water to regions which were previously free from infestation. Root-knot is often particularly

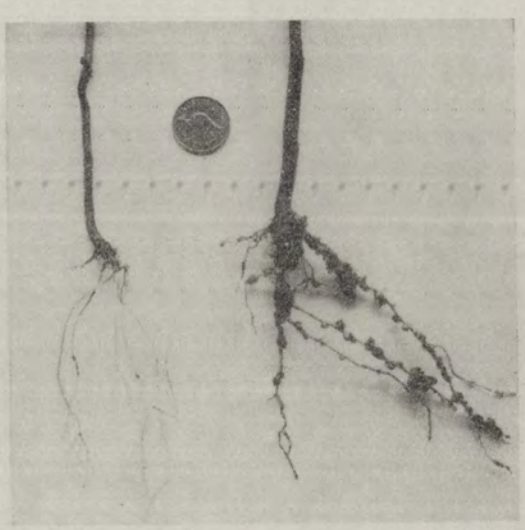


PLATE 4. Galls formed by the root-knot nematode on the roots of young *Leucaena glauca*. Uninfected roots appear on the left for comparison.

TABLE II.—*Comparison of root knots and nodules.*

—	Root Knots	Nodules.
Size and shape	Less than 1/10th inch to 3 inches in diameter ; irregular shape.	1/10th inch to ¼ inch in diameter, sometimes formed in clusters ; shape fairly regular, spherical or lobed.
Colour	Internally white or cream-coloured with deformed conducting tissue readily visible.	Effective nodules are pink internally ; ineffective nodules are a greenish colour.
Attachment to root	Formed as a swelling which projects from the surface of the root and which may partly or wholly surround it.	Nodule is attached by a short stalk, about 1/16th inch long, to main body of root.

prevalent in soils with a sandy texture or a high content of organic matter.

Some species of plants are much more susceptible to damage by the eelworms than are others ; for example, tomato, eggplant and cucumber are particularly liable to attack but peanuts, sorghum and maize are more resistant.

Introduction of eelworms into clean soil should be avoided. Clean soil may be infested accidentally, for example by using the litter of *Mimosa invisa,* a recorded host of the nematode as a mulch on gardens.

By observing simple precautions it is possible to prevent the population of eelworms from increasing to such an extent that economic cultivation is no longer practicable. After a garden crop, e.g., tomatoes, has finished bearing, the roots should be examined for signs of damage and, if these are found, the ground should be planted to a more resistant crop, such as maize. All infected material should be scrupulously removed and burnt. If susceptible hosts are planted several times in succession on infested soil, the population of nematodes will increase to such a level that only poor crops will be obtained.

Small areas of intensively-cultivated soil

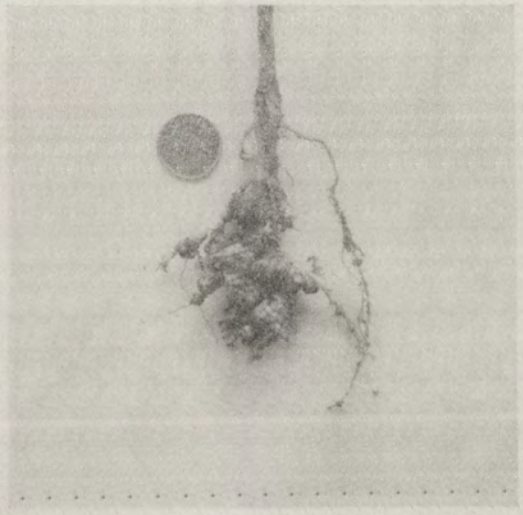


PLATE 5. Heavily infected root system of *Phaseolus mungo.*

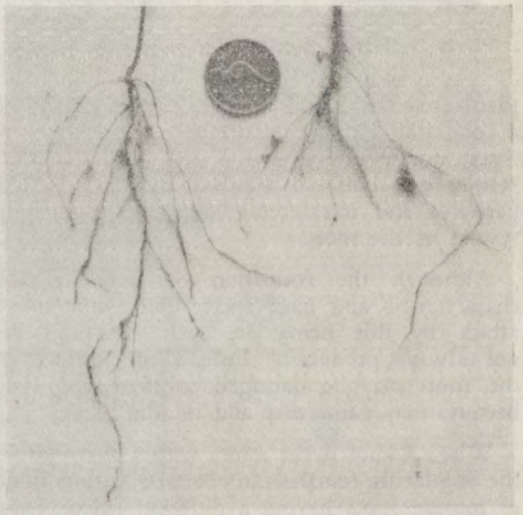


PLATE 6. Nodules on the roots of *Phaseolus mungo* (left) and *Leucaena glauca.* Note the more regular shape of the nodules compared with the root-knots, and their more tenuous attachment to the roots.

TABLE III.—Properties of some common soil fumigants

Fumigant	Description.	Hazards.	Cost (Approximate).	Phytotoxicity.	Rate of application.	Delay in planting.	Soil treatment.
Chloropicrin	Yellowish liquid; Corrosive to metals	Reasonable care required; used as a "tear-gas".	2 lb bottles £1 6s.	Phytotoxic	25 gal./acre 1 teaspoonful/ s. ft.	10 days	Compact soil surface immediately after application of fumigant.
D-D mixture	Black liquid; boiling range 95-150°F.	Toxic; reasonable care required.	1 gal. tin £1 10s.; 4 gal. drum £5 11s.	Phytotoxic; not within 3 ft. of living plants.	12-16 gal./acre ½ teaspoonful/s.ft.	3 weeks	Water seal desirable, i.e., soil sprayed with water after injecting fumigant.
Ethylene dibromide	Colourless liquid; non-corrosive	Toxic; reasonable care required to avoid contact and inhalation.	1 gal. £1 2s. 6d. 4 gal. £4 4s.	Phytotoxic; not within 1 ft. of living plants.	20 gal./acre 1 teaspoonful/ s. ft.	10 days	Compact soil surface immediately after application. Water seal advantageous but not essential.
Methyl bromide	Colourless, odourless gas (B.P. 40°F.); non-inflammable	Vapours toxic to man and animals.	1 lb. pressure canister 13s. 9d.; also 125 lb. containers.	Phytotoxic	1 lb./400 s. ft. of soil surface. Expose to gas for 24-36 hours.	48 hours	Soil covered with plastic sheet beneath which gas is applied.
Nemagon	Brown liquid; mildly pungent odour. Boiling point 384°F.; flash point 170°F.	Avoid inhalation or contact with skin.	2 gal. £19 16s. 4 gal. £37 13s. 8d.	Crops vary in tolerance to fumigant.	Tolerant crops 4-8 gal./acre. Intermediate crops less than 2 gal./acre.	Tolerant crops no delay. Intermediate crops allow delay of 8 days per gal. used per acre.	Inject at 6" depth at intervals of 12-15". Do not apply to very wet or dry soil.

* Costs appropriate at time of writing, are approximate only and may vary in different areas.

which have become infested can often be freed from the nematode by some form of sterilization or fumigation. One simple method is to spread the soil thinly on an iron plate beneath which a fire is burning. If this process is properly managed considerable quantities of soil can be treated. The sterilized soil is then returned to the beds and the crop is planted immediately.

Pots or boxes of soil may be treated by pouring boiling water over them in the proportion of seven gallons per cubic foot of soil.

A simple chemical treatment for potting soil or soil in shallow beds is to apply a solution of one part of commercial formalin in one hundred parts of water at the rate of 1½ gallons per square yard of surface soil. The soil should be stirred so that it is thoroughly wetted, and planting should be delayed for seven days after treatment.

A number of other substances have been used successfully as soil fumigants. However, the fact must be pointed out that these chemicals are toxic to plants and can be used only as pre-planting treatments. Furthermore, only the eggs and larvae in the soil can be reached by such fumigants so that all plants and infected debris should be removed before fumigation. Little work has been done on soil nematocides in this Territory and, as yet, their only application would appear to be in vegetable cultivation. The information in Table III is included so that interested persons can become aware of the materials that are available. When soil is to be treated with a fumigant, it should be worked finely and freed from clods, which are not readily penetrated by the vapour.

The foregoing remarks apply particularly to the cultivation of vegetables and ornamental plants. For the planter, the situation is somewhat different. In an earlier section, it was stated that *Leucaena glauca* may be attacked by the root-knot nematode. Few serious cases have been encountered but, in such instances, stakes should be used as planting material if these are available. Among the cover crops, *Phaseolus calcaratus* and *P. mungo* should not be planted where eelworms have been noticed. The resistant *Crotalaria anagyroides, C. goreensis* or *Pueraria phaseoloides* should be used instead.

When short-term crops are considered, a rotation that includes resistant species is important as a control measure. Most of the grasses, including maize and sorghum, possess a high degree of resistance to the eelworm. Peanuts are also resistant to the species of root-knot nematode that have been recorded in Papua and New Guinea to date.