31

NEMATODE DISEASES AND THEIR CONTROL

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31.1 Introduction

In a basic plant pathology text, it is impossible to cover all aspects of plant nematology. There are hundreds of species of plant parasitic nematodes and students seeking information on this diverse group of parasites should consult one of a number of nematology textbooks. This chapter concentrates on the most widespread and economically important nematodes in Australia and New Zealand.

31.2 Sedentary endoparasites

Root-knot nematodes (Meloidogyne spp.)

Root-knot nematodes, Meloidogyne spp., are the world’s most damaging nematode genus. They are widely distributed in the tropics and sub-tropics and are common in temperate regions where summers are warm to hot. Severe infestations cause total crop loss, while yield losses of 5–20% occur in some crops despite routine use of nematicides. There are more than 40 species of root-knot nematodes but worldwide, 95% of the damage is caused by just four species, M. arenaria, M. hapla, M. incognita and M. javanica. These species attack more than 2,000 plant species, including most crop plants. Some crops that are commonly infected by root-knot nematodes in Australia and New Zealand are listed in Table 31.1.

The disease cycle (Fig. 31.1) commences when second-stage juveniles hatch from eggs, move through the soil and invade roots near the tips. These juveniles
affect the differentiation of the plant's cells near their heads, so that a number of multinucleate giant cells are formed through a process of multiple mitoses in the absence of cytokinesis. The juveniles then become sedentary and start feeding on these giant cells, thus establishing a specialised host–parasite relationship. Developing nematodes eventually lose their worm-like shape and moult three times to become adults. The pear-shaped adult females are embedded in gall tissue and can be observed by carefully teasing galls apart under a stereo microscope. In most *Meloidogyne* spp., males are rare and reproduction occurs by parthenogenesis. Each mature female lays hundreds of eggs in an egg mass outside her body. These eggs are protected from desiccation by a gelatinous material and hatch in warm, moist soils to continue the life cycle. The length of the life cycle is temperature-dependent, but at temperatures of 24–28°C, a generation takes 4–6 weeks. Continued infection of galled tissue by second and later generations of nematodes causes the large galls that are sometimes seen on plants such as tomatoes at the end of the growing season.

**Table 31.1** Crops commonly infested by root-knot nematodes in Australia.

<table>
<thead>
<tr>
<th>Horticultural crops</th>
<th>Vegetable crops</th>
<th>Field crops</th>
<th>Ornamental crops</th>
</tr>
</thead>
<tbody>
<tr>
<td>almond, grape, kiwi fruit, nectarine, passionfruit, pawpaw, peach, plum, banana, ginger, pineapple, strawberry, aloe vera</td>
<td>bean (mung, French, navy), beetroot, capsicum, carrot, celery, cucurbits (cucumber, melon, pumpkin), eggplant, lettuce, okra, onion, potato, sweet potato, tomato</td>
<td>clover, cowpea, kenaf, lucerne, lupin, pigeon pea, peanut, soybean, sugarcane, tea, tobacco</td>
<td>carnation, <em>Chrysanthemum</em>, <em>Dahlia</em>, gerbera, gladioli, <em>Protea</em>, <em>Ozothamnus</em> (riceflower), rose</td>
</tr>
</tbody>
</table>

The presence of nematodes in the root stimulates the surrounding tissues to enlarge and produce the galls which are the typical symptom of infection by root-knot nematode (Fig. 31.2). Galling restricts root volume and hinders the normal translocation of water and nutrients within the plant, so that plants exhibit above-ground symptoms of stunting, wilting and chlorosis. Damage caused by the nematode also predisposes plants to attack by other soil-borne pathogens, particularly fungi and bacteria. The end result is a loss in yield and a reduction in the quality and marketability of plant products that are produced underground (e.g. tubers and rhizomes).

Fumigants such as ethylene dibromide and methyl bromide and chemicals which liberate methyl isothiocyanate have been widely used for control of root-knot nematodes, particularly in high-value horticultural, vegetable and ornamental crops. Since the availability of many of these broad-spectrum biocides is declining, they have been replaced in some instances by the organophosphate and carbamate nematicides. These materials are acetylcholinesterase inhibitors and therefore affect processes under the control of the nervous system (e.g. host finding, feeding, egg hatch). Since the chemicals tend to be nematostatic rather than nematicidal, nematode activity resumes when the concentration of chemical declines below a critical level. Thus control is generally maintained for only a relatively short period.
Because there are health and environmental risks associated with the use of most nematicides, considerable effort is being devoted to the development of alternative control strategies. Rootstocks with resistance to root-knot nematodes have been successfully used in the grape and stonefruit industries for many years and in the long-term, resistance is likely to be the most convenient and economically feasible method of controlling root-knot nematodes in other cropping systems. Resistance genes are available in wild plant species but at present there are few commercially available crop cultivars with resistance to one or more species of root-knot nematode. Development of resistant cultivars and rootstocks has been slow because of the genetic diversity of Meloidogyne, because there are problems in making interspecific and intergeneric crosses of some plant species and because, when using traditional plant breeding techniques, it has proved difficult to prevent the transfer of deleterious genes that are closely linked to the resistance genes. Recently however, tobacco with transgenic resistance to Meloidogyne has been produced. The resistance involves a gene which acts by destroying the giant cells produced by the developing nematode, thereby preventing nematodes from obtaining nutrients from these cells.

Crop rotation also has potential for use in managing root-knot nematode but its value is limited by the specificity of resistance genes. However, it is not always possible to use species identification to determine host range, as populations with different host ranges can occur within one Meloidogyne species. Grasses are generally more resistant to Meloidogyne than non-grasses and are often useful in rotation with Meloidogyne-susceptible crops. Rotation crops must have a high level of resistance, otherwise sufficient nematodes may carry over to damage the next susceptible crop. Some cultivars of maize, signal grass (Brachiaria
decumbens) and forage sorghum show good resistance to most species and races of *Meloidogyne* in Australia.

![Symptoms of root-knot nematodes](image)

**Figure 31.2** Symptoms of root-knot nematodes. (From Brown and Colbran, 1980.)

**Cereal cyst nematode** (*Heterodera avenae*)

*Heterodera avenae* is distributed world-wide on cereals and most grasses. It is one of the major causes of yield loss of wheat in the winter rainfall areas of southern Australia and is also a problem on barley and oats.

In early autumn, with the onset of rain and falling temperatures in the southern parts of Australia, second-stage juveniles hatch from eggs that have survived over summer within cysts. The juveniles migrate to the roots of the seedling crop, enter behind the root tip and then become sedentary, feeding on specialised cells called *syncytia* which consist of multinucleate transfer cells that are formed by extensive cell wall dissolution among contiguous cells. Towards the end of winter the adult female swells, ruptures the root cortex and protrudes from the roots so that it is visible to the naked eye. Females are fertilised by worm-like males and then lay eggs which are retained within the body. As the
females age and die, their body walls harden and darken to form mature, brown cysts which protect eggs during summer. There is therefore only one generation per year (Fig. 31.3).

![Image of life cycle of cereal cyst nematode](image)

**Figure 31.3** Life cycle of the cereal cyst nematode (*Heterodera avenae*) in relation to growth of wheat. (From Dubé et al. 1979.)

In the field, damage caused by *H. avenae* typically appears as patches of poor growth similar to those caused by nitrogen deficiency or water stress. Plants are stunted and yellowish. When examined closely, the roots have small swellings or knots, with many side roots protruding from these swellings. This gives the roots a brush-like appearance. Soil tends to adhere closely to infected roots so they are difficult to wash clean.

Juveniles hatch in response to low temperature and moisture, so that in the absence of a host plant, eggs hatch but juveniles cannot find a suitable feeding site. As a consequence they die without reproducing. In the absence of a host plant, nematode populations decline at the rate of annual hatching (70-90% per annum). Rotations are therefore effective in controlling *H. avenae*. Generally, two years free of host crops (susceptible cultivars of wheat, barley, oats, rye and triticale) and weeds (particularly wild oats and annual ryegrass) are needed to reduce nematode numbers below the economic threshold. Useful rotation crops include resistant cereal cultivars, lupins, leguminous pasture, beans and peas.

Resistant cultivars can be used to reduce nematode reproduction and maintain low nematode populations. Genes for resistance to the Australian pathotype of *H. avenae* are available in wheat, barley, oats, rye and triticale. Since there are a number of sources of resistance and only one pathotype of *H. avenae* has been found in Australia, the potential for use of resistance genes to overcome any change in nematode pathotype is good. Tolerance (the capacity of cultivars to withstand attack from nematodes with minimum yield loss) is also a useful attribute and is often used in combination with resistance.
Potato cyst nematodes (Globodera rostochiensis and G. pallida)

For many years, Australia was the only continent free of potato cyst nematode. However, since 1986 it has been found in Western Australia and Victoria. The nematode probably originated with the potato in South America. Although its main host is potato, it can also reproduce on other solanaceous crops such as tomato and eggplant.

There are two species of potato cyst nematode, golden (Globodera rostochiensis) and pallid (G. pallida). Both species occur in New Zealand but evidence to date suggests that only the golden nematode occurs in Australia. Since races can occur within species race identification is important when making recommendations for control with resistant cultivars.

The life cycle is similar to that of H. avenae, with one generation being completed on each crop. Between crops, eggs survive within cysts in soil. When a potato plant is growing, substances exuded by the roots stimulate the eggs to hatch. Each egg contains a second-stage juvenile which hatches, moves from the cyst into the soil and penetrates a host root just behind the root-tip. The juvenile establishes a permanent feeding site in the root and develops to become an adult.

After reaching the adult stage, males leave the root and move through the soil to find females. Females remain in the root, expanding and eventually rupturing it, remaining attached by the head and neck only. After fertilisation, the female produces 300 to 500 eggs which she retains within her body. The female dies with the root but the cuticle hardens and tans, forming a protective cyst for the eggs.

Potato cyst nematode is one of the most serious pests of potatoes. Low populations of the nematode are often not noticed because above-ground symptoms are not obvious. However, as the number of nematodes increases, plants become stunted, leaves are smaller and yellowish and plants dry off early. Yields may be reduced by as much as 90%, mainly as a result of the production of smaller tubers.

The potato cyst nematode is such a serious pest that quarantine controls are strictly enforced in most countries. Once it has been introduced, hygiene measures and local quarantine procedures can be adopted to slow the rate of spread. The potato cyst nematode is most commonly introduced in soil adhering to tubers, machinery and vehicles or in contaminated soil associated with root and bulb crops that are imported from nematode-infested regions.

It may be many years from the time potato cyst nematode is introduced to its detection by visible symptoms. In this time the nematode can spread throughout the crop and to other crops and properties. To reduce the chances of this happening, a susceptible potato crop should be grown only once every four years. In the other three years, other non-solanaceous crops or resistant potatoes should be grown. Once the nematode becomes endemic to a region, cultivar resistance is the most feasible control option. Cultivar Atlantic is resistant to race 1 of the golden nematode which is present in restricted areas in Western Australia and Victoria.

31.3 Sedentary semi-endoparasites

Citrus nematode (Tylenchulus semipenetrans)

This nematode is by far the most important nematode pest of citrus. It occurs in all citrus-producing regions of the world and limits production under a wide range of environments. It is also economically important on grapes in areas where citrus and grapes are grown together.
The first-stage juvenile develops within the egg and moultst once before hatching as a second-stage juvenile. Once in the soil, the juvenile survives on stored food reserves until a suitable citrus root is located and a specialised feeding site consisting of several nurse cells is established in the root cortex. Once feeding commences, the nematode starts to grow and three additional moultst are completed. The posterior portion of the female body remains outside the root and swells, eventually assuming a characteristic kidney shape (Fig. 31.4). The mature female produces a gelatinous material that covers the entire body of the nematode and contains several hundred eggs. One generation of the nematode normally takes 6–8 weeks at soil temperatures of 24–26°C.

Reproduction is bisexual but may also be parthenogenetic, with unfertilised females laying eggs that will develop into juveniles of both sexes. The male juvenile does not feed and will develop into an adult within 7–10 days. Soil populations consist of both newly hatched juveniles and males.

Citrus nematode is associated with a slow decline of established citrus trees. Nematode-free trees planted into fumigated soil and infested trees planted into clean soil are able to tolerate the nematode for about 10 years before nematodes begin to cause economic damage. The extent of decline in mature citrus trees is related to their vigour and tolerance to the nematode and to the degree of infection. Slow decline, as the name implies, develops gradually on mature trees, beginning with the production of smaller and fewer fruit. Generally, environmental conditions that stress the tree (i.e. infertile soil, marginal salinity, alkaline soils, extreme fluctuations in soil moisture and temperature) exacerbate the effects of the citrus nematode. The symptoms of slow decline are often nondescript and difficult to diagnose, so that the presence of citrus nematode is best confirmed by microscope analyses of soil and root samples. Heavily infected roots often appear encrusted with soil particles that are not easily washed off. This is due to soil adhering to the gelatinous material excreted by the female during production of eggs. There are usually fewer and shorter feeder roots on infected plants compared with uninfected plants.

The most serious and rapid effects of the nematode occur when young trees are planted in old citrus soil heavily infested with the nematode. This condition is referred to as the citrus replant problem. Young trees develop slowly in such situations and production is delayed.
Sanitation is important in preventing nematode infestation of new or fumigated land. Nursery trees should be free of nematodes. Once citrus nematode becomes established, it is virtually impossible to eliminate as it can survive for at least 7 years after an old, infested orchard is removed. The nematodes may also survive for extended periods on other hosts, such as persimmon, olive, and grape. Most management systems for citrus nematode are designed to minimise environmental stress on the tree so that its economic impact is minimised.

Resistant or tolerant rootstocks provide protection from some biotypes of citrus nematode. Some cultivars of *Poncirus trifoliata* are highly resistant to citrus nematode and F1 hybrids with *Citrus* spp. (e.g. Carrizo and Troyer citrange) are useful against some biotypes. The resistance is characterised by a hypersensitive response to nematode feeding and the subsequent formation of wound periderm.

Chemical control with organophosphate and carbamate nematicides is the primary management strategy in some countries. However, the cost of nematicides and the need to reapply them regularly limits their usefulness.

**31.4 Migratory endoparasites**

*Lesion nematodes (Pratylenchus spp.)*

Lesion nematodes are widely distributed and their economic importance is frequently underestimated. In Australia, some of the most important problems involve *P. brachyurus* (many crops), *P. thornei* and *P. neglectus* (cereals), *P. penetrans* (pome fruits) and *P. zeae* (sugarcane and other grasses). Most species have a wide host range.

Lesion nematodes remain migratory throughout their life cycle, moving within roots and from root to root. Males, females and all juvenile stages are infective. When nematodes enter the root cortex, they move within and between cells, depositing their eggs in root tissue. Eggs then hatch to continue the life cycle which takes about 27 days at 27–30°C.

*Pratylenchus* usually destroys the outer cortical tissue of roots, but nematodes may reach the vascular tissues in some hosts. As the nematodes feed, they destroy cells, so that extensive lesions develop when large numbers of nematodes are present. When the destruction has proceeded beyond a certain point, the nematodes migrate from damaged roots and move into more favourable tissues. Elongate, narrow, dark lesions are characteristic of roots infested by *Pratylenchus* but they are not diagnostic of them. Formation of lesions is often followed by root rotting due to invasion of fungi and bacteria. *Pratylenchus* may also be involved in disease complexes (e.g. wilts of solanaceous crops caused by *Pratylenchus* and *Verticillium*).

Control procedures for *Pratylenchus* tend to vary with the crop involved. In horticultural crops such as apple, stonefruit or grape, where *Pratylenchus* spp. cause severe damage when trees or vines are replanted, nematicides are often used. On broad-acre crops, lesion nematode problems are often not recognised. Crop rotation is frequently unsuccessful because of the wide host ranges of most species. Genetic resistance has not yet been exploited as few sources of resistance have been identified.

*Burrowing nematode (Radopholus similis)*

*Radopholus similis* is an important pathogen of banana throughout the tropics and subtropics where it causes ‘toppling disease’. In Australia, *R. similis* is found throughout the main banana-growing areas of Queensland and New South Wales.
The life cycle of the burrowing nematode consists of the egg, four juvenile stages and the adult. The juveniles and females penetrate roots, parasitise host tissue and cause decay. Nematodes feed directly on the cell cytoplasm, so that the nucleus disintegrates and the cell wall ruptures. A cavity then forms and the nematode moves into this space. Nematodes continue to enlarge these cavities by feeding and tunnelling in the cortex (Fig. 31.5). Males have a degenerate stylet, and therefore do not feed and cannot enter roots. However, they can be observed inside roots after developing juveniles in the tissues undergo the final moult into males. More than one generation can occur inside the root, but usually, as the root deteriorates, the nematodes migrate to the soil in search of other roots. Females lay 4–5 eggs per day. Both males and females are required for reproduction with the egg-to-egg cycle being completed in 20–25 days at temperatures ranging from 24–32°C.

Figure 31.5 The burrowing nematode, Radopholus similis. (A) Symptoms on root. (B) Nematodes in root tissue.

The above-ground signs of the burrowing nematode are leaf chlorosis, dwarfing, a thin pseudostem, small bunches and premature lodging of plants. Dark red lesions appear on the cortical or outer part of the root as a result of nematode infection. The cortex later turns black as the nematodes multiply and other organisms invade the tissues. Healthy roots are bone-white. Nematodes do not invade the central region of the root (i.e. the stele) unless it is colonised by secondary invaders (e.g. fungi). Nematode infestation can be easily detected by making a longitudinal cut along the root. Heavily infected roots have numerous depressed and opened lesions from which the cortical tissue sloughs off easily. The lesion eventually girdles the root which causes the roots to break. Plants with short necrotic roots cannot support the weight of the bunch or the stress of moderate to heavy winds. As a result, the plant falls over or becomes uprooted. Other symptoms include reduction in bunch weight and increased time to bunching.

*R. similis* is currently controlled by routine use of chemical nematicides. However, because the nematode is disseminated with infected corms, the selection, cleaning and treatment of planting material is an important control procedure. Corms free of necrotic parts are selected and should be properly
peeled so that necrotic tissue is discarded. Peeled corms can then be dipped in hot water (55°C for 15 minutes) and left to dry for 24 hours before planting. The use of disease free, tissue-cultured plantlets is now encouraged.

31.5 Ectoparasitic nematodes

These nematodes are widely distributed and most soil samples contain at least some ectoparasitic species. Dagger, stubby and needle nematodes are the most economically important ectoparasites.

Stubby root nematodes (Trichodorus and Paratrichodorus) have a wide host range and cause symptoms of stunting, chlorosis and reduced yield. Roots of infested plants may be short, stubby and slightly swollen. This group of nematodes also transmits some plant viruses.

Dagger and needle nematodes (Xiphinema, Longidorus and Paralongidorus) cause stunting and swelling of roots and poor above-ground growth. They tend to be most important on perennial crops, but a serious disease of rice in north Queensland is caused by P. australis. These nematodes are also vectors of some plant viruses.

Many other ectoparasitic species cause economic damage, but they tend to be important only in specific crops or situations. High numbers of nematodes must usually be present before crop losses occur. The nematodes involved include stunt nematodes (e.g. Tylenchorhynchus, Merlinius), ring nematodes (e.g. Criconema, Criconemella, Macroposthonia), sheath nematodes (e.g. Hemicyclothora, Colbranum), pin nematodes (e.g. Paratylenchus) and spiral nematodes (e.g. Rotylenchus, Helicotylenchus, Hoplolaimus, Scutellonema).

Ectoparasitic nematodes remain outside the host throughout their life cycles or penetrate with only a small portion of their body. They have a relatively simple life cycle as eggs are laid in soil and development through all juvenile stages to the adult occurs in soil. All stages of the life cycle can feed on roots. The length of the life cycle varies considerably, from a few weeks in most species to months or even years for some dagger and needle nematodes.

Since ectoparasitic nematodes feed by inserting only their stylet into roots (Fig. 31.6), many species cause no obvious symptoms. Often thousands of nematodes must be present before damage becomes apparent. The more pathogenic species tend to feed on root tips, causing root stunting, thickening or galling of root tips and a general reduction in the number of feeder roots.

Figure 31.6 The needle nematode, Paralongidorus australis, feeding on a root tip of rice. (From Stirling and Shannon, 1986.)
Because of the diversity of ectoparasitic species it is not possible to provide specific control procedures. They are controlled with the same range of methods that are used for other nematodes.

31.6 Above-ground parasites

**Stem and bulb nematode (Ditylenchus dipsaci)**

*Ditylenchus dipsaci* is widespread in cool temperate regions of the world. There are at least 20 morphologically indistinguishable biological races. Races attacking onions, daffodils, faba beans and lucerne, clover and field peas have been known in New South Wales, Victoria, Western Australia and South Australia for many years. An oat-attacking race is present throughout South Australian cereal regions.

All developmental stages of the nematode invade the stems and leaves of plants, entering the host through the stomata. The nematode colonises parenchymal tissues where it feeds and reproduces. Each female may lay 200–500 eggs. Nematode feeding and movement causes large cavities in the infected tissues. Because the nematodes require a film of water on the outside of the stem to move to the penetration site, nematode infestations are favoured by wet conditions and mild temperatures (15-20°C). When the environment is favourable, the life cycle takes 19–23 days. Under unsuitable conditions, the nematode survives as a quiescent fourth-stage juvenile in seed, bulbs and tubers. In this dehydrated state, nematodes form a white, cottony mass sometimes called 'eelworm wool'. They can survive in this state for decades.

The characteristic symptom of infection by *D. dipsaci* is deformed leaves and bulbs. Infected oat plants tend to be stunted, swollen and distorted with a proliferation of tillers. Severely affected plants are killed so that infested crops often have bare patches. Internodes of legume hosts tend to be shortened, resulting in a stunted plant. At the infection site, stems become cracked and rotten. In crops such as faba bean and field pea, the nematode causes necrosis of the stem base and distortion of leaves, stems, buds and pods. Fourth-stage juveniles accumulate at the necrotic stem base and inside the seeds. On lucerne and clovers, the nematode distorts buds and causes chlorosis, swelling and loss of leaves. Distortions and swellings of leaves and bulbs are the most common symptoms induced on bulbous plants. At late infection stage, the plant may die and rot because of secondary invasion by pathogenic bacteria and fungi.

Physical control methods such as hot water treatment of bulbs and tubers are effective in preventing dispersal of the nematode in planting material. Chemical nematicides may control the nematode but are rarely cost-effective. Even though the nematode can survive in a metabolically inactive state for many years in a protected environment, under field conditions of wetting and drying the survival time is much less. Crop rotation can therefore be useful. Effective management practices include a 2–3 year rotation with non-host crops, good weed control, wide row spacing and replacement of overhead irrigation with drip irrigation. These strategies prevent nematode build-up in soil and spread among plants. Resistance is likely to be the most successful form of control in the long-term and resistant cultivars are available for some crops.

**Foliar, leaf or bud nematodes (Aphelenchoides spp.)**

*Aphelenchoides* spp. are widely distributed. Economically important species in Australia include *A. besseyi* (strawberry and rice), *A. fragariae* (ferns and succulent plants), *A. ritzemabosi* (many Asteraceae, including chrysanthemum)
and *A. composticola* (mushroom). Although often referred to as foliar, leaf or bud nematodes, common names such as strawberry crimp nematode (*A. besseyi*), white tip of rice (*A. besseyi*) or chrysanthemum foliar nematode (*A. ritzemabosii*) are also used.

Nematodes in infected plant tissue or soil climb the plant in moist, humid conditions and feed on buds or leaves. Some species feed ectoparasitically, others endoparasitically. Generally the nematodes are tissue-surface feeders. They migrate, feed and reproduce in water films and enter leaf intercellular spaces via stomata to feed on the cells of the spongy mesophyll. They find suitable conditions for survival in the protected environment of buds and around the growing point. Their life cycle is 10–14 days and they can survive in dry leaves for several months.

Feeding causes necrosis of damaged leaf tissue, so that blotches are produced on leaves. The form and pattern of the blotches follows closely the leaf anatomy and venation, so that lesions are often sharply delimited by veins. Feeding within buds may kill the growing point or bud or result in plants that show distortions and abnormal growth.

Removal and destruction of old foliage at the end of the season will lessen the risk of spread. Use of clean planting material or hot water treatment of infested planting material is also a practical method of control. In crops where leaf wetness is caused by irrigation rather than rainfall, a change in irrigation methods or timing may create conditions which are less conducive to the nematodes.

### 31.7 Annual ryegrass toxicity (*Anguina funesta*)

Annual ryegrass toxicity (ARGT) is caused by a bacterium, *Rathayibacter toxicus*, which is spread into the plant by the nematode *Anguina funesta*. The nematode and bacterium are spread throughout the wheat/sheep belts of South Australia and Western Australia where ARGT can cause deaths of sheep, cattle and horses. The nematode, but not the bacterium, has been found in the Wimmera region of Victoria. Related nematodes and bacteria have also been found in association with toxicity of *Agrostis avenacea* and *Polypogon monspeliensis* to sheep and cattle in western New South Wales and south-eastern South Australia. Annual ryegrass toxicity and related diseases are discussed in Chapter 6.

Control of ARGT involves reducing annual ryegrass in paddocks. This means use of selective herbicides in crops, so that ryegrass does not survive. In pastures, ryegrass is controlled by burning or with herbicides. Monitoring of grazing paddocks by examining seed will give an early warning of developing toxicity.

Acknowledgement: The figure on page 514 has been provided by the Department of Primary Industries, Queensland, from their book *Queensland Agricultural Journal* (September-October, 1986) published by the DPI Queensland.

### 31.8 Further reading


