13 Nematode Parasites of Coconut and other Palms*

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The botanical order Arecales has but a single family, Arecaceae, also known as Palmae. Palm is the common name for any flowering plant of the family. Although many of the 2800 known species of palms have some particular economic importance to any given local population, only a few are of major economic importance worldwide.

Cocos nucifera L., the coconut palm, which originated in Malaysia, South-east Asia, is widely distributed throughout the tropics.

Elaeis guineensis Jacq., the African oil palm, with its origin in Central Africa, has now been introduced throughout the tropics including Latin America.

Phoenix dactylifera L., date palm, is native to the near East where it has been cultivated for its fruit for nearly 8000 years.

Areca catechu L., arecanut, occurs mainly in the humid regions of Asia and the Malay Islands. It was introduced into India in the pre-Christian era where it is now widely cultivated and used as a masticatory.

Metroxylon spp., the sago palms, provide a starchy food material which is stored in their trunks as they develop to the point of flowering. These palms are hypoxanthic and only mature palms just prior to flowering and death are cut and used for starch production. These palms are also used during and after starch production for palm weevil (*Rhynchophorus bilineatus*) larval culture for human consumption in Papua New Guinea (Giblin-Davis, 2001). Sago palms of this genus are native to the Indonesian archipelago.

The fruits and seeds of eight genera of the world's palms are oil-bearing and can be commercially exploited for oil. Only *Cocos* is entirely of an Old World origin; *Elaeis* has one species (*guineensis*) that is of Old World origin and another (*oleifera*) which belongs to tropical America. The other six genera are considered neotropical. There are many palms that are ornamental and are important in horticulture and landscaping.

*A revision of the chapter by R. Griffith and P.K. Koshy.

Coconut

It is generally accepted that coconut palm originated in South-east Asia and was capable of being transported to the Americas and the West Indies by means of ocean currents, as primarily evidenced by its presence on shores and the water-resistant pericarp of its fruit or coconut. Most cultivated forms, however, have been introduced to the New World by man.

Coconut palm is most adapted to temperatures around 27°C with a diurnal range of about 7°C; it does not thrive at temperatures lower than 20°C and is damaged at temperatures below 15°C. Rainfall requirements are about 2500 mm/year; when less than 1000 mm/year, irrigation is normally necessary. The absence of rain for more than three successive months causes a shedding of young fruit and a reduction in fruit size. The palm does best with about 2000 h of sunlight/year, or an average of 6 h/day. Thus, with few exceptions, cultivation is limited by the 20° parallels of latitude and the 500 m contour line.

The largest producers of coconuts are Indonesia, the Philippines, India and Sri Lanka. Significant quantities are produced, however, from most tropical countries of South and East Asia, East and West Africa and the Pacific. Despite there being some large plantations, coconuts are predominantly a smallholder crop, with the average holding less than 1 ha.

The total world area under coconuts was estimated in 1996 as being 11 Mha, with a total production of over 47 Mt (FAO, 2000). The two biggest producers, Indonesia and the Philippines, have about 3.7 and 3.1 Mha, respectively; India is the third largest producer with nearly 1.8 Mha under cultivation. In all producing countries, coconuts make a significant contribution to the diet in addition to being an important source of export earnings.

Nematodes of Coconut

Many different nematodes have been found in diverse forms of association with the living coconut palm, others have been found associated in different types of symbiosis with insect visitors of the palm, operating and existing in various niches (Govindankutty and Koshy, 1979; Koshy and Banu, 2002), but the major nematode disease affecting the crop is red ring disease caused by *Bursaphelenchus cocophilus*. The only other nematode known to cause severe damage leading to malfunction in the coconut is *Radopholus similis*.

Bursaphelenchus cocophilus

The red ring nematode, *B. cocophilus* (Cobb, 1919) Baujard, 1989, was first described by Cobb (1919) as *Aphelenchus cocophilus* from specimens sent from Grenada. Since then it has been known as *A. (Chitinoaphelenchus) cocophilus* and *Chitinoaphelenchus cocophilus* (Micoletzky, 1922), *Aphelenchoides cocophilus* Goodey (1933) and *Rhadinaphelenchus cocophilus* (Goodey, 1960). Giblin-Davis *et al.* (1989b) presented morphological evidence supporting the similarities between *Rhadinaphelenchus* and *Bursaphelenchus*. Baujard (1989) synonymized the monotypic genus *Rhadinaphelenchus* with *Bursaphelenchus*, creating the new combination, *B. cocophilus*. Hunt (1993) retained the genus *Rhadinaphelenchus* as a monotypic genus on the grounds that: (i) more information was necessary to make a decision about its generic ranking; (ii) it is an economically well known genus with an extensive literature as *Rhadinaphelenchus cocophilus*; (iii) both sexes of the nematode are exceptionally long; (iv) host range is restricted to palms; and (v) the genus *Bursaphelenchus* appears to be an uneasy grouping of organisms. Recent sequence data of D2/D3 expansion segments of the LSU rRNA gene, 18S SSU rRNA, and a partial sequence of COI mitochondrial DNA of 20 species of *Bursaphelenchus*, including *B. cocophilus*, support its inclusion within the *Bursaphelenchus* radiation and not in the monotypic genus of *Rhadinaphelenchus* (Ye *et al.*, 2004d). Thus, the Baujard (1989) designation of *B. cocophilus* is accepted (see Chapter 2 for description).

Brief history of red ring disease

The disease was first reported as occurring in Trinidad by Hart in 1905. The first investigations into its nature were by Stockdale in 1906, who thought that two different diseases were being confused because they both culminated in decay of the bud. One of these was red ring disease, then called root disease, and the other bud rot initiated by *Phytophthora palmivora* Butl. Barrett (1906), however, reported that there were few genuine cases of bud rot among the coconuts in Trinidad and that 95% of the losses were really due to root disease.

Nowell (1919) found that a large number of roots examined from diseased trees in Trinidad contained hundreds of nematodes of the same species. They were also present in the constant red ring found in trees in Grenada and also in the material collected in Trinidad by Rorer (1911). Later, he examined stained sections from many other sources and confirmed Rorer's earlier conclusion that a fungus was not the causal organism, but noted that nematodes of the same species previously observed were constantly present in stems, leaves and roots. The name red ring disease was then used by Nowell (1919) and became established.

Distribution of red ring disease

At present, red ring disease has a restricted distribution in tropical America and has only been reported from the West Indies (Trinidad, Tobago, Grenada and St Vincent) and from Latin America (Venezuela, Guyana, Surinam, French Guyana, Colombia, Ecuador, Peru, Mexico, Brazil, Panama, Nicaragua, Costa Rica, Honduras, Belize and El Salvador). It is also reported that red ring disease occurs in Guatemala, but does not occur in the northern Caribbean islands, Florida, Cuba or other parts of the world (Dean, 1979). There are unconfirmed reports of red ring disease from Barbados, Dominica and Jamaica, but the European and Mediterranean Plant Protection Organization (EPPO) considers the disease to be absent from these countries. Some sources have reported the nematode present in the Bahamas, Dominican Republic and Haiti; however, we consider these questionable assertions. A single diseased palm was discovered in Dominica in 1982 but, after its destruction, there has been no further incidence of the disease in that country. The disease in Barbados claimed to be red ring in 1995 was found to be cedros wilt disease caused by a protozoan flagellate (R. Griffith, unpublished). CAB International stated in their Crop Protection Compendium data sheet that there were unconfirmed reports of the nematode being present in Puerto Rico in 2002; however, CAB International now record it as an 'Absent, unreliable record' from the country. None of the more recent surveys has found the nematode in Puerto Rico.

Symptoms of red ring disease

Young or adolescent coconut palms easily succumb to red ring disease. There is no record of any tree, once affected, having recovered. The disease occurs more commonly in trees 2.5–10 years old, with the greatest incidence in those 4–7 years old. Occasionally, a palm as young as 1.5 years or as old as 20 years or more may be attacked.

The symptoms characteristically described are those for palms of the tall cultivar of coconuts or 'typical' which grow in the West Indian islands. These symptoms differ somewhat in the dwarf variety 'nana' and also some 'Panama talls'. Chlorosis first appears at the tips of the oldest leaves and spreads towards their bases but, occasionally, one of the younger leaves may first be affected. The brown lower leaves may break across the petiole or the lower part of the rachis, or they may become partly dislodged at the base and hang down (Plate 14A). Nuts are shed prematurely either simultaneously with the development of leaf symptoms or slightly before. The crown often topples over about 4–6 weeks after symptoms first appear due to associated severe damage caused internally by the larvae of the palm weevil. However, the trunk remains standing in the field for several months until it decays. At the onset of symptoms, the chlorotic yellow appearance of the leaves around the stem is sometimes indistinguishable from that of trees growing under conditions of poor drainage or during intense drought.

The most characteristic symptoms are the internal lesions. In a cross-section of the stem, they appear as an orange to brick-red coloured ring, 2–4 cm wide, and at a distance of 3–5 cm in from the periphery (Fig. 13.1, Plate 14B). In longitudinal section, the reddened tissue may appear as two united bands joined in the bole forming a U-shape (Fig. 13.2). Lesions at the upper end of the stem in the vicinity of the crown are discrete, appearing first as streaks and then as dots. The meristematic tissue in the bud remains white and apparently healthy. Occasionally, in some older trees, the entire central cylinder of the stem becomes one solid block of red (Plate 14C). There is no putrefaction of the bud associated with red ring disease. In the roots, the normally white soft cortex becomes orange to faint red in colour, and dry and flaky in texture when diseased. In the leaves, a solid core of mottled tissue, dull red to brown in colour, extends from the leaf base for varying distances up to about 75 cm in the petioles.

Fig. 13.1. Characteristic red ring symptoms in a cross-section of coconut stem caused by *Bursaphelenchus cocophilus*. (Photo: R. Giblin-Davis.)

Fig. 13.2. Longitudinal section of coconut stem showing red ring tissues in two united bands joined in the bole forming a U-shape. (Photo: R. Giblin-Davis.)

The disease is not recognizable externally in its very early stages. The roots, stems and leaf petioles are already infested and there is full development of internal symptoms before the first external symptoms become visible. In the dwarf cultivars, the red colour gives way to shades of brown. Thus, instead of a red ring internally, there is a brownish band. The discrete spots are also brownish and the yellow discoloration of the leaves is not often apparent. Generally, the leaves become dried and brown, beginning at the tips of the leaflets and progressing downwards. The yellow dwarf cultivars respond in the same way as the green and the crosses between talls and dwarfs, or between 'Panama tall' and any dwarf. They show a browning instead of a characteristic reddening of the leaves and stem tissue.

Biology of the red ring nematode

The chief vector of the red ring nematode is an insect, the palm weevil (*Rhynchophorus palmarum* L.), and the biology and life cycle of *B. cocophilus* are intimately associated with this and other palm-associated weevils, such as *Dynamis borassi* and *Metamasius hemipterus* (Giblin-Davis, 2001) (Figs 13.3 and 13.4). However, experimentally, it has also been shown that red ring disease can be initiated by the nematodes via the root system.

Studies on the biology of the nematode were initiated by both Cobb and Nowell around 1919. Cobb found that 50% of adult *R. palmarum* and their larvae contained the red ring nematode. As a result, he implicated the palm weevil as being a carrier of the nematode from diseased palms to healthy ones. On the other hand, Nowell's opinion was that the nematode was soil inhabiting.

The general consensus is that *B. cocophilus* does not build up large populations in the soil, as some of the earlier investigators had believed to support their early recommendations of isolated trenches to control the movement of the nematode (Martyn, 1953). It would seem, moreover, that although root infection could be induced artificially, it was not a normal method of initiation of the disease in the field. In the ordinary course of events, the nematodes would not persist in the soil in sufficient numbers to give a reasonable chance of infection. If a persistent source of inoculum was present, e.g. a buried red ring trunk (which remains quite fresh for 2 weeks after burial), or if a high population of *B. cocophilus* (10^4 nematodes/cm^3) is artificially added to the soil in large quantities of water, the nematodes could gain entry through damaged or senescent roots and eventually migrate up into the trunk, producing the usual symptoms.

Transmission of red ring nematode

Larvae of the palm weevil, *R. palmarum*, feed by burrowing through coconut stems and, when this occurs in trees with red ring disease, they can become infested with the nematode. Adult weevils emerging from diseased trees carry the nematode to new sites (Figs 13.3 and 13. 4). Nematodes enter the haemocoel of weevil larvae via the gut tract; in newly emerged adult weevils, the nematodes can be found in the tracheae, gut, body cavity and the region of the ovipositor (Griffith, 1968a).

Survival of the red ring nematode depends on the third stage juvenile. They are sometimes found in tracheal sacs in the insect, from where they can move directly to the ovipositor of the female vector palm weevil (Griffith, 1968a). The percentage of palm weevils associated with red ring nematodes (up to 100%) and the levels of infestation ($>$ 13,000 nematodes/insect) can be quite variable. Evidence has been presented which indicates a connection between weevil size and percentage of weevils carrying the nematodes (Griffith, 1968a). However, other results have shown that variation in levels of infestation apparently are not correlated with other variables, such as weevil size (Giblin-Davis, 1993). The nematodes are putatively injected into the tissues of the coconut tree when the insect deposits its eggs, normally in a leaf axil in the crown of the tree (Griffith, 1968a,b) (Fig. 13.3). The palm

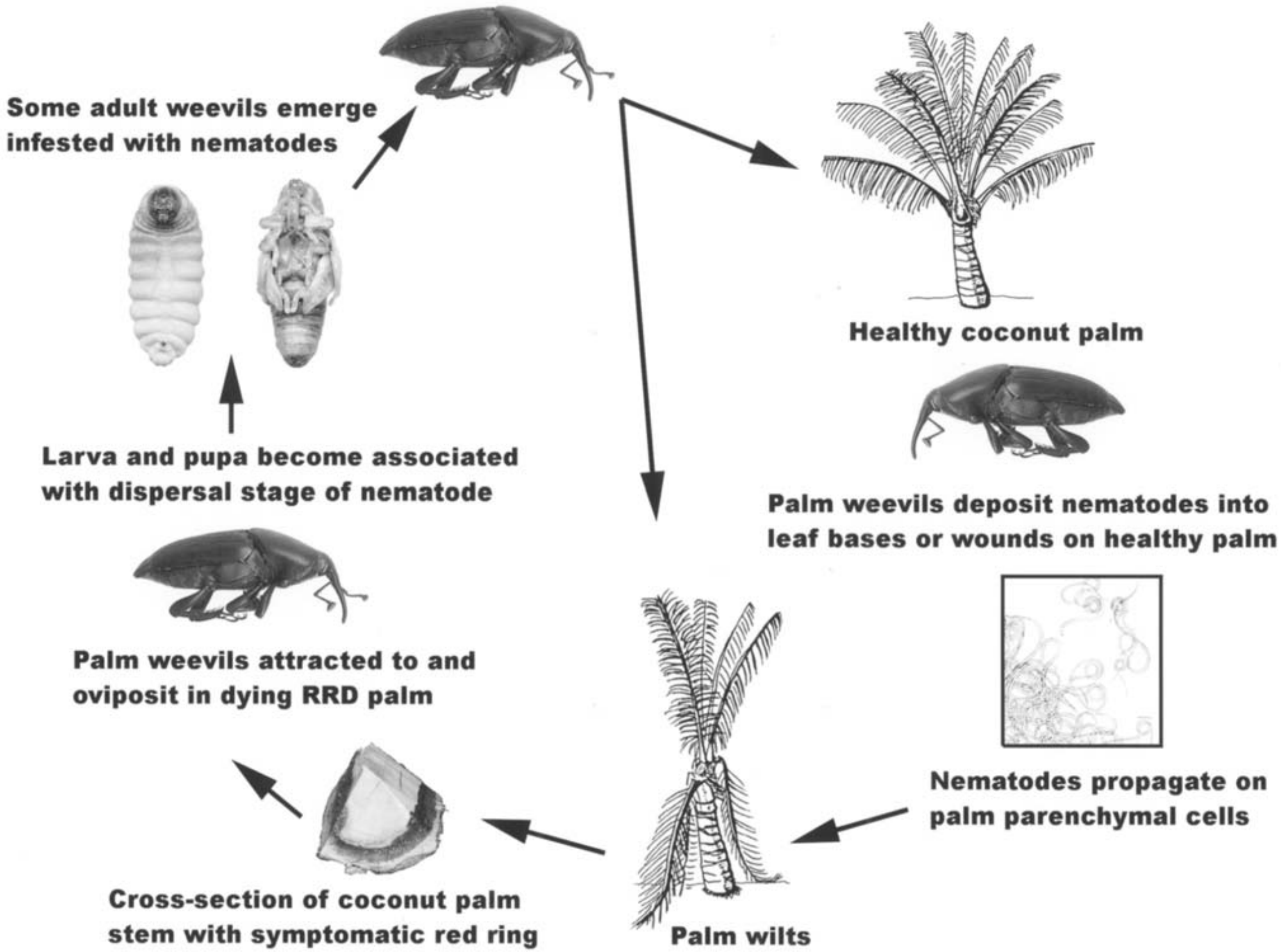

Fig. 13.3. Life cycle of the coconut palm weevil, *Rhyncophorus palmarum*, and transmission of the red ring nematode, *Bursaphelenchus cocophilus*. (R. Giblin-Davis.)

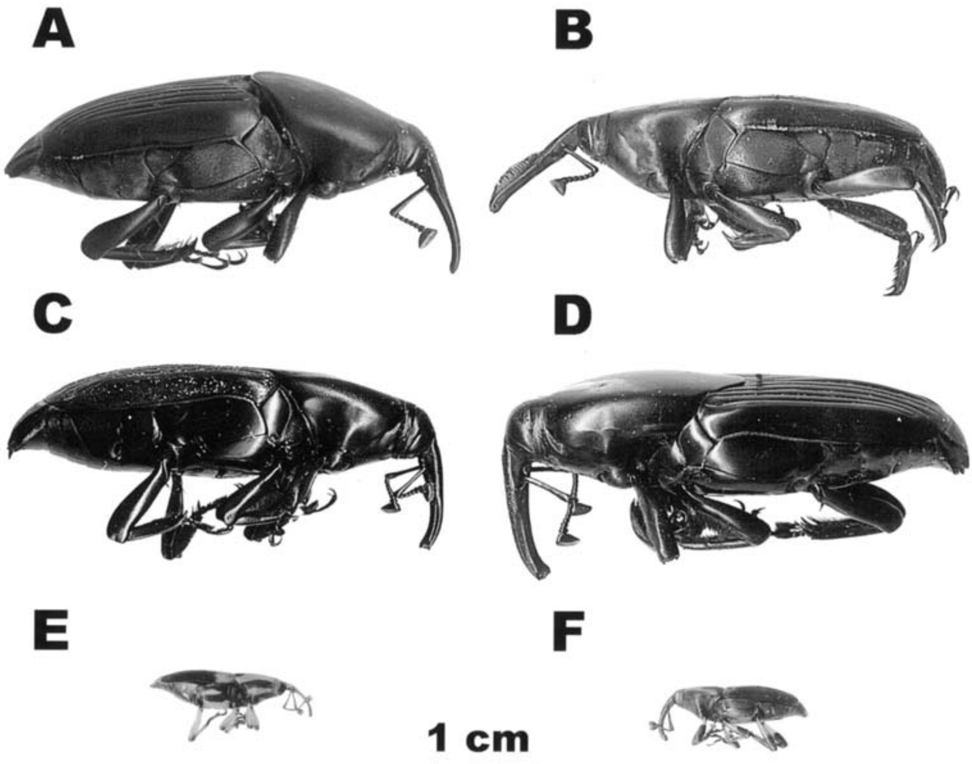

Fig. 13.4. Palm and sugarcane weevils known or suspected to be vectors of the red ring nematode. (A and B) *Rhynchophorus palmarum* female and male, respectively; (C and D) *Dynamis borassi* female and male; (E and F) *Metamasius hemipterus* female and male.

weevil might be considered an obligate transportation host, whereas the coconut palm, in which the nematode multiplies, could be considered as the definitive host.

The palm weevil, *D. borassi* (Fabricius) (Fig. 13.4), can carry close to 2000 red ring nematodes through metamorphosis and is assumed to be a potential vector in coconut where it is sometimes a pest in South America, e.g. Ecuador, Colombia and Brazil, in unopened inflorescences and the crown of coconut (Gerber *et al.*, 1990; Giblin-Davis, 2001).

The weevil, *M. hemipterus* (L.) (Fig. 13.4), has been incriminated as a vector of red ring nematodes in Colombia (Mora *et al.*, 1994) but not in Costa Rica (Bulgarelli *et al.*, 1998) or Trinidad (Hagley, 1963). Trap captures of *M. hemipterus* in African oil palm plantations tend to be up to 35 times higher than *R. palmarum*, but the percentage association and numbers of red ring nematode per weevil were lower with *M. hemipterus* than *R. palmarum* (Mora *et al.*, 1994). *M. hemipterus* may become associated with red ring disease because it attacks the pruned or damaged petioles and frond bases of living coconut, African oil palm, date and other palms (Giblin-Davis, 2001), which are development sites for the red ring nematode (Giblin-Davis *et al.*, 1989a).

Palm and sugarcane weevils in the Dryopthoridae, such as *R. palmarum*, *D. borassi* and *M. hemipterus*, are highly attracted to the volatiles emanating from recently wounded or pruned palms, red-ring-diseased palms, and moist fermenting tissue from palms, sugarcane stalks, various fruits and molasses (Chittenden, 1902; Giblin-Davis, 2001). In addition, males of these weevils produce male- and femaleattracting aggregation pheromones identified as methyl-branched secondary alcohols (Giblin-Davis *et al.*, 1996; Giblin-Davis, 2001). The main aggregation pheromones are (4*S*, 2*E*)-6-methyl-2-hepeten-4-ol for *R. palmarum* (Rochat *et al.*, 1991; Oehlschlager *et al.*, 1992b), and (4*S*, 5*S*)-4-methyl-nonan-5-ol for *D. borassi* (Giblin-Davis *et al.*, 1997) and *M. hemipterus* (Rochat *et al.*, 1993; Perez *et al.*, 1997), which are commercially available as synthetic racemic blends at ChemTica Internacional SA (http://www.pheroshop.com/en/home_en.htm or info@pheroshop.com). These pheromones work as synergists with fermenting palm, sugarcane, or pineapple tissue and can be used to create lethal traps that are effective for monitoring or mass trapping efforts. In addition, *R. palmarum*, *D. borassi* and *M. hemipterus* respond to each others' pheromones, increasing the chances that once a weevil finds a stressed tree, other weevils will help to overcome it and use it as a host (Giblin-Davis, 2001). This phenomenon may also increase the chances for spreading red ring disease. In nature, the combination of weevil recruitment through chemical ecology and the killing potential of the red ring nematode may function together as a form of populational mutualism where enhanced reproduction of both partners is the result of the association (Giblin-Davis, 2004).

Soil transmission has been considered as an alternative means of spreading the nematodes. Despite the lack of experimental proof of transmission, some researchers have considered that insect visitors to the decomposing palms, e.g. ants, spiders and many saprophagous and predatory Coleoptera, are vectors of the nematodes to healthy palms. By their normal behaviour, these insects do not encounter healthy trees either directly or indirectly after leaving the decomposing, infected tree.

Biology of B. cocophilus *in coconut tissues*

The nematodes naturally invade only parenchymatous tissue in roots, stems and leaves, and artificially infested nuts. At first, nematodes occur as intercellular parasites in newly invaded tissue, but later they can be found both intercellularly and intracellularly. In many cases, lysigenous cavities are formed in which large numbers of nematodes are present. One gram of such tissue can contain as many as 10,000 nematodes. Nematodes have never been found in xylem vessels nor has there been any evidence of direct damage to the tracheal elements. Despite this, however, many of the vessel elements in the discoloured areas become occluded with tyloses. It has been shown that the uptake of water injected into the stems of trees is much slower in diseased trees than in healthy trees. Thus, one feature of the external symptoms coincides with a pathological condition due to water imbalance in the plant.

The cause of the restriction of nematodes to the narrow band or ring of necrotic tissue in stems has never been explained satisfactorily. Nowell (1923) found no anatomical or physiological factors in trees which might have accounted for it. Martyn (1953) expressed the view that the outer limit of the red zone was determined by the harder tissue at the periphery of the stem and the inner limit was set by aeration and water supply. Nevertheless, occasionally, there is a solid cylinder of discoloured tissue instead of just a band. Nematodes are often found intercellularly in white, apparently healthy tissue for 1 cm on the outside and 2.5 cm on the inside of the red ring tissue. They are less abundant here than in the body of the ring where they are found both intercellularly and intracellularly. It would, therefore, appear that there are other factors which naturally limit the occurrence and activity of the nematode on the outside and inside of the ring. The most outstanding characteristic of all tissue invaded by *B. cocophilus* is the presence of relatively large intercellular spaces. The inadequacy of intercellular space may, therefore, determine the outer limit. The colour of the band appears to be a specific plant chemical reaction to the invasion, and this varies in the talls and dwarf forms of coconut.

Nematodes inoculated into the mesocarp of nuts were found to have a life cycle, from egg to egg, of 9–10 days (Blair, 1964). The red ring nematode can persist in the diseased coconut tissue for about 3 months (Griffith, 1968b). Ashby (1921) found that juveniles were extremely susceptible to desiccation. They died within 6 h of drying and 15 h when provided with small fragments of tissue. The absence of moisture for half an hour only, followed by exposure to a saturated atmosphere for 24 h, resulted in death of the juveniles in nine cases out of ten.

There are other nematodes species besides *B. cocophilus* associated with *R. palmarum*, *D. borass*, and *M. hemipterus* (Griffith, 1968a; Gerber and Giblin-Davis, 1990a,b) that might cause some confusion during dissections. However, all of these additional nematode associates, such as *Rhabditis* spp., have been confirmed to be phoretic saprobionts.

Environmental factors affecting red ring disease

The larvae of the palm weevil often die when they develop in a tree that is attacked by *Phytophthora palmivora* Butl. (bud rot) or *Micrococcus roseus* Ali-Cohen (cedros wilt disease) subsequent to the contracting of red ring disease. Cannibalism in larvae of the palm weevil resulting from overcrowding often affects the number of emerging weevils. It is known that the red strain of *M. roseus* produces disease and septicaemia in affected palm weevils. Some ground lizards also feed on the adult insects.

The heaviest losses due to red ring disease occur at the end of the wet season and in the first 2 or 3 months of the dry season, i.e. between December and March, in Trinidad (Hagley, 1963). The abundance of the disease may be associated with pruning activities or with the activities of other insects that wound the tree first, inducing fermentation to which the palm weevil is attracted for oviposition. The age of the diseased palm is important since the palm weevil rarely becomes infested with nematodes from old trees. Thus, there is never an epidemic in old groves, even if abandoned, despite the fact that older trees can become heavily infested with the palm weevil alone, as seen in Ecuador.

The palm weevil is a pest in its own right and may relate to the environment differently. *R. palmarum* is a pest of the coconut palm, the gru-gru palm and several others. Some of the host palms are wild in the forest and in other uncultivated areas of Latin America, and many represent reservoirs that could become a source of migrant insects. However, epidemics in wild palms have never been reported.

In many Latin American countries, there exist different levels of attack from red ring disease only and palm weevil attack without red ring disease. In Ecuador, where the Creole tall palms seem to have more Panama Tall stock, the palm weevil is a major pest and the adult insects attack healthy trees of any age. In other countries, such intense attack without red ring disease is quite rare, but, in Ecuador, the insect is a pest in a habitat consisting of several other interplanted kinds of food sources for the weevil, such as pineapples, papayas and sugarcane, that are non-hosts for red ring nematode.

The effects of climate on red ring disease incidence are very apparent as one moves from the dry southern Ceara coconut regions to the northerly more humid areas such as Bahia in Brazil. In Ceara, where the dry season extends for 7.5 months, the incidence of red ring is significantly lower than in Rio Grande del Norte, where the dry season is for 5.5 months and less than in Paraiba where the season lasts for 3.5 months. However, in Pernambuco, where the dry season only lasts for 2 months, the incidence is almost as high as in Bahia Sul where there is little or no dry season. The larvae of the palm weevil can develop adequately within the tissues of the coconut trunk; however, the dissemination stage of the adult is affected by the low humidity in the driest regions where one is more likely to find dead adult palm weevils in the field.

Other hosts

Although red ring is primarily a disease of the coconut palm, it has been found in many palms (Table 13.1) including an unidentified species of *Cocos* (probably *syagrus*) in the Botanic Gardens, Grenada (Nowell, 1924), and the date palm, *Phoenix dactylifera*, in the Botanic Gardens, Trinidad. Hagley (1963) found one case of natural infestation of the cabbage palm *Roystonea oleracea*. Disease incidence was reported to be high in the plantation of oil palms, *Elaeis guineensis*, in Venezuela in 1953 (Malaguti, 1953). Nowell (1924) reported successful inoculation of the cabbage and the gru-gru palm, *Acrocomia aculeata*. Latterly, various ornamentals have been artificially inoculated, among them are the Sabal palm, *Sabal palmetto* and the cocorite palm *Mauritia caribea*. The disease has also been found in Brazil on *Attalea cohune*, the Cohune nut.

The palm weevil does not transmit the nematode to any other non-palm host species, e.g. sugarcane, papaya and pineapple. On the other hand, countries such as the USA, which utilize the *Sabal* sp. for decorative purposes in the presence of the American palmetto weevil, *Rhynchophorus cruentatus*, need to ensure proper quarantine measures against both the palm weevil, *R. palmarum*, and the red ring nematode. The date palm, the coconut and the sabal palm have all been reported as hosts of *R. cruentatus*.

Table 13.1. Natural and inoculated host list records for *Bursaphelenchus cocophilus*.

Acrocomia aculeate (gru-gru palm)
Acrocomia intumescens
Attalea cohune (Cohune palm)
Bactris gasipaes
Bactris sp.
Cocos nucifera (coconut)
Cocos sp.
Elaeis guineensis (African oil palm)
Euterpe pacifica (?; = *E. precatoria*, or *Mauritiella pacifica*??)
Jessenia polycarpa
Mauritia flexuosa (Ita palm)
Mauritia caribea (Cocorite)
Mauritia mexicana
Maximiliana maripa
Oenocarpus distichus
Phoenix canariensis (Canary Island date palm)
Phoenix dactylifera (date palm)
Roystonea oleracea (royal or cabbage palm)
Roystonea regia
Sabal palmetto (Sabal palmetto)
Sabal sp.

Epidemiology and general management measures

Red ring disease in new groves generally begins by infection of a 4- to 10-year-old palm by a weevil carrying the nematodes. The most effective management should be implemented during the initial phase of palm weevil and red ring disease infestation to prevent the development of an epiphytotic.

The rate of spread from a primary infector plant depends upon the development of vector palm weevils within the diseased tree. Typically, 3 months after infection, nearby susceptible healthy trees can be infected by a vector(s) emerging from the infector plant (Fig. 13.3). The initially diseased tree remains a source of red ring nematode inoculum for 6–8 weeks after its death as it continues to attract other sugarcane and palm weevils that might become contaminated with red ring nematodes and serve as vectors. Phytosanitary measures of control are critical at this time since disease symptoms are apparent before the vector progeny emerge, and successful intervention can prevent an epiphytotic of red ring disease.

Emerging palm weevils disperse to leaf axils of diseased trees or wounded trees emitting attractive compounds (kairomones such as ethyl acetate and ethanol) (Giblin-Davis *et al.*, 1996; Rochat *et al.*, 2000). In addition, males of *R. palmarum*, *D. borassi* and *M. hemipterus* produce aggregation pheromones that synergize attraction and recruit conspecifics and heterospecifics of both sexes (Giblin-Davis, 2001). These weevils oviposit in newly diseased palms and cause increased insect populations. Control measures relate directly to the abundance of the disease. Since all red-ring-diseased trees are breeding grounds for palm and sugarcane weevils and red ring nematodes, the destruction and removal of these trees and the reduction of their attractiveness is essential to preventing epiphytotics.

Specific management measures for red ring disease in coconut

There are no simple means of controlling red ring disease, and no effective measures are available as yet for control of the nematode in living palms. Control is based on prevention rather than cure by the destruction of infested palm material, and by the trapping and killing of the weevil vectors before they spread the nematodes.

Many trees show yellowing and browning of leaves that may not be due to red ring disease. To prevent unnecessary destruction of trees, a 'core sample' of the trunk should be taken with a 2 cm diameter pipe (see below) to determine the presence of red ring disease and the nematodes before control measures are employed.

INSECTICIDE AND HERBICIDE TREATMENTS. A fundamental principle in the control of the disease is phytosanitary roguing, based primarily on the fact that the diseased palm is the major source of inoculum and the niche for the vector development. After confirmation that a tree has red ring disease (see below), the leaf axils should be sprayed with 0.1% Lannate (Methomyl) solution to kill off the palm weevils living in the crown (Griffith, 1971). Trees should be killed with 100–150 ml (48.3% a.i.) of the herbicide monosodium acid methanearsonate (MSMA) or other herbicide that is injected or placed into the trunk. This usually takes 2–3 weeks. Occasionally, trees injected with MSMA will harbour weevil larvae. Thus, the tree should be cut and sectioned to make sure that weevils are not present. When trees are discovered in advanced stages of the disease or when they are seen in a 'broken neck' condition, they cannot be poisoned with herbicides. Such trees should be cut down and the pieces and remaining stump sprayed thoroughly with an insecticide, such as methomyl, trichlorfon, monocrotophos, carbofuran, carbaryl, imidichlopride or lindane. If the tree is sprayed adequately with an insecticide, all larvae and pupae of the palm weevil that were developing in the diseased tree will be killed. It is recommended that the site be checked every couple of weeks until the palm has decomposed or that the dried out remains of the palm be burned with the aid of kerosene.

MASS TRAPPING OF PALM WEEVILS. Phytosanitation (removal and destruction of red ring-diseased trees) and trapping of weevils using pesticide-treated palm or fruit tissue have been recommended methods of management of red ring disease in coconut for many years (Mariau, 1968; Griffith, 1969; Delgado and Moreno, 1986). Trapping becomes significant in reducing the abundance of palm weevils generally and, dependent upon the density of traps per hectare, catch the smaller percentage of vector weevils which generally visit and infect palms in the near vicinity, one or two trees away, from the source of infection. The identification, synthesis and commercial availability of male-produced aggregation pheromones of palm weevils have significantly improved the efficacy of the older methods of trapping with fermenting tissue alone (Oehlschlager *et al.*, 1993, 2002; Moura *et al.*, 2000). Although more research is needed in coconut, Moura *et al.* (2000) demonstrated in Brazil that by using 54 100-l perimeter traps of pheromone (Rhyncholure; racemic 6-methyl-2-hepten-4-ol; ChemTica International) plus sugarcane around a red ring-diseased coconut plantation (54 ha) for 26 months, the *R. palmarum* capture rate ($>$ 97,000 weevils were captured during this period) remained constant but the red ring disease incidence dropped dramatically. In Tabasco, Mexico using pheromones in guerrero-type coconut tissue traps over several months showed a positive correlation with the number of insects captured and incidence of disease (Perez-Marquez, 1999, personal communication). Future research in the management of red ring disease in coconut palm, which is a very suitable and susceptible host for red ring disease and *R. palmarum*, must examine the efficacy and cost effectiveness of perimeter mass trapping in concert with phytosanitation in different situations (small versus large crop holdings of various aged palms) in rural tropical America.

BIOLOGICAL CONTROL MEASURES. Natural enemies have not been evaluated thoroughly for management of potential palm and sugarcane weevil vectors. Several organisms may hold promise, including entomopathogenic nematodes in the families Steinernematidae and Heterorhabditidae, the prokaryote *Micrococcus roseus*, and tachinid parasites, *Billaea rhynchophorae* and *B. menezesi* (references cited in Giblin-Davis, 2001).

Methods of diagnosis

RECOVERY OF *B. COCOPHILUS* FROM COCONUT TISSUE. The well-established methods for obtaining samples of nematodes from living trees are still used. A stainless steel tube, sharpened at one end, is driven at an angle of 45° at the point selected for sampling. The extracted core is placed in a blender with 50 ml of water and processed for 2 min. The contents of the blender are then poured into a dish and left for 20 min for the nematodes to emerge. The nematodes are then recovered by sieving. The red ring nematodes are often highly mobile in water (swimming and coiling), leading to knots of clumped nematodes or resuspension of nematodes after centrifugation. In coconut and the palmiste palms, the nematodes are most active in the stem tissue except in the very necrotic regions. The core tissue generally shows a red cylinder of necrotic red ring tissue. In the method originally used by Fenwick and Maharaj (1963), diseased coconut stem, petiole or root tissue is chopped into fine pieces about 1 cm in thickness, placed in a large funnel of water, whose stem is closed at one end with a tube and clip, and whose neck has a small plug of cotton acting as a filter. This can be modified by macerating the diseased tissue in a blender to release more nematodes and then screening through a no. 400 USA Standard Testing Sieve (38 μm openings) before backwashing into the funnel. The funnel is allowed to stand overnight before harvest. Schuiling and Van Dinther (1981) offer another modification for extracting red ring nematodes from tissue.

Radopholus similis

The burrowing nematode, *R. similis*, occurs in most tropical and subtropical areas of the world and has been reported from coconut palms in Florida, Jamaica, Sri Lanka and India (Van Weerdt *et al.*, 1959a,b; Ekanayake, 1964; Latta, 1966; Weischer, 1967; Koshy *et al.*, 1975). Koshy (1986) suggested co-evolution of the nematodes along with black pepper and certain cultivars of banana in the western hills of South India. It occurs deep inside the forests on wild black pepper and is widespread on a number of crops such as coconut, arecanut, black pepper, banana, betel vine and ginger in south India.

Symptoms of damage

The burrowing nematode causes non-specific general decline symptoms such as stunting, yellowing, reduction in number and size of leaves and leaflets, delay in flowering, button shedding and reduced yield. *R. similis* infestation produces small, elongate, orange-coloured lesions on tender creamy-white roots. Consequent to nematode parasitization and multiplication, these lesions enlarge and coalesce to cause extensive rotting of the roots (Fig. 13.5). Tender roots of coconut seedlings with heavy infestation become spongy in texture. Surface cracks develop on the semi-hard orange-coloured main roots. Lesions and rotting are confined to the tender portions of the root. Lesions are also not conspicuous on the secondary and tertiary roots since these are narrow and rot quickly on infestation.

Fig. 13.5. Progressive development of necrotic lesions (from right to left) on coconut roots caused by *Radopholus similis*. (Photo: V.K. Sosamma.)

As many as 4000 nematodes are known to occur in 1 g (2.5 cm length) of main roots. The nematode also attacks the plumule, leaf bases and haustoria of seedlings. The above-ground symptoms being non-specific, the only definite method to identify an infested palm is to look for characteristic lesions on fresh, creamy-white to orange-coloured tender main roots after cleaning and rubbing the epidermis.

R. similis does not enter or penetrate the coconut roots that have developed a hardened or suberized epidermis, but does penetrate the absorbing region behind the root cap covered by very delicate epidermis by lysis of cells. The cavities that form in the outer cortex are always surrounded by deeply stained and heavily suberized cells of irregular shape, whereas those formed in the inner cortex do not have any such deformed darkly stained border cells. The maximum numbers of nematodes and cavities are seen in the outer cortex (Fig. 13.6). Nematodes have not been observed in the stelar region or in the closely packed 4–6 layers of cells outside the endodermis even in heavily infested roots. In the early stage of infection, roots have separate cavities that later merge with each other consequent to feeding and multiplication of nematodes.

Multiple cavities and their coalescence destroy the cortex to a great extent, but the stelar tube remains intact. Eggs and all stages of nematodes with different orientations are seen in the cavities in longitudinal sections (Fig. 13.6) (Koshy and Sosamma, 1982a, 1987; Sosamma and Koshy, 1991, 1998).

Biology and life cycle

The burrowing nematode is a migratory endoparasite and is capable of spending its entire life within roots. Most juvenile stages and adult females including gravid females infest healthy succulent root tips; fourth stage and adult males do not. The nematode takes 25 days at 25–28°C to complete one life cycle (J2 to J2) (Geetha, 1991).

The coconut isolate of *R. similis* from Kerala, India is the ‘banana race’ as they do not infest *Citrus* spp. or *Poncirus trifoliata* (Koshy and Sosamma, 1977), and has a haploid number (n = 4) of chromosomes (Koshy, 1986; Jasy, 1991). The *R. similis* population from coconut root is easily cultured axenically on carrot discs placed on 1% water agar or 10% tapioca pearl (Koshy and Sosamma, 1980; Banu and Sosamma, 1999). It can also be cultured within the mesocarp of growing tender coconuts without affecting the size or quality of the nuts (Koshy and Sosamma, 1982b).

Fig. 13.6. Longitudinal section of coconut root showing *Radopholus similis* in cavities formed in the roots. (Photo: V.K. Sosamma.)

Survival and means of dissemination

The burrowing nematode survives under field conditions for 6 months in moist soil (27–36°C) and for 1 month in dry soil (29–39°C); it survives for 15 months in moist soil (26–29°C) and for 3 months in dry soil (27–31°C) under glasshouse conditions. The nematode survives in roots of stumps of felled coconut palms for up to 6 months (Sosamma and Koshy, 1986) and as adult females in coconut roots and soil during summer months, causing annual recurrence of infection (Sosamma, 1984).

Coconut seedlings are raised by sowing seed nuts in the interspaces in coconut plantations in Kerala, India. Most of the nurseries in Kerala and Tamil Nadu (south India) are infested by *R. similis* (Sundararaju *et al.*, 1995a,b). One-year-old coconut saplings raised in these infested nurseries harbour large populations of the nematode in roots internal and external to the husk. Such seedlings when distributed for planting help in the dissemination of the nematode over long distances (Koshy and Sosamma, 1978b, 1979).

Environmental factors affecting parasitism

Infested coconut roots yield a maximum number of *R. similis* during October to November and minimum during March to July in India. Factors favourable to nematode multiplication are a mean soil temperature below 25°C and a light rainfall coupled with availability of tender fleshy roots. Nematode populations in roots of individual palms were found to vary considerably during low and high peaks depending upon the age, cultivar and conditions of the palms involved (Koshy and Sosamma, 1978a). The burrowing nematode multiplies well on coconut in loamy sand, followed by riverine alluvium, but least in Kari type soils. However, it causes maximum plant damage in riverine alluvium and the lowest in laterite soil (Sosamma, 1984; Sosamma and Koshy, 1985).

Other hosts

The coconut isolate of *R. similis* has a wide host range including several economically important plants, weeds and trees. Of 115 plant species tested, 48 species belonging to 45 genera in 17 families were recorded as hosts (Koshy and Sosamma, 1975; Sosamma and Koshy, 1977, 1981).

Disease complexes

The fungi *Cylindrocarpon effusum*, *C. lucidum* and *Cylindrocladium clavatum* have been recorded in association with lesions produced by *R. similis* in coconut roots. In pathogenicity studies, the fungus *C. effusum* did not cause any appreciable damage to inoculated seedlings. The fungus, when inoculated simultaneously with the nematode, reduced the rate of multiplication of the nematode and damage to coconut seedlings (Sosamma and Koshy, 1978, 1983; Koshy and Sosamma, 1987; Sosamma, 2000b). *Aphelenchoides aligarhiensis*, *Panagrolaimus rigidus* and *Rhabditis* sp. were isolated from leaf rot disease-affected spindle leaves of coconut in Kerala, India (Nadakkal, 1965; Sosamma, 2000c). Application of Phorate at 2 g a.i./palm to the base of the unopened spear leaf is found helpful in control of the disease. However, the role of nematodes in the disease complex as passive vectors/synergists is yet to be defined (Koshy, 2000; Koshy *et al.*, 2002c).

Economic importance and population damage threshold levels

Surveys of different coconut-growing tracts of Kerala, Karnataka and Tamil Nadu States of India (964,000 ha) revealed the widespread occurrence of *R. similis*. Twenty-four per cent of the root samples yielded *R. similis*, and, of these, 50% yielded one or more *R. similis*/g of root (Koshy *et al.*, 1978; Sosamma, 1984). A 30% increase in yield was recorded by application of *Hydrocarpus* sp. oil cake at 8 kg/palm/year or phorate and aldicarb at 10 g a.i./palm in June–July and October–November to the burrowing nematode-infested coconut palms (Koshy, 1986).

The pathogenicity of *R. similis* on coconut was established by conducting two experiments, the first with a duration of 5 years and the second over a period of 1 year. An initial inoculum level of 62,500 nematodes per seedling caused 4, 22, 76, 18, 25, 40, 48 and 79% reduction with respect to height, girth at collar region, shoot weight, number of leaves, number of leaflets per leaf, leaflet length, lamina length and root weight, respectively, over control plants. The effect of parasitization of the nematode was more pronounced on the root system, especially on the number and mass of feeder roots. The threshold inoculum density required for causing significant reduction of various growth parameters was 100 nematodes in 625 cm^3 or 900 g of soil under field conditions over a period of 5 years.

In the second experiment, an initial inoculum level of 100,000 nematodes caused 40, 55, 20, 65, 20, 48 and 52% reduction with respect to height, shoot weight, number of leaves, leaf area, number of lateral roots, volume and weight of roots, respectively, over control plants over a period of 1 year. Leaf bases and haustoria of seedlings were also infested by nematodes. No appreciable damage was noticed in plants inoculated with the fungus, *C. effusum* alone. The pathogenic threshold level of the axenic *R. similis* population for causing damage to all plant growth parameters was 1000 nematodes per seedling or 10 nematodes/100 cm^3 or 140 g of sandy loam soil under greenhouse conditions. The histopathology of infested roots recorded the presence of nematodes in the cortex in the inter- and intracellular positions (Koshy and Sosamma, 1983, 1987; Sosamma, 1984).

To facilitate normal growth of the plant to flower and exhibit the disease under natural conditions, a detailed pathogenicity trial was initiated in 1.8 m × 1.8 m × 1.2 m field tanks (microplots) over a period of 11 years using axenic inoculum. This experiment, the first of its kind on a perennial crop, clearly brought out the damage potential of burrowing nematodes on coconut. All the uninoculated palms came to flowering during 65–83 months after planting, between leaf axils 31 and 49, whereas four out of the five palms that received an initial inoculum level of 100 nematodes flowered during 67–130 months in the leaf axils from 39 to 56. Two palms each that received an initial inoculum level of 1000 and 10,000 nematodes came to flowering after 108 months and one out of five palms that received an initial inoculum level of 1 lakh (100,000) nematodes also came to flowering after 132 months. None of the palms that received 10 lakh (1,000,000) nematodes came to flowering. The control palms produced a total of 155 inflorescences compared with 67 inflorescences in palms inoculated with 100 nematodes as an initial inoculum level. However, the palms that received an initial inoculum of 1000 nematodes and above did not yield any nuts even 11 years after planting. The control plants produced an average of 125 nuts compared with 37 nuts by palms that were inoculated initially with 100 nematodes. Even 1 nematode in 35,640 cm^3 of soil or 100 nematodes per seedling reduced the yield by 77% (Koshy and Sosamma, 1994, 1996).

Management measures

Management of the burrowing nematode on a perennial palm such as coconut with a massive root system is difficult, especially under the high density multispecies cropping system that exists along the west coast of south India involving susceptible crops such as arecanut, banana, black pepper, betel vine, ginger and turmeric. Unlimited use of nematicides for the control of the burrowing nematode may cause problems of residual toxicity in coconut water and copra (Habeebullah *et al.*, 1983; Sosamma, 1996). Apart from this, it may also lead to residual toxicity in the products of the intercrops. Therefore, control of nematodes by field application of nematicides alone is not a practical proposition.

CULTURAL PRACTICES. The cultural practices existing in Kerala and Karnataka (India) are the application of neem and marotti (*Hydrocarpus*) oil cakes at 2–4 kg/palm/year, farmyard manure at 50 kg/palm/year, and green foliage and tender stem of *Glyricidia maculata* to the basins at 50 kg/palm/year. The growing of green manure crops such as cowpea, *Crotolaria* or *Sesbania* in the basins and interfaces during June to August and ploughing in of the entire crop at flowering help in reducing the burrowing nematode population and enriching the nutritional status of the soil. In addition, the growing of intercrops such as cacao that enrich the soil with sizeable quantities of shed foliage helps in the build-up of beneficial organisms and antagonistic microorganisms that may inhibit nematode multiplication (Koshy *et al.*, 1991a,b, 2002a).

BIOLOGICAL. A significant increase in width and leaf area has been recorded in coconut seedlings that received mycorrhizae alone. An increase in shoot weight, root weight and a decrease in lesion indices occur in seedlings inoculated with mycorrhizae prior to *R. similis*. A mixture of mycorrhizae consisting of multiple endophytes, i.e. *Acaulospora bireticulata*, *Glomus fasciculatum*, *G. macrocarpum*, *G. mosseae*, *G. versiforme*, *Sclerocystis rubiformis* and *Scutellospora nigra*, was found effective in improving the plant growth and reducing *R. similis* infestation of coconut seedlings (Sosamma, 1994).

Minimum growth characters and maximum multiplication of nematodes were recorded in plants that were inoculated with *R. similis* alone. In combined inoculation of mycorrhizae and nematode, maximum growth is recorded in plants inoculated with *A. bireticulata*. The mycorrhizae, *A. bireticulata*, has maximum multiplication on coconut compared with *G. macrocarpum*, *Scutellospora coralloidea* and *S. rubiformis* in nematode-free as well as nematode-inoculated plants. Nematode populations are also low in plants inoculated with *A. bireticulata* (Sosamma, 1994; Sosamma *et al.*, 1998a).

A new isolate of *Pasteuria* parasitizing *R. similis* in Kerala, India has great potential for use in integrated pest management. The infective propagules of *Pasteuria* adhered to the cuticle of adult males, females and juveniles of *R. similis* (Sosamma, 1999, 2000b,d, 2002). Introduction of *Paecilomyces lilacinus*, *Pasteuria penetrans* and mycorrhizae into potting mixture contained in plastic bags in coconut nurseries and again in the planting pit at the time of transplantation of coconut seedlings in the field helps in better establishment of plants and imparts better growth by offering protection against *R. similis* (Koshy, 1998; Koshy *et al.*, 1998a; Sosamma *et al.*, 1998b). *Catenaria vermicola* was also found parasitizing *R. similis* in Kerala (Sosamma, 2000a). Introduction of *P. lilacinus*, *P. penetrans* and vesicular arbuscular mycorrhizae (VAM) into potting mixture contained in poly bags in coconut nurseries and again in planting pits at the time of transplantation of coconut seedlings in the field helps in better establishment of plants and imparts better growth by offering protection against *R. similis* (Koshy, 1998; Sosamma *et al.*, 1998b).

RESISTANCE AND TOLERANCE. All the coconut cultivars (29 exotic, 15 indigenous and 15 hybrids) screened for resistance to *R. similis* in India were found susceptible in varying intensities. The dwarf cultivars Kenthali and Klappawangi recorded the least nematode multiplication and lesion indices. Similar reactions were noticed in hybrids such as Java Giant × Kulasekharam Dwarf Yellow, Kulasekharam Dwarf Yellow × Java Giant, Java Tall × Malayan Yellow Dwarf and San Ramon × Gangabondam (Sosamma *et al.*, 1980, 1988; Sosamma, 1984).

CHEMICAL. Burrowing nematode infestation in coconut nurseries has been detected in India. Increased incidence of *R. similis* can occur when banana is used as a shade crop in coconut nurseries. In these situations, there is possibly a case for treatment of nurseries with nematicides to produce nematode-free seedlings to prevent spread of the nematode into the main field and to uninfested areas.

Past experience has shown that a dip in 1000 ppm dibromochloropropane (DBCP) for 15 min is effective in controlling nematodes in seedlings for *R. similis*-infested coconut nurseries (Koshy and Sosamma, 1978b, 1979). Complete control of *R. similis* can be obtained with soil application of phenamiphos or phorate at 25 kg a.i./ha during September, December and May in infested coconut nurseries (Koshy and Nair, 1979; Koshy *et al.*, 1985).

Summary of management measures

The following measures are suggested towards developing an integrated management schedule for *R. similis* infestation on coconut palms (Koshy, 2002).

- Application of cow dung (50 kg), oil cakes (2–4 kg) and green manuring with *Glyricidia maculata* (50 kg) per palm/year to the basins.
- Growing *Crotolaria juncea*, cowpea or *Sesbania* in the basins and interspaces and incorporating into the soil by ploughing in at flowering stage.
- Application of phorate at 10 g a.i./palm twice yearly (in June–July and in October–November in India).
- Avoid growing bananas as a shade crop in coconut nurseries.
- Use of nematode-free planting material of coconut and other intercrops.
- Use of tolerant or less susceptible cultivars or their hybrids in infested areas.
- Cut and remove all roots external to the husk of seedlings raised in the field before planting.
- Raise coconut seedlings in potting mixture enriched with bioagents such as *P. lilacinus*, *P. penetrans* and mycorrhyzae in plastic bags.
- Introduce bioagents into the planting pits while planting in the main field.
- Apply phorate at 3 g a.i./plant to intercrops such as banana, black pepper and arecanut in June–July and October–November.

Methods of diagnosis

SAMPLING. Soil and root samples for detection of *R. similis* should be collected when maximum populations of the nematode occur (October–November in India). Maximum populations of *R. similis* are found on coconut at a distance of 100 cm from the bole of the palm and at a depth of 50–100 cm. Fifty g of tender, creamy-white to orange-coloured, semi-hard, main roots (~1 cm diameter) showing lesions and rotting should be collected to obtain live populations in large numbers (Koshy *et al.*, 1975).

EXTRACTION. The semi-hard, orange-coloured, main root bits are peeled and sliced longitudinally into 4–8 pieces of 3–5 cm length. These sliced root bits are submerged in water contained in Petri dishes or shallow pans; a temperature of 20–25°C is ideal for extraction of live nematodes from polyphenol-rich coconut roots (Koshy *et al.*, 1975). After every 24 h of incubation, the water needs to be changed; 50% of the population is extracted after 72 h. Most of the nematodes are recovered within 4–7 days.

DETERMINATION OF POPULATIONS AND CROP LOSS. Nematode populations in the tender portions of the main roots can be estimated by staining and blending. Roots may be cut into 2-cm long pieces, sliced longitudinally into eight sections and then stained.

Nematodes for the control of other coconut pests

Entomopathogenic nematodes *Heterorhabditis indica* and *Steinernema* spp. were isolated from soil around coconut in Kerala which were used in the integrated management schedule for the Rhinoceros beetle, *Orycetes rhinoceros* L. and red weevil, *Rhynchophorus ferrugineus* F. (Sosamma and Banu, 1996; Banu *et al.*, 1998; Sosamma, 2000, 2003).

Conclusion and future prospects

The burrowing nematode, *R. similis*, is second in importance to the red ring nematode, *B. cocophilus*, on the basis of its damage potential on coconut. Though the nematode has been reported in association with various coconut diseases (Govindankutty and Koshy, 1979), no detailed investigations have been carried out anywhere else except India. Screening for resistance/tolerance to *R. similis* in coconut cultivars and their hybrids has indicated the availability of possible resistance in some cultivars. Though breeding in coconut is a long-term process, this area could be profitably exploited. Developing an integrated management schedule for the coconut based on subsistence farming systems involving susceptible perennial crops such as arecanut, black pepper, cacao and banana should be the priority area of research.

Oil Palm

The oil palm, *Elaeis guineensis* Jacq., has a natural distribution in West Africa between latitudes 13°N and 12°S from the coast to the Great Lakes. Ecologically, it is found in the transition regions between the rainforest and the savanna. It has also been cultivated extensively in Malaya and Indonesia. Commercial production of oil palm in Central and South America dates back only to the 1960s, though production is expanding in all tropical South America. In the New World, it is a plantation crop with holdings of several hundred to several thousand hectares per unit, whereas in Africa or Asia it can be a large plantation or smallholders crop as with the coconut.

Nematodes of Oil Palm

Generally, the major diseases of the oil palm are found in its area of origin. Curiously, although there are fungal-, bacterial- and suspected viral- or phytoplasma-induced diseases, no records of any economic losses due to nematode damage occur in the Old World. However, *B. cocophilus* causes economic loss in oil palm in Central and South America. Other plant parasitic nematodes have been reported on oil palm in India, Pakistan and other countries (Maqbool, 1991; Salazer *et al.*, 1992; Sundraraju *et al.*, 1995; Sundraraju and Sudha, 1998).

Bursaphelenchus cocophilus

Freeman, in 1925, in Trinidad, appears to have been the first to record the pathogenicity of the red ring nematode on oil palms. Red ring disease caused by *B. cocophilus* has been known from African oil palm from Venezuela since before 1953 (Webster and Gonzales, 1959) from a single plantation of 1000 ha where the disease caused severe losses. Malaguti (1953) demonstrated that African oil palm, which at that time had recently arrived in Latin America from Africa, was invaded by the red ring nematode. Malaguti cites a group of 100 palms showing only 16 doubtful cases in January, but which by August had 22 deaths, nine doubtful or affected cases and only 69 palms remaining healthy. On that Venezuelan estate, about one-third of the total palm population became infected.

Symptoms of red ring disease in oil palms and biology

The coloration in the diseased palm is similar to that of the browning associated with the 'nana' or dwarf cultivar of coconuts, i.e. brownish rather than reddened tissue internally (Plate 14E). Also, the leaves dry out and turn brown instead of the usual yellowing and then browning associated with the tall cultivar of coconuts (Plate 14F). Often, the centre of the crown takes on a dwarfed appearance and the newly opened 'little leaves' become bundled together, the leaflets being twisted, corrugated and adhering to a stiff upright rachis. The developing bunches show necrosis and the inflorescences do not set fruit. The ultimate symptoms of red ring disease in oil palm are similar to those of the coconut palm, but there are some fundamental differences in the progress of the infection that can lead to new and distinct measures for treating the disease in the crop.

Pathogenesis is longer than in the coconut, generally 5–10 months in the more susceptible cultivars. In the coconut, the young 3- to 10-year-old palm is virtually dead within 3 months after infection. In the case of the oil palm, this process can take up to 3–4 years with a palm of the same age group. This is partially because the nematode does not colonize as rapidly in the oil palm tissue as it does in the coconut. Where 5000–10,000 nematodes/g of tissue can be found in the red ring zone of coconut, a similar region in the oil palm often yields less than 500 nematodes/g of tissue. A further difference is that most nematodes are found outside the necrotic zone, even in areas that show no necrosis such as the distal or basal portion of the stem and occasionally in the rachis of the inflorescence (the nematode has not been isolated from the rachis of the coconut panicle). In addition, the red ring disease infection rate is often highest in older oil palms (15 to $>$ 20 years old) (Oehlschlager *et al.*, 2002).

As in the case of the coconut, the most persistent form of the nematode is the third stage juvenile, which can subsist for a long time in the diseased tissue. In the coconut, this juvenile form readily proceeds to the adult in the healthy tissue not showing symptoms. However, in the oil palm, this interval is prolonged for some reason, with the result that colonization of the oil palm is not rapid and pathogenesis is attenuated. A notable feature in accordance with this is that the band of necrotic tissue is usually very narrow and often irregular in shape (Chinchilla, 1988). Eggs appear as usual in the brownish spots that are present in the advancing area of the disease. Such necrotic areas indicate evidence of plant reaction to the cellular damage caused by abundance of the nematode. The nematodes often show no evidence of their presence, and an abundance of nematodes can occur without the plant reacting visibly. Yet, artificial inoculation studies have demonstrated that increased logarithmic strengths of the inoculum correlate inversely with the length of the period for pathogenesis in 8-year-old palms at Centeno, Trinidad.

The palm weevil, *R. palmarum*, as with coconut, is the main vector of *B. cocophilus*. The canopy in an oil palm plantation is always closed, with reduced light intensity and more humidity than in coconuts. This presents ideal conditions for the vector of the nematodes, the palm weevil, which is crepuscular.

In the state of Amazonas, Brazil, the number of weevils infested with nematodes showed high monthly variations and irregular distribution, with higher percentages occurring in November 1988 and September 1991. The relatively low incidence of red ring disease in the area did not suggest any association between the disease and the variations in rainfall measured (Araujo *et al.*, 1998).

Spacial disposition of diseased oil palms

In young 5- to 10-year-old groves, there is a tendency for the diseased palms to be clustered in a 50 m radius that gradually expands. In older groves, however, the diseased trees appear to be distributed at random, giving the impression that the vectors come in from fields that are more susceptible to the simultaneous development of both the nematode and the palm weevil. The major constraint is the poor opportunity for association of the developing weevil larvae in the oil palm with a large number of nematodes. This is a result of the slower rate of colonization of the nematode in the oil palm compared with the coconut palm. Therefore, unlike a coconut estate where most weevils develop in diseased trees which become the main or focal developmental niche (97.3% in Trinidad), the proportion, in oil palm fields, would relate more to the Ecuador situation, with greater percentages of the weevils developing outside the ambit of the nematode. This is markedly so as the incubation period of the pathogen in oil palm is very long and quite variable. The principle of the diseased palm being the main attractive focus for palm weevils would have reduced relevance here; thus, weevil lures would assume a more significant role in disease management in the field. Consequently, weevil trapping in oil palm estates is an important form of control for reduction of the disease. Moreover, location and elimination of sources of infection, other than oil palm, particularly diseased coconut fields, near the affected grove is important. Phytosanitary measures, however, comprise the most utilized method of control in Latin America.

Other hosts for red ring disease in some oil palm estates in Brazil

The wild palm *Oenocarpus distichus* Mart. was found by Schuiling and Van Dinther (1981) to be capable of contracting red ring disease and serving as a host for *R. palmarum*. This is a typical palm of primary and secondary forest of the Amazon estuary. Nematodes are often fewer in number, often less than 100/g of tissue. However, palm weevil larvae found growing in these trees were internally contaminated with red ring nematodes. The weevil *R. palmarum* is reported from 31 plant species, belonging to 12 families, with palms being the main hosts (Sanchez and Cerda, 1993).

Economic importance and damage threshold levels

In Latin America, there is an apparent direct correlation between levels of red ring disease in coconuts and those in oil palms. Countries with high levels of red ring disease in coconut groves also have high levels of red ring in oil palm groves. Generally, in oil palms 8–10 years old, the incidence is around 0.1%, and in palms over 20 years old the incidence is rare. However, in some zones adjoining old coconut establishments, the incidence of disease in oil palms, 11–18 years old, can be as high as 30%. In one parcel of 62 ha of the plantation of Palmeras de la Costa in Colombia, the maximum accumulated disease total for 1987 was 8.3% (Villanueva and Gonzales, 1988).

Little leaf disease of oil palms

The oil palm, as most palms, has a tendency towards producing so-called ‘little leaves’, the cause of which may be diverse and related to symptoms of other diseases. In Surinam, Van Hoof and Seinhorst (1962) observed that little leaf syndrome was associated with attack by the red ring nematode. Little leaf symptomatic trees can easily be recognized by their erect, short and often deformed leaves with suberized patches especially on the inner side of the leaf stalks (Chinchilla, 1988).

Many *B. cocophilus* have been found on discoloured tissue of young (up to 1.75 m long) folded leaves, still protected from the sun. The nematodes live ectoparasitically in the buds of the palms. In one survey of 50 diseased oil palms cut for investigation, only one did not contain nematodes. *B. cocophilus* was never found on the young leaves of numerous trees that did not suffer from little leaf but were cut for other reasons (Van Hoof and Seinhorst, 1962). Palms exhibiting this symptom can live for many years, but with a reduced leaf emission rate and abortion of inflorescences (Chinchilla, 1988). It has been hypothesized that red ring nematode-induced little leaf is symptomatic of unsuccessful cases of the systemic red ring disease and is more common in African oil palm than coconut where it is rarely observed because coconut is so susceptible and succumbs so easily to red ring disease (Giblin-Davis, 1993).

Management of red ring in oil palm

Generally, control of red ring disease in oil palm is similar to that in coconut by a combination of methods. The destruction of diseased trees is paramount as soon as the symptoms are detectable in order to destroy inoculum.

Injections of systemic nematicides, such as fenamiphos, oxamyl and carbofuran, into little leaf symptomatic palms can help with palm recovery. However, because of the damage to the very young leaves in little leaf palms, the recovery can take between 6 and 8 months (Chinchilla, 1988). This measure is unsuccessful in coconuts because the nematode colonizes the palm tissue too rapidly, but, in oil palm, the slower rate of colonization allows for such a possibility to control the nematode directly. Non-target effects and cost effectiveness must also be considered, and little leaf symptomatic oil palms are usually better removed, providing more light into the canopy and increased productivity to nearby palms (Chinchilla, 1988).

Research by Oehlschlager *et al.* (1992a, 1993, 1995, 2002) in African oil palm plantations in Costa Rica suggests that concerted aggressive phytosanitation and mass trapping with traps baited with sugarcane and synthetic aggregation pheromone (Rhyncholure; racemic 6-methyl-2-hepten-4-ol; ChemTica International) reduce the numbers of *R. palmarum* and change their distribution patterns (from highly aggregated to random) while significantly reducing red ring disease incidence. Initial bimonthly inspections and removal of red-ring-diseased palms did not reduce red ring disease incidence in two large African oil palm plantations in Costa Rica. One year after the initiation of mass trapping at trap densities of about one trap per 5 ha, red ring disease incidence plummeted by more than 80% (Oehlschlager *et al.*, 2002). At mass trapping onset, most *R. palmarum* were captured in 'border' traps of test sites, suggesting removal of potential immigrants into the study area. A combination of perimeter and 'internal' traps appears to be most effective for mass trapping in African oil palm (Oehlschlager *et al.*, 1995). There are many trap designs available for effectively capturing palm and sugarcane weevils (Oehlschlager *et al.*, 1993; Giblin-Davis, 2001). The most important features involve baiting with sugarcane or palm tissue (changed every 2 weeks) and a pheromone release device and making the trap lethal with pesticide treatment of tissue or by using a special trap design with soapy water. The traps must be examined and refreshed at least every 2 weeks with fresh pesticide-treated sugarcane tissue and pheromone (as needed).

Studies to determine whether *Metamasius* sp. is a vector of *B. cocophilus* did not achieve transmission of red ring in oil palms, but the frequency of the nematodes occurring in the insects was significant (Silva, 1991).

Methods of diagnosis

The methods for extraction of *B. cocophilus* from oil palm are similar to those described for the nematode in coconut; however, they are much less accurate because of the lower numbers of nematodes present and the often irregular shape of rings in the oil palm (Chinchilla, 1988). Nematodes also seem to thrive in the petioles.

Date Palm

The date palm, *Phoenix dactylifera* L., is dioecious, and artificial pollination by man has played a significant role in the historical development of the crop. Tissue culture programmes have become important for improving yields. The FAO estimate worldwide production of dates peaked in 1996 at 4,492,000 t. The main contributors were: Iran, which produced 765,000 t; Egypt, 680,000 t; Saudi Arabia, 597,000 t; Iraq, 550,000 t; Pakistan, 533,000 t; Algeria, 361,000 t; and the United Arab Emirates, 240,000 t. Though the palms will grow throughout the tropics, the number of heat units required from the time of blossoming to ripening should be between 4000 and 5500 for various cultivars. Growth of the palm ceases around 10°C. Suitable climatic conditions occur in the dry parts of California where the palm has been grown successfully on a commercial scale. In this introduced environment, the palm has to cope with the new prevailing nematode fauna.

Nematodes of Date Palm

The date palm is affected by numerous pests and diseases wherever it is grown, but nematodes parasitic on date palm, with the exception of root knot nematodes, *Meloidogyne* spp., have not been well studied. However, nematodes have not been found to be a limiting feature in the countries with date as an ancient culture. Root knot nematodes, *Meloidogyne* spp., were found in the Coachella Valley of California on date palms in 1925, where they are now known to be widely distributed in commercial date plantings. Buhrer *et al.* (1933) first reported the occurrence of root knot nematodes on date, and Jensen (1961) found *M. incognita* on roots of date palms in nurseries. Carpenter (1964) reported that root knot nematodes, principally *M. javanica*, can severely damage or kill date palm seedlings.

Young seedlings of 50 date cultivars were susceptible to infection by root knot nematodes; more than 90% of the seedlings were killed prior to emergence when seeds were sown in heavily infested soil. Secondary damage by fungi to roots of field-grown palms infested with the nematodes seemed to be an important factor in the deterioration and death of roots. Minz (1958) reported the occurrence of *M. arenaria*, *M. hapla*, *M. incognita* and *M. javanica* on date palms in Israel. *Meloidogyne* sp. has been reported from Sidi Yaia in Algeria (Lamberti *et al.*, 1975), from the Mauritanian oases of Tayaret and Tejitt (Netscher and Luc, 1974) and from Libya (Fourgani and Edongali, 1989; Edongali, 1996).

The combination of *Thielaviopsis paradoxa* (*Ceratocystis paradox*) with *M. javanica* increased the susceptibility of date palm cutivars to infection by the fungus (Aboud *et al.*, 2002).

Histopathological studies of date palm (*P. dactylifera*) roots infected with *Pratylenchus penetrans*, the root lesion nematode, showed puncture of epidermal cells and disarrangement of cortical cells with large empty, abnormal cavities. Membranous cell walls were wavy and collapsed as the supporting material was destroyed by nematode infection (Khan *et al.*, 2002).

The cellular alteration in *M. incognita*-infected roots of susceptible and resistant date palm cultivars was histologically studied in pot experiments. Giant cell formation was favoured in the susceptible cv. Zaghlool, while in resistant cvs Deglet Noor and Samani, the infected roots reacted to the nematode infection by forming a necrotic area around the invading nematode. In certain cases, malformed small giant cells were observed in association with nematode juvenile stages (Eissa *et al.*, 1998). In Egypt, the largest *M. incognita* populations were found at soil depths of 30–50 and 51–70 cm at 1 and 2 m distances from the trunk of date palm cv. Siwi (Youssef and Eissa, 1994). Thirty-seven species of plant parasitic and free-living nematodes were encountered on date palm in India. Date palm trees infected with *M. incognita* (450 second stage juveniles/250 cm^3 of soil) showed yellowing of leaves and stunted growth (Lal and Mathur, 1986).

A survey of plant parasitic nematodes in the rhizosphere of 30 date palm cultivars in Riyadh, Saudi Arabia, found 18 genera of plant parasitic nematodes in the following descending order of frequency: *Helicotylenchus* (64.9%), *Meloidogyne javanica* (52%), *Hemicriconemoides* (37.8%), *Tylenchorhynchus* (24.3%), *Criconemoides* (16.9%), *Tylenchus* (15.5%), *Aphelenchus* (14.5%), *Hoplolaimus* (10.8%), *Rotylenchulus* (7.4%), *Paratrichodorus* (6.4%), *Pratylenchus* (6.1%), *Trichodorus* (5.7%), *Ditylenchus* and *Longidorus* (3.7%, each), *Zygotylenchus* (2.7%), *Xiphinema* (2%), *Aphelenchoides* (1.7%) and *Paratylenchus* (0.7%). Only *Helicotylenchus* and *Meloidogyne* were found on all the surveyed date palm cultivars (Al-Yahya *et al.*, 2001). A survey in the United Arab Emirates found nematodes associated with diseased date palms (Hashim, 1997). During field surveys of date diseases in coastal regions of Libya, root knot nematodes (*M. incognita* and *M. javanica*), root lesion nematodes (*P. penetrans* and *Pratylenchus* sp.), ring nematode (*Criconemoides* sp.) and others were associated with date palm rhizospheres (Edongali, 1996). A survey carried out in Algeria revealed the occurrence of five species of *Pratylenchus*. The most common species was *P. penetrans*, often associated with date palm (Troccoli *et al.*, 1992). *Criconemoides curvatus* and *Longidorus* sp. nov. were found on date palm in Florida (MacGowan, 1989). In Algeria, Lamberti *et al.* (1975) reported the occurrence of *P. penetrans* on date palm roots in the crescent of oases from Beni Ounif to Biskra, and there are reports of associations with species of *Hemicricononemoides*, *Xiphinema*, *Criconemoides*, *Trichodorus* and *Tylenchus*. *B. cocophilus* is also known to affect the date palm. A specimen in the Botanic Gardens, Trinidad, came down with red ring disease and produced a brownish ring. However, date palms growing in the main production areas prefer a hot dry environment that would limit the activities of the palm weevil, the vector of the red ring nematode, which thrives in areas of high humidity.

Management of date palm nematodes

Nematicides added to cultivated soil were screened for their ability to control soil nematodes. The higher the concentration, the higher the mortality rate. On date palms exhibiting Al-Wijam symptoms, dazomet gave the best control, followed by carbofuran and oxamyl. *Longidorus* spp. were the most susceptible nematodes, followed by *Xiphinema*, but *Meloidogyne* were the most resistant species. However, there was no sign of recovery of treated date palm trees with Al-Wijam disease (Abdulsalam *et al.*, 1996).

Arecanut

Arecanut or betel nut, *Areca catechu* L., occurs in the humid regions of Asia and the Malay islands. It is a masticatory of great antiquity, and betel chewing is a habit of nearly one-third of the world's population. The ripe fruits are sometimes used as an anthelmintic and astringent in Europe.

Nematodes of Arecanut

A number of nematodes have been reported from the rhizosphere of arecanut (Nair, 1964; Weischer, 1967; Pizarro, 1969;

Koshy *et al.*, 1976, 1978, 1981; Reddy, 1978; Sundararaju and Koshy, 1982a; Sundararaju *et al.*, 1984; Dasgupta and Rama, 1987; Rama, 1987; Subramaniyan *et al.*, 1988; McSorley and Dunn, 1989), but only *R. similis* is known to be an important parasite of the palm. A number of other palms have been reported as hosts of *R. similis* (Table 13.2), and it would not be unexpected if nematode problems with some of these other palms became apparent in the years ahead.

Radopholus similis

The burrowing nematode, *R. similis*, was first reported from soil around roots of arecanut palm in Mysore, India by Kumar *et al.* (1971) and later by Koshy *et al.* (1975, 1976) and Sosamma (1998).

Symptoms of damage

The most conspicuous symptoms of *R. similis* infestation are the appearance of lesions and rotting of roots. The nematode produces small, elongate, orange-coloured lesions on the young, succulent, creamy-white to light-orange coloured portion of the main and lateral roots. Subsequently, the adjoining lesions coalesce and cause extensive root rotting. The thick primary roots produced from the bole region of the palm exhibit large, oval sunken, brown to black lesions, 2 mm to 2 cm in length (Plate 14F).

Nematodes occur inter- and intracellularly in the cortex, but do not enter the stelar tissues. Large numbers of nematodes and their eggs are seen in the cavities that develop consequent to nematode feeding in the cortex (Sundararaju, 1984, 2000).

Table 13.2. Palms reported as hosts of the burrowing nematode, *Radopholus similis*.

Archontophoenix cunninghamiana Wendl. and Drude (Seaforthia or Picabeen bungalow palm)
Areca (Actinorhytis) calapparia
Areca catechu L. (Betel-nut palm)
A. langlosiana
A. macrocalyx Beec.
A. normanbyii
A. triandra Roxb.
Chamaedorea cataractarum Martius
C. elegans Martius (parlour palm or Neanthebelia palm)
Cocos nucifera L. (coconut)
Elaeis guineensis Jacq. (African oil palm)
Phoenix canariensis Hort. ex Chabaud (Canary Island date palm)
P. dactylifera L. (date palm)
Rhapis excelsa (Thunb.) Henry (large lady palm)
Roystonea regia (H.B.K.) Cook. (royal palm)
Syagrus romanzoffiana (Cham.) Glassman (queen palm)

Biology and life cycle

The burrowing nematode takes 25–30 days to complete one life cycle (J2–J2) on arecanut seedlings at a temperature range of 21–31°C under glasshouse conditions. Chromosome studies have recorded the presence of a haploid number of chromosomes ($n = 4$) in many isolates of *R. similis* from arecanut roots (Koshy, 1986). The arecanut isolate of *R. similis* belongs to the banana race (Koshy and Sosamma, 1977) and multiplies well on carrot discs maintained on 1% water agar (Koshy and Sosamma, 1980).

The population densities of *R. similis* in arecanut fluctuate; maximum population occurs in roots during October to November and the minimum during March to June in India. Populations are also known to vary between samples, types of roots, palms, groves and soil types during the same period (Koshy and Sosamma, 1978a).

Disease complexes

The fungus *Cylindrocarpon obtusisporum* is found associated with lesions caused by *R. similis* in arecanut roots. The fungus when introduced 3 weeks after nematode inoculation caused more damage to plants compared with inoculations with the nematode alone and it inhibited the rate of multiplication of the nematode (Sundararaju and Koshy, 1984, 1987).

Economic importance and population damage threshold levels

R. similis was recorded from 32% of root samples in the three major arecanut-growing states in south India, with a maximum population of 440 nematodes/g of root. *R. similis* was found in 55, 45, 44, 30 and 11% of root samples from plantations intercropped with banana, black pepper, cardamom, coconut and cacao, respectively, compared with 25% from plantations monocropped to arecanut (Sundararaju, 1984).

The population damage threshold level on arecanut seedling is 100 nematodes/seedling or 1/800 g of laterite soil. The percentage reduction of growth over uninoculated plants at this inoculum level can be 23, 39, 25, 19 and 38% with respect to shoot length, shoot weight, girth at collar region, root length and root weight, respectively, under pot conditions in laterite soil.

Management

RESISTANCE/TOLERANCE. None of the 46 accessions of arecanut germplasm in the CPCRI germplasm collection is immune or highly resistant to *R. similis*. The cultivars Mangala (VTL-3) and Fiji (VTL-26) are highly susceptible, whereas the cultivars Singapore (VTL-17), Solomon Islands-2 (VTL-18c) and Saigon (VTL-27) are less susceptible to *R. similis*; cultivars Indonesia 6 (VTL-11), Mahuva 8 and Andaman-5 (VTL-29e) are tolerant to *R. similis* (Koshy *et al.*, 1979; Sundararaju and Koshy, 1982b). The cultivars Indonesia-6 (VTL-11) and Singapore (VTL-17) are known to yield 15% more nuts over local South Canara cultivar (Anon., 1974). Thus, these cultivars could profitably be recommended for *R. similis*-infested areas. The hybrid VTL-11 × VTL-17 is highly resistant to *R. similis*.

CHEMICAL AND BIOLOGICAL. As arecanut is chewed directly by many consumers, dosage, frequency and time of application of nematicides on arecanut have to be calculated carefully to avoid residues in the nut.

A pot culture experiment carried out under field conditions revealed that fensulfothion and aldicarb at 1 g a.i./seedling applied thrice a year for 3 consecutive years in pots gave control of *R. similis* both in soil and in roots. Increases in plant growth with regard to shoot length, shoot weight, root length, root weight, number of leaves and collar girth with fensulfothion were 46, 168, 33, 173, 25 and 41%, respectively, over control plants after 3 years (Sundararaju and Koshy, 1986a). In a field experiment in India, treatment with fensulfothion at 50 g a.i./palm and aldicarb at 10 g a.i./palm applied during May/June, September/October and December/January for 5 years resulted in control of *R. similis* and a substantial increase in both number and weight of nuts compared with untreated palms (Sundararaju and Koshy, 1986b). However, the nuts were not analysed for their residues, if any, and the cost–benefit ratio has not been determined.

Field experiments were carried out in arecanut monocrop, arecanut + banana and arecanut + banana + pepper to evaluate the efficacy of neem oil cake and phorate singly and in combination for control of *R. similis* in the cropping system. Even though all the treatments were significantly superior over the untreated control, the best treatment in these experiments was 15 g of phorate in combination with 1 kg of neem oil cake, which controlled the *R. similis* population in arecanut and subsidiary crops very well (Sudha and Sundararaju, 1998). A pot trial study to evaluate the combined effect of organic amendments and biocontrol agents, i.e. *P. lilacinus*, *P. penetrans* and arbuscular mycorrhizal fungi (AMF), against *R. similis* infecting arecanut (*A. catechu* var. Mangala) was conducted using sandy loam soil amended with various organic matter. The organic amendments used were neem and marotti oil cakes, leaves and tender shoots of sunnhemp and *Glyricidia*, vermicompost, cow dung and coir pith. Maximum nematode control (95%) was recorded in soil amended with *Glyricidia* leaves and bioagents. Significant reduction in root lesion index and maximum leaf area was recorded in these plants. The percentage increase in height and root growth was maximum in plants grown in coir pith-amended soil with bioagents which was on a par with plants grown in soil enriched with *Glyricidia* leaves and bioagents. A decrease in nematode population was on a par in all treatments receiving organic amendments and bioagents as well as bioagents alone compared with nematode alone. All of the bioagents were re-isolated from all of the treated plants, even after 3 years. Although amendment of soil with organic matter in general was found to increase plant growth and reduce nematode population, the differences were not significant compared with introduction of bioagents in the absence of organic amendments (Koshy *et al.*, 1998c, 2002b).

Summary of management measures

Control of *R. similis* on arecanut is difficult under the high density, multispecies, subsistence farming systems involving perennial crops such as coconut, banana, black pepper, betel vine, cardamom and cacao. Use of nematicides for the control of burrowing nematode on coconut or arecanut may cause problems of residual toxicity. The following control measures are suggested: (i) use of nematode-free planting material of arecanut and other intercrops; (ii) avoiding *R. similis*-susceptible intercrops such as black pepper and banana in infested areas; (iii) use of resistant/tolerant cultivars of arecanut, when available, and other crops in farming systems; (iv) application of 5–10 kg of green manure preferably *Glyricidia* or *Crotolaria*; (v) application of 1 kg of neem oil cake/palm/year; and (vi) application of phorate at 3 g a.i./plant to the root zone of arecanut, banana and black pepper in June–July and October–November in arecanut-based farming systems (Sudha and Sundararaju, 1998; Sundararaju and Sudha, 1998).

Methods of diagnosis

Soil and root samples for detection of *R. similis* should be collected at a distance of 25–75 cm from the bole of the palm at a depth of 25–75 cm when high population densities are present, such as during October/November in India. The method suggested for extraction of *R. similis* from coconut root can also be adopted for arecanut.

Other Palms

Reniform nematode, *Rotylenchulus reniformis*, is a sedentary endoparasitic nematode that sometimes causes concern in field-grown or containerized palms for shipment in the USA. The concern is a regulatory issue rather than one of palm pathology. Most palms, except *Washingtonia robusta* Wendland and *Acoelrrhapphe wrightii* Grisebach and Wendland, are non-hosts for the reniform nematode (Inserra *et al.*, 1994). These hosts, although suitable for nematode reproduction, are devoid of above-ground symptoms, suggesting tolerance. The regulatory problem arises because ornamental palms grow well in southern Florida conditions where reniform nematode is a damaging pest to dicotyledenous field and vegetable crops. Ornamental palms that are contaminated or infested with reniform nematode are subject to quarantine in non-infested areas in Arizona, California and New Mexico that grow valuable and susceptible crops such as cotton. *R. reniformis* has also been found in the rhizosphere of ornamental palms in Egypt (Ismail and Eissa, 1993).

Hot-water treatments were evaluated to disinfect roots and media of potted bamboo or Reed palm, *Chamaedorea seifrizii* Burret, and fishtail palm, *Caryota mitis* Lour. of *R. similis*. A continuous hot-water drenching (50°C for 15 min) of roots and media in pots or hot-water dipping (50°C for 15 min) of bare-rooted plants were successful in eliminating all burrowing nematodes in bamboo palms. Fishtail palms were disinfected of burrowing nematodes after hot-water drenching at 50°C for 13 min. Dipping plants intact in pots in a constant temperature water bath was not effective, as the root temperature remained below the thermal death point for nematodes due to slow heat transfer. No evidence of thermal damage was observed in either palm species drenched with hot water at 50°C for up to 20 min followed by hydro-cooling to ambient temperature. Ambient air-cooling after heat-treatment was detrimental as the residual heat caused both vegetative and root damage in the potted palms. These air-cooled palms suffered reduced growth and required a longer recovery period (Tsang *et al.*, 2003).

General Conclusions and Future Activities on Nematodes of Palms

The foregoing has shown that fatal diseases in palms due to nematodes are unknown except for those palms that are naturally attacked by *B. cocophilus* and its chief insect vector *R. palmarum*. The fact that red ring disease is at present confined to the New World restricts its economic importance to those palms that occur in the area, but others, such as the arecanut palm, are likely to be naturally susceptible even in their areas of origin. Nematodes that have been recorded as pathogenic to palms in their areas of origin are only those that exist in the rhizosphere such as *R. similis* of arecanut and coconut. This problem has not yet been recognized in the New World, but it is very possible that this and other nematode root problems on palms will become apparent in the years ahead. There is a danger of root nematodes, particularly *R. similis* and *R. reniformis*, being introduced through ornamental palms and other hosts.

The major concern of nematologists, plant pathologists and quarantine personnel, therefore, is to ensure against the possibility of red ring disease becoming universal since the likelihood that other species of the palm weevil (e.g. other *Rhynchophorus* spp.) could be vectors to *B. cocophilus* is quite strong. The palms of horticultural value are also susceptible and could in fact increase the likelihood of the disease eventually moving out of Latin America in a palm where symptoms are not so distinct and in which pathogenesis is prolonged. Indeed, there is every probability that symptomless carriers might exist, as in oil palms, that are slowly colonized by the nematode. Another problem occurs with the confusion of similar symptoms in other wilt diseases of palms that can hide the problem of a nematode until it is too late.

The International Bureau of Plant Genetic Resources has been helping in a number of coconut and other palm germplasm collection programmes, and some methods have been developed such as embryo rescue for introduction of clean coconut germplasm for research purposes. Koshy and Kumaran (1997) collected 1342 embryos of 15 accessions from the Indian Ocean islands for the first time. The commercial availability of synthetic male-produced aggregation pheromones for the weevils that can vector red ring nematode allows for monitoring ports of entry for potential vectors.

Generally, as crop plants for small farmers, cordon sanitaires are always necessary for vector-borne pathogens that can have fatal and cumulative effects on the agroecosystems. Thus, control measures for palm diseases must always be inexpensive, effective and readily applicable in all economic circumstances. Essentially, of course, biological control measures and resistant cultivars should always be sought. The stability of the coconut agroecosystem favours management procedures with limited pesticide usage.

References

Abdulsalam, K.S., Abdel-Megeed, M.I., Rezk, M.A., Nageeb, M.A. and Tameem, M. (1996) Efficiency of certain nematicides against nematodes associated with Wijamed date palm trees. *Annals of Agricultural Science Cairo* 41, 475–482.

Aboud, H.M., Said, S.A. and Saleh, H.M. (2002) Role of *Meloidogyne javanica* in predisposing two date palm cultivars to infection by *Thielaviopsis paradoxa*. *Pakistan Journal of Nematology* 20, 49–53.

Al-Yahya, F.A., Ibrahim, A.A.M. and El-Sherbiny, A.A. (2001) Frequency and population density of plant parasitic nematodes associating with date palm cultivars in Riyadh, Saudi Arabia. *Alexandria Journal of Agricultural Research* 46, 127–137.

Anonymous (1974) *Annual Report 1973*. Central Plantation Crops Research Institute, Kasaragod, Kerala, India.

Araujo, J.C.A., Araujo, A.E. and Santos, A.F. (1998) Population dynamics of *Rhynchophorus palmarum* and its association with *Bursaphelenchus cocophilus* on oil palm in the state of Amazonas, Brazil. *Fitopatologia-Brasileira* 23, 23–26.

Ashby, S.P. (1921) Some recent observations on red ring disease. *Agricultural News (Bridgetown)* 20, 350–351.

Banu, J.G. and Sosamma, V.K. (1999) Tapioca pearl as a substitute for agar in culturing *Radopholus similis* on carrot discs. *Indian Journal of Nematology* 29, 98–99.

Banu, J., Sosamma, V.K. and Koshy, P.K. (1998) Natural occurrence of an entomopathogenic nematode, *Heterorhabditis indicus* (Poinar, Karunakar and David) from Kerala, India. *Proceedings of the Third International Symposium of AFRO ASIAN Society of Nematologists (TISAAN) Nematology – Challenges and Opportunities in 21st Century*. Sugarcane Breeding Institute, Coimbatore, 16–19 April 1998, pp. 274–280.

Barrett, O.W. (1906) Notes upon miscellaneous crops. *Proceedings of Agricultural Society of Trinidad* 7, 303.

Baujard, P. (1989) Remarques sur les genres des sous-familles Bursaphelenchina Paramonov, 1964 et Rhadinaphelenchinae Paramonov, 1964 (Nematoda: Aphelenchoididae). *Revue de Nématologie* 12, 323–324.

Blair, G.P. (1964) Red ring disease of the coconut palm. *Journal of Agricultural Society of Trinidad and Tobago* 64, 31–49.

Buhrer, E.M., Cooper, C. and Steiner, G. (1933) A list of plants attacked by the root knot nematode (*Heterodera marioni*). *Plant Disease Reporter* 17, 64–96.

Bulgarelli, J., Chinchilla, C.M. and Oehlschlager, A.C. (1998) The red ring/little leaf syndrome and *Metamasius hemipterus* captures in oil palm in Costa Rica. *ASD Oil Palm Papers* 18, 17–24.

Carpenter, J.B. (1964) Root knot nematode damage to date palm seedlings in relation to germination and stage of development. *Date Growers Institute Report* 41, 10–14.

Chinchilla, C.M., Oehlschlager, A.C. and Gonzalez, L.M. (1992) Use of pheromone-based traps for the management of the American palm weevil, *Rhynchophorus palmarum*, in a commercial oil palm plantation. *Proceedings of the International Oil Palm Congress*. Palm Oil Research Institute of Malaysia, Kuala Lumpur, Malaysia.

Chittenden, F.H. (1902) The palm and palmetto weevils. *US Department of Agriculture Entomology Bulletin* 38, 23–28.

Cobb, N.A. (1919) A newly discovered nematode *Aphelenchus cocophilus* n.sp. connected with a serious disease of the coconut palm. *West Indian Bulletin* 17, 203–210.

Dasgupta, N.K. and Rama, K. (1987) Plant parasitic nematode associated with plantation crops. *Review of Tropical Plant Pathology* 4, 289–304.

Dean, C.G. (1979) *Red Ring Disease of* Cocos nucifera *L. Caused by* Rhadinaphelenchus cocophilus *(Cobb, 1919) Goodey, 1960. An Annotated Bibliography and Review*. Technical Communication No. 47, Commonwealth Institute of Helminthology, St Albans, UK.

Delgado, H.V. and Moreno, F.O. (1986) Evaluacion de atrayentes vegetales y un sistema de trampa para la captura de aldultos de ‘gualpa’ (*Rhynchophorus palmarum*) insecto-plaga de palma Africana y cocotero. Instituto Nacional de Investigaciones Agropecuarias, Estacion Experimental Santo Domingo, Ecuador, September, *Boletín Técnico* No. 63, 1–10.

Edongali, E.A. (1996) Diseases of date palms (*Phoenix dactylifera* L.) of Libya. *Arab Journal of Plant-Protection* 14, 41–43.

Edongali, E.A. and Dabaj, K.H. (1986) Nematodes associated with date-palms (*Phoenix dactylifera* L.) in some regions of Libya. *Proceedings of the 2nd Symposium of the Date Palm*, Saudi Arabia.

Eissa, M.F.M., El-Sherief, M.A., Abdel-Gawad, M.M., Ismail, A.E. and El-Nagdi, W.M.A. (1998) Histological response of susceptible and resistant date-palm cultivars to *Meloidogyne incognita* infection. *Pakistan Journal of Nematology* 16, 103–109.

Ekanayake, U.B.M. (1964) Annual report of the crop protection officer, Coconut Research Institute for 1963. *Ceylon Coconut Quarterly* 15, 50–57.

FAO (2000) Agriculture: towards 2015/30. Technical Interim Report, April 2000. Available at:

www.fao.org/es/esdat2015/toc-e.htm
Fenwick, D.W. and Maharaj, S. (1963) Recovery of *Rhadinaphelenchus cocophilus* (Cobb, 1919) Goodey, 1960 from coconut tissues. *Journal of Helminthology* 37,11–14.
Fourgani, G.M. and Edongali, E.A. (1989) Speciation of root-knot nematodes (*Meloidogyne* spp.) associated with crop plants in Libya. *International Nematology Network Newsletter* 6 (1), 38–39.
Geetha, S.M. (1991) Studies on the biology, pathogenicity and bio control of different populations of *Radopholus similis*. PhD Thesis, Kerala University, Kerala, India.
Gerber, K. and Giblin-Davis, R.M. (1990a) Association of the red ring nematode, *Rhadinaphelenchus cocophilus*, and other nematode species with *Rhynchophorus palmarum* (Coleoptera: Curculionidae). *Journal of Nematology* 22, 143–149.
Gerber, K. and Giblin-Davis, R.M. (1990b) *Teratorhabditis palmarum* n.sp. (Nemata: Rhabditidae), an associate of *Rhynchophorus palmarum* and *R. cruentatus* (Coleoptera: Curculionidae). *Journal of Nematology* 22, 337–347.
Gerber, K., Giblin-Davis, R.M. and Escobar-Goyes, J. (1990) Association of the red ring nematode, *Rhadinaphelenchus cococophilus*, with weevils from Ecuador and Trinidad. *Nematropica* 20, 39–49.
Giblin-Davis, R.M. (1993) Interactions of nematodes with insects. In: Khan, M.W. (ed.) *Nematode Interactions*. Chapman and Hall, London, pp. 302–344.
Giblin-Davis, R.M. (2001) Borers of palms. In: Howard, F.W., Moore, D., Giblin-Davis, R.M. and Abad, R. (eds) *Insects on Palms*. CAB International, Wallingford, UK, pp. 267–305.
Giblin-Davis, R.M. (2004) Nematodes as mutualists: where and how did these associations evolve? In: Cook, R. and Hunt, D.J. (eds) *Proceedings of the Fourth International Congress of Nematology*, 8–13 June 2002, Tenerife, Spain. *Nematology Monographs and Perspectives* 2 (in press).
Giblin-Davis, R.M., Gerber, K. and Griffith, R. (1989a) *In vivo* and *in vitro* culture of the red ring nematode, *Rhadinaphelenchus cocophilus*. *Nematropica* 19, 135–142.
Giblin-Davis, R.M., Mundo-Ocampo, M., Baldwin, J.G., Gerber, K. and Griffith, R. (1989b) Observations on the morphology of the red ring nematode, *Rhadinaphelenchus cocophilus*. *Revue de Nématologie* 12, 285–292.
Giblin-Davis, R.M., Oehlschlager, A.C., Perez, A., Gries, G., Gries, R., Weissling, T.J., Chinchilla, C.M., Peña, J.E., Hallett, R.H., Pierce, H.D. and Gonzalez, L.M. (1996) Chemical and behavioral ecology of palm weevils (Curculionidae: Rhynchophorinae). *Florida Entomologist* 77, 247–255.
Giblin-Davis, R.M., Gries, R., Gries, G., Peña, E., Pinzon, I., Peña, J.E., Perez, A.L., Pierce, H.D. Jr and Oehlschlager, A.C. (1997) Aggregation pheromone of palm weevil *Dynamis borassi*. *Journal of Chemical Ecology* 23, 2287–2297.
Goodey, J.B. (1960) *Rhadinaphelenchus cocophilus* (Cobb, 1919) n. comb., the nematode associated with 'red-ring' disease of coconut. *Nematologica* 5, 98–102.
Goodey, T. (1933) *Plant Parasitic Nematodes and the Diseases They Cause*. E.P. Dutton and Co. Inc., New York.
Govindankutty, M.P. and Koshy, P.K. (1979) Nematodes associated with the coconut palm (*Cocos nucifera* L.) In: *Technical Bulletin 2 – Nematodes, Fungi, Insects and Mites Associated with the Coconut Palm.* Central Plantation Crops Research Institute, Kasaragod, India, pp. 1–50.
Griffith, R. (1968a) The relationship between the red ring nematode and the palm weevil. *Journal of Agricultural Society of Trinidad and Tobago* 68, 342–356.
Griffith, R. (1968b) The mechanism of transmission of red ring nematode. *Journal of Agricultural Society of Trinidad and Tobago* 68, 437–457.
Griffith, R. (1969) A method of controlling red ring disease in coconuts. *Journal of Agricultural Society of Trinidad and Tobago* 69, 827–845.
Griffith, R. (1971) Red ring disease: the mechanism of spread and recommendations for control. *Nematropica* 1, 2.
Habeebullah, A., Reghupathy, A., Rethinam, P. and Koshy, P.K. (1983) Residues of aldicarb in coconut. *Seminar on Pesticides and Environment*, 4–5 August 1983, Coimbatore, Tamil Nadu, India, 21 (abstract).
Hagley, E. (1963) The role of the palm weevil *Rhynchophorus palmarum* L. as vector of red ring disease in coconut. 1. Result of preliminary observations. *Journal of Economic Entomology* 56, 375–380.
Hart, J.H. (1905) Coconut disease. *Bulletin of Miscellaneous Information*, *Royal Botanic Gardens, Trinidad* 6, 241–243.
Hashim, A. (1997) Date palm diseases in the United Arab Emirates. *Arab and Near East Plant Protection Newsletter* 25, 29.

Holdeman, Q.L. (1986) *The Burrowing Nematode,* Radopholus similis, sensu lato. Division of Plant Industry. California Department of Food and Agriculture and the Agriculture Commissioners of California.

Hunt, D.J. (1993) *Aphelenchida, Longidoridae and Trichodoridae: Their Systematics and Bionomics*. CAB International, Wallingford, UK.

Inserra, R.N., Dunn, R.A. and Vovlas, N. (1994) Host response of ornamental palms to *Rotylenchulus reniformis. Supplement to the Journal of Nematology* 26, 737–743.

Ismail, A.E. and Eissa, M.F.M. (1993) Plant parasitic nematodes associated with ornamental palms in three botanic gardens in Egypt. *Pakistan Journal of Nematology* 11, 53–59.

Jasy, T. (1991) Host specificity, pathogenicity and morphological variations in the populations of burrowing nematode infesting plantation crops. PhD Thesis, Kerala University, Kerala, India.

Jensen, H.J. (1961) The nematode menace. *American Nursery-man* 114, 7–8, 105–113.

Khan, A., Bilqees, F.M., Samad, M.A., Khatoon, N. and Rizwana, A.G. (2002) Histopathology of date palm roots infected with *Pratylenchus penetrans* root-lesion nematode. *Pakistan Journal of Nematology* 20, 35–39.

Koshy, P.K. (1986) The burrowing nematode *Radopholus similis* (Cobb, 1893) Thorne, 1949. In: Swarup, G. and Dasgupta, D.R. (eds) *Plant Parasitic Nematodes of India – Problems and Progress*. IARI, New Delhi, India, pp. 223–248.

Koshy, P.K. (1998) *Biological Control of Burrowing Nematode on Palms and Black Pepper*. Final Technical Report. USIF Project No. 1 N-AES-779 C.P.C.R.I., Kayangulam, Kerala, India.

Koshy, P.K. (2000) Leaf rot disease of coconut. *Indian Coconut Journal* 31 (2), 4–10.

Koshy P.K. (2002) Dr. G.I. D'Souza memorial lecture on nematode diseases of plantation crops. *Indian Journal of Nematology* 32, 107–117.

Koshy, P.K. and Banu, J.G. (2002) Nematode diversity in plantation crops – the world scenario. In: Jairajpuri, M.S. (ed.) *Nematode Diversity*. Silverline Printers, pp. 390–425.

Koshy, P.K. and Kumaran, P.M. (1997) *Survey and Collection of Coconut Germplasm from Indian Ocean Islands*. Deputation report. Central Plantation Crops Research Institute, Kasaragod, Kerala, India.

Koshy, P.K. and Nair, C.P.R. (1979) Control of *Radopholus similis* (Cobb 1893) Thorne, 1949 in coconut nursery. *Indian Journal of Nematology* 9, 15–19.

Koshy, P.K. and Sosamma, V.K. (1975) Host range of the burrowing nematode, *Radopholus similis* (Cobb, 1893) Thorne, 1949. *Indian Journal of Nematology* 5, 255–257.

Koshy, P.K. and Sosamma, V.K. (1977) Identification of the physiological race of *Radopholus similis* populations infesting coconut, arecanut and banana in Kerala, South India. *Indian Phytopathology* 30, 415–416.

Koshy, P.K. and Sosamma, V.K. (1978a) Studies on the population fluctuations of *Radopholus similis* in coconut and areca roots. *Indian Phytopathology* 31, 180–183.

Koshy, P.K. and Sosamma, V.K. (1978b) Susceptibility of coconut plumule to *Radopholus similis* (Cobb, 1893) Thorne, 1949. *Indian Journal of Nematology* 8, 77–78.

Koshy, P.K. and Sosamma, V.K. (1979) Control of the burrowing nematode *Radopholus similis* on coconut seedlings with DBCP. *Indian Journal of Nematology* 7, 32–33.

Koshy, P.K. and Sosamma, V.K. (1980) Culturing of burrowing nematode, *Radopholus similis* on carrot discs. *Indian Journal of Nematology* 10, 247–249.

Koshy, P.K. and Sosamma, V.K. (1982a) A simple method for inoculation and production of symptoms by *Radopholus similis* on coconut. *Indian Journal of Nematology* 12, 200–203.

Koshy, P.K. and Sosamma, V.K. (1982b) Culturing of *Radopholus similis* within mesocarp of coconut. *Plant Disease* 66, 811.

Koshy, P.K. and Sosamma, V.K. (1983) Pathogenicity of *Radopholus similis* on *Areca catechu*. *Indian Phytopathology* 36, 469–472.

Koshy, P.K. and Sosamma, V.K. (1987) Pathogenicity of *Radopholus similis* on coconut (*Cocos nucifera* L.) seedlings under green house and field conditions. *Indian Journal of Nematology* 17, 108–118.

Koshy, P.K. and Sosamma, V.K. (1994) Effect of *Radopholus similis* on growth, flowering and yield of coconut. In: *International Symposium on Plantation Crops (PLACROSYM XI)*. 30 November–December 1994. NRC for SPICES, Calicut, Kerala, pp. 20–23.

Koshy, P.K. and Sosamma, V.K. (1996) Effect of *Radopholus similis* on growth, flowering and yield of coconut. *Journal of Plantation Crops* 24 (Supplement), 157–165.

Koshy, P.K. and Sosamma, V.K. (2001) Nematode diseases of plantation crops and their management. Paper presented in National Congress on Centenary of Nematology in India. Appraisal and Future Plans, 5–7 December 2001, IARI, New Delhi, pp. 48–49 (abstract).

Koshy, P.K., Sosamma, V.K. and Nair, C.P.R. (1975) Preliminary studies on *Radopholus similis* (Cobb, 1893) Thorne, 1949 infesting coconut and arecanut palms in South India. *Indian Journal of Nematology* 5, 26–35.

Koshy, P.K., Sosamma, V.K. and Sundararaju, P. (1976) Yellow leaf disease: nematological studies. *Arecanut and Spices Bulletin* 8, 37–41.

Koshy, P.K., Sundararaju, P. and Sosamma, V.K. (1978) Occurrence and distribution of *Radopholus similis* (Cobb, 1893) Thorne, 1949 in South India. *Indian Journal of Nematology* 8, 49–58.

Koshy, P.K., Sosamma, V.K. and Sundararaju, P. (1979) Reactions of thirty one *Areca* germplasm collections to the burrowing nematode *Radopholus similis*. *Plant Disease Reporter* 63, 433–435.

Koshy, P.K., Raski, D.J. and Sosamma, V.K. (1981) *Brachydorus swarupi* sp. n. (Nemata Dolichodorinae) from soil about roots of arecanut palms in Kerala state. *Indian Journal of Nematology* 13, 401–404.

Koshy, P.K., Sundararaju, P., Sosamma, V.K. and Ravikumar, K. (1985) Efficacy of four systemic nematicides against *Radopholus similis* in coconut nursery. *Indian Journal of Nematology* 15, 148–151.

Koshy, P.K., Sosamma, V.K. and Sundararaju, P. (1991a) Nematode management in coconut and coconut based cropping system. *Proceedings International Symposium on Coconut Research and Development – II*. Kasaragod, Kerala, India, 26–29 November 1991.

Koshy, P.K., Sosamma, V.K. and Sundararaju, P. (1991b) *Radopholus similis*, the burrowing nematode of coconut. *Journal of Plantation Crops* 19, 139–152.

Koshy, P.K., Sosamma, V.K. and Samuel, R. (1998a) Interactive effect of Vesicular Arbuscular Mycorrhizae (VAM) with *Radopholus similis* on coconut seedlings. *Proceedings of the Third International Symposium of AFRO ASIAN Society of Nematologists (TISAAN) Nematology – Challenges and Opportunities in 21st Century*. Sugarcane Breeding Institute, Coimbatore, April 16–19 1998, pp. 106–110.

Koshy, P.K., Sosamma, V.K. and Samuel, R. (1998b) Standardisation of sampling zone and type of root for arbuscular mycorrhizal fungal estimation on coconut. *PLACROSYM XIII UPASI*. Tea Research Institute, Valapari, 16–18 December, pp. 53–54 (abstract).

Koshy, P.K., Sosamma, V.K., Samuel, R., Lekhakumari, P.R. and Bindu, S.M. (1998c) Effect of biocontrol agents and organic amendments on *Radopholus similis* infecting arecanut. *Proceedings National Symposium on Rational Approaches in Nematode Management for Sustainable Agriculture*, 23–25 November 1998, GAU, Anand, p. 24.

Koshy, P.K., Sosamma, V.K. and Banu, J.G. (2002a) *Milestones of Nematological Research in Kerala*. Seminar on Centenary on Nematological Research in Kerala, 21–22 February 2002, CPCRI, Kayangulam, Kerala, India.

Koshy, P.K., Sosamma, V.K. and Samuel, R. (2002b) Management of *Radopholus similis* infesting arecanut using bio-control agents. *Proceedings National Symposium on Crop Protection and WTO – Indian Perspective*. 22–25 January 2002, CPCRI, Kasaragod, Kerala, India.

Koshy, P.K., Kumar, Y., Jayasree, D., Joseph, U. and Sosamma, V.K. (2002c) Integrated management of leaf rot disease and insect pests on coconut. *Indian Phytopathology* 55, 45–50.

Kumar, A.C., Viswanathan, P.R.K. and D'Souza, G.I. (1971) A study of plant parasitic nematodes of certain commercial crops in coffee tracts of South India. *Indian Coffee* 35, 222–224.

Lal, A. and Mathur, V.K. (1986) Nematodes in the rhizosphere of date palm with description of *Longidoroides bikanerensis* sp.n. (Nematoda: Dorylaimoidea). *Date Palm Journal* 5, 208–214.

Lamberti, F., Greco, N. and Zaouchi, H. (1975) A nematological survey of date palms and other major crops in Algeria. *FAO Plant Protection Bulletin* 23, 156–160.

Latta, R. (1966) Attempts to relate nematodes to lethal yellowing disease of coconut palms in Jamaica. *Tropical Agriculture Trinidad* 43, 59–68.

MacGowan, J.B. (1989) Bureau of nematology: nematode detections of special interest. *Triology Technical Bulletin* 28 (9), 1–3.

Malaguti, G. (1953) 'Pudricion de Cogollo' de la palmera do aceite Africana (*Elaeis guineensis* Jacq.) en Venezuela. *Agronomia Tropical* 3, 13–21.

Maqbool, M.A. (1991) *Nematode Pests of Economic Significance Affecting Major Crops of the Countries in Asia and the Pacific Region*. Technical Document, Asia and Pacific Plant Protection Commission No. 140.

Martyn, E.B. (1953) Red ring disease of coconuts in Trinidad and Tobago. *Tropical Agriculture* 32, 45–53.

Mariau, D. (1968) Methodes de lutte contre le Rhynchophore. *Oleagineux* 23, 443–446.

McSorley, R. and Dunn, R.A. (1989) Effects of root-knot nematodes on *Areca catechu*. *Supplement to the Journal of Nematology* 21, 717–719.

Micoletzky, H. (1922) Die freilebenden erd-Nematoden mit besonderer Berucksichtigung der Steiermark und der Bukowina, zugleich mit einer Revision sämtlicher nicht mariner, freilebender Nematoden in Form von Genus – Beschreibunger und Bestimmungsschlüsseln. *Archiv für Naturgeschichte, Berlin* 87, 1–650.

Minz, G. (1958) Two *Diplodia* species in date palms. *Ktavim* 8, 213–216.

Mora, T.L.S., Calvache, G.H. and Avila, P.M. (1994) The spread of *Rhadinaphelenchus cocophilus* (Cobb) Goodey, causal agent of red ring-little leaf in oil palm. San Carlos de Guaroa (Meta). *Palmas* 15, 15–27.

Moura, J.I.L., Vilela, E.F., Brasil, G.H. and Cangucu, R. (2000) Mass trapping of *Rhynchophorus palmarum* using pheromone in coconut plantation in Brazil. *Proceedings XXI International Congress of Entomology*. Abstract 610. Book 1. Foz do Iguassa, Brazil, p. 154.

Nair, R.B. (1964) Nematodes from arecanut soils. *Arecanut Journal* 15, 87–88.

Netscher, C. and Luc, M. (1974) Nématodes associés aux cultures maraîchéres en Mauritanie. *L'Agronomie Tropicale, Nogent* 29, 697–701.

Nadakkal, A.M. (1965) A note on the occurrence of nematodes on the leaves of coconut palms in Kerala. *Science and Culture* 31, 157–158.

Noriega, C.D.H., Becerra, L.N. and Hernandez, R.F. (1991) Coconut diseases in the Coast of Guerrero, Mexico. *Revista Mexicana de Fitopatologia* 9, 84–93.

Nowell, W. (1919) Red ring or root disease of coconut palms. *West Indian Bulletin* 17, 189–192.

Nowell, W. (1923) *Disease of Crop Plants of the Lesser Antilles*. The West Indian Committee, London.

Nowell, W. (1924) Red ring disease of coconuts. *Proceedings 9th West Indies Conference, Jamaica*, pp. 167–172.

Oehlschlager, A., Chinchilla, C. and Gonzalez, M. (1992a) Management of the American palm weevil *Rhynchophorus palmarum* and the red ring disease in oil palm by pheromone-based trapping. *ASD. Oil Palm Paper* 5, 15–23.

Oehlschlager, A.C., Pierce, H.D. Jr, Morgan, B., Wimalaratne, P.D.C., Slessor, K.N., King, G.G.S., Gries, G., Gries, R., Borden, J.H., Jiron, L.F., Chinchilla, C.M. and Mexzon, R. (1992b) Chirality and field testing rhynchophorol, the aggregation pheromone of the American palm weevil. *Naturwissenschaften* 79, 134–135.

Oehlschlager, A.C., Chinchilla, C.M., Gonzalez, L.M., Jiron, L.F., Mexzon, R. and Morgan, B. (1993) Development of a pheromone-based trap for the American palm weevil, *Rhynchophorus palmarum* (L.). *Journal of Economic Entomology* 86, 1381–1392.

Oehlschlager, A.C., McDonald, R.S., Chinchilla, C.M. and Patschke, S.N. (1995) Influence of a pheromone-based mass trapping system on the distribution of *Rhynchophorus palmarum* (Coleoptera: Curculionidae) in oil palm. *Environmental Entomology* 24, 1005–1012.

Oehlschlager, A.C., Chinchilla, C., Castillo, G., Bulgarelli, J. and Gonzalez, L.M. (2002) Control of red ring disease by mass trapping of *Rhynchophorus palmarum* (Coleoptera: Curculionidae). *Florida Entomologist* 85, 507–513.

Pérez, A.L., Campos-Piedra, Y., Chinchilla, C.M., Oehlschlager, A.C., Gries, G., Gries, R., Castrillo, G., Giblin-Davis, R.M., Peña, J.E., Duncan, R.E., Gonzalez, L.M., Pierce, H.D., McDonald, R. and Andrade, R. (1997) Aggregation pheromones and host kairomones of the West Indian sugarcane weevil, *Metamasius hemipterus sericeus* (Oliv.) (Coleoptera: Curculionidae). *Journal of Chemical Ecology* 22, 357–368.

Pizarro, A.C. (1969) Nematodes associated with roots of coconut and other palms. *Philippine Journal of Plant Industry* 34, 155–158.

Poucher, C., Ford, H.W., Suit, R.F. and Ducharme, E.P. (1967) *Burrowing Nematode in Citrus*. Bulletin No. 7. Division of Plant Industry, Florida Department of Agriculture.

Rama, K. (1987) Ecology of plant parasitic nematodes affecting some major perennial crops in West Bengal. PhD thesis, Visva Bharati.

Raski, D.J., Maggenti, A.R., Koshy, P.K. and Sosamma, V.K. (1980) *Epicharinema keralense* n.gen., n.sp. (Nemata: Tylenchidae) and comments on Atylenchinae and Echphyadophorinae. *Revue de Nématologie* 3, 297–304.

Reddy, D.B. (1978) Insect pests, diseases and nematodes of *Areca catechu* and betel vine (*Piper betle*) recorded in Asia and the Pacific. Technical Document No. 114. Plant Protection Committee for the South East Asia, Asia and Pacific Region. FAO, Bangkok.

Rochat, D., Malosse, C., Lettere, M., Ducrot, P.H., Zagatti, P., Renou, M. and Descoins, C. (1991) Male-produced aggregation pheromone of the American palm weevil, *Rhynchophorus palmarum*: collection, identification, electrophysiological activity and laboratory bioassay. *Journal of Chemical Ecology* 17, 2127–2141.

Rochat, D., Malosse, C., Lettere, M., Ramirez-Lucas, P., Einhorn, J. and Zagatti, P. (1993) Identification of new pheromone-related compounds from volatiles produced by males of four Rhynchophorinae weevils. *Comptes Rendus de l'Academie des Sciences, Paris, Serie II* 316, 1737–1742.

Rochat, D., Meillour, P.N., Estaban-Duran, J.R., Malosse, C., Perthuis, B., Morin, J.P. and Descoins, C. (2000) Identification of pheromone synergists in American palm weevil, *Rhynchophorus palmarum* and attraction of related *Dynamis borassi*. *Journal of Chemical Ecology* 26, 155–187.

Rorer, J.B. (1911) Diseases of the coconut palm. *Circular 4. Board of Agriculture, Trinidad*, 27–33.

Salazar, S., Mora, O. and Sosa, M. (1992) Diseases of oil palm in the Central West region of Venezuela. *FONAIAP Divulga* 9, 39–40.

Sanchez, P.A. and Cerda, H. (1993) *Bursaphelenchus cocophilus* (Cobb) (Tylenchida: Aphelenchoididae), en Palmeras. *Boletin de Entomologia Venezolana* 8, 1–18.

Schuiling, M. and Van Dinther, J.B.M. (1981) 'Red ring disease' in the Paricatuba oil palm estate, Para, Brazil. A case study. *Zeitschrift für Angewandte Entomologie* 91, 154–169.

Silva, H.M. (1991) *Metamasius* sp. (Coleoptera: Curculionidae) vector of *Rhadinaphelenchus cocophilus* causal agent of the oil palm red ring. *Pesquisa em Andamento Unidade de Execucao de Pesquisa de Ambito Estadual de Belem* No. 17.

Sosamma, V.K. (1984) Studies on the burrowing nematode of coconut. PhD thesis, Kerala University, Trivandrum, Kerala, India.

Sosamma, V.K. (1994) *Interactions Between Vesicular Arbuscular Mycorrhizae (VAM) and Burrowing Nematode on Coconut*. Final Report ICAR AP Cess Fund Scheme 1988–93. CPCRI, Kayangulam, Krishnapuram, Kerala, India.

Sosamma, V.K. (1996) Integrated nematode management – principles and practices. In: *Recent Advances in Integrated Management of Pests and Diseases of Coconut*. CPCRI, Kayangulam, pp. 215–221.

Sosamma, V.K. (1998) Nematode parasites of palms. Paper presented in the group meeting of nematologists working on horticultural crops. 16–18 January 1998, CPCRI, Kayangulam.

Sosamma, V.K. (1999) Occurrence of *Pasteuria* sp. a hyperparasite of *Radopholus similis* and *Heterodera oryzicola* from Kerala. *Annual Meeting and Symposium on Plant Disease Management for Sustainable Agriculture*. 14–16 December 1999, CPCRI, Kayangulam, p. 5 (abstract).

Sosamma, V.K. (2000a) Report of *Catenaria vermicola* from *Radopholus similis* in Kerala. Paper presented in the National Symposium organised by IPS at Directorate of Wheat Research, Agarsain Marg, Karnal, Haryana, p. 153 (abstract).

Sosamma, V.K. (2000b) Nematodes of palms. In: Trivedi, P.C. (ed) *Plant Diseases*. Pointer Publishers, Jaipur, Rajasthan, India, pp. 393–413.

Sosamma, V.K. (2000c) Nematodes associated with spindle leaves of leaf rot affected coconut palms. Paper presented at the National Nematology Symposium on Integrated Nematode Management for Sustainable Agriculture in Changing Agro-ecological and Economic Scenario in the New Millennium, 23–24 November 2000, OUAT, Bhubaneswar.

Sosamma, V.K. (2000d) Host range and specificity of two *Pasteuria* isolates from Kerala, India. Paper presented at the International Conference on Plantation Crops PLACROSYM XIV, 12–16 December 2000, Hyderabad.

Sosamma, V.K. (2002) Nematodes of coconut, arecanut and oil palm. Paper presented at the seminar on Centenary of Nematological Research, 21–22 February 2002, Kerala. CPCRI, Kayangulam, Kerala.

Sosamma, V.K. (2003) *Investigations of Entomophilic Nematodes Associated with Red Palm Weevil,* Rhychophorus ferrugineus *F and Rhinoceros Beetle,* Oryctus rhinoceros *L. on Coconut*. Final Report ICAR Cess Fund Scheme, CPCRI, Kayangulam.

Sosamma, V.K. and Banu, J.G. (1996) Entomophilic nematodes. In: *Recent Advances in Integrated Management of Pests and Diseases of Coconut*. CPCRI, Kayangulam, pp. 230–241.

Sosamma, V.K. and Koshy, P.K. (1977) Additional hosts of the burrowing nematode *Radopholus similis* infesting coconut palm in South India. *Plant Disease Reporter* 61, 760–761.

Sosamma, V.K. and Koshy, P.K. (1978) A note on the association of *Cylindrocarpon effusum* and *C. lucidum* with *Radopholus similis* in coconut. *Indian Phytopathology* 31, 381–382.

Sosamma, V.K. and Koshy, P.K. (1981) Other host records of *Radopholus similis*. *Indian Journal of Nematology* 11, 73–74.

Sosamma, V.K. and Koshy, P.K. (1983) A note on the occurrence of *Cylindrocladium clavatum* Hodges & May in lesions caused by *Radopholus similis* on coconut roots. *Current Science* 52, 438.

Sosamma, V.K. and Koshy, P.K. (1985) Effects of different types of soils on multiplication of *Radopholus similis* and growth of coconut seedlings. *Indian Journal of Nematology* 15, 217–222.

Sosamma, V.K. and Koshy, P.K. (1986) Survival of *Radopholus similis*. *National Conference – Plant Parasitic Nematodes of India – Problems and Progress*, 17–20 December 1986. IARI, New Delhi, India, p. 107.

Sosamma, V.K. and Koshy, P.K. (1991) Etiology – nematodes. *Coconut Root (Wilt) Disease Monograph Series No. 3*. CPCRI, Kasaragod, India.

Sosamma, V.K. and Koshy, P.K. (1998) Etiology – nematodes. In: Nampoothiri, K.U.K. and Koshy, P.K. (eds) *Coconut Root (Wilt) Disease*, revised edn. CPCRI, Kasaragod, pp. 21–27.

Sosamma, V.K. and Vasanthi, T. (2001) Effect of bio-control fungi *Trichoderma harzianum* and *T. viride* for the control of *Radopholus similes* on arecanut. Paper presented at the National Symposium on Ecofriendly Approaches for Plant Disease Management, 22–24 January 2001, CAS Botany, University of Madras, Guindy Campus, Chennai, India.

Sosamma, V.K., Koshy, P.K. and Bhaskara Rao, E.V.V. (1980) Susceptibility of coconut cultivars and hybrids to *Radopholus similis* in field. *Indian Journal of Nematology* 10, 250–252.

Sosamma, V.K., Koshy, P.K. and Bhaskara Rao, E.V.V. (1988) Response of coconut cultivars to the burrowing nematode, *Radopholus similis*. *Indian Journal of Nematology* 18, 136–137.

Sosamma, V.K., Koshy, P.K. and Samuel, R. (1998a) Effects of vesicular arbuscular mycorrhizae, *Glomus mosseae* on nematodes infesting banana under coconut based high density multi species cropping system. *Proceedings of the Third International Symposium of AFRO ASIAN Society of Nematologists (TISAAN) Nematology – Challenges and Opportunities in 21st Century*, Sugarcane Breeding Institute, Coimbatore, India, 16–19 April 1998, pp. 94–97.

Sosamma, V.K., Koshy, P.K., Samuel, R. and Bindu, S.M. (1998b) Interaction of arbuscular mycorrhizal fungi (AMF) isolated from healthy high yielding coconut palms with burrowing nematode, *Radopholus similis* on coconut. *Proceedings National Symposium on Rational Approaches in Nematode Management for Austainable Agriculture*, 23–25 November 1998, GAU, Anand, pp. 34–37.

Sosamma, V.K., Jaijo, M.J. and Rasmi, B. (2000) Occurrence of entomogenous nematodes and an entomopathogenic fungus *Metarhizium flavoviride* associated with Rhinoceros beetle, a pest of coconut. *Proceedings National Nematology Symposium on Integrated Nematode Management for Sustainable Agriculture in Changing Agro-ecoclogical and Economic Scenario in the New Millennium*, 23–24 November 2000, OUAT, Bhubaneswar.

Stockdale, F.A. (1906) Coconut palm disease. *Proceedings of the Agricultural Society of Trinidad and Tobago* 7, 9–31.

Subramaniyan, S., Lakshmanan, P.L. and Vadivelu, S. (1988) Plant parasitic nematodes associated with arecanut palm in Tamil Nadu. *South Indian Horticulture* 36, 89.

Sudha, S. and Sundararaju, P. (1998) Effect of neem oil cake and nematicides for the control of *Radopholus similis* in arecanut based cropping system. *Third International Symposium of Afro Asian Society of Nematologists*, Coimbatore, 16–19 April 1998.

Sundararaju, P. (1984) Studies on the burrowing nematode of arecanut. PhD thesis, Kerala University, Trivandum, Kerala, India.

Sundararaju, P. (2000) Etiology – nematodes. In: Nampoothiri, K.U.K., Ponnamma, K.N. and Chowdappa, P. (eds) *Arecanut Yellow Leaf Disease*. Technical Bulletin No. 39, CPCRI. Kasaragod, Kerala, India, pp. 11–17.

Sundararaju, P. and Koshy, P.K. (1982a) Distribution of phytoparasitic nematodes on arecanut in South India. *Proceedings of the Silver Jubilee Symposium on Arecanut Research and Development*, 12–14 December 1982, Vittal, South Kanara, Karnataka, India, pp. 143–146.

Sundararaju, P. and Koshy, P.K. (1982b) Response of *Areca* collections against *Radopholus similis*. *Indian Journal of Nematology* 12, 404–405.

Sundararaju, P. and Koshy, P.K. (1984) A note on the association of *Cylindrocarpon obtusisporum* on lesions caused by *Radopholus similis* on arecanut (*Areca catechu* L.) roots. *Indian Phytopathology* 37, 578.

Sundararaju, P. and Koshy, P.K. (1986a) Control of *Radopholus similis* on arecanut seedlings with aldicarb, aldicarb sulfone, carbofuran and fensulfothion. *Indian Journal of Nematology* 16, 4–7.

Sundararaju, P. and Koshy, P.K. (1986b) Effect of different nematicides and neem oil cake in the control of *Radopholus similis* in yellow leaf disease affected arecanut palms. *Indian Journal of Nematology* 16, 44–47.

Sundararaju, P. and Koshy, P.K. (1987) Separate and combined effects of *Radopholus similis* and *Cylindrocarpon obtusisporum* on arecanut seedlings. *Indian Journal of Nematology* 17, 302–305.

Sundararaju, P. and Ratnakaran, K. (2002) Factors influencing the prevalence of the root-lesion nematode, *Pratylenchus coffeae* on oil palm (*Elaeis guineensis* Jacq.). *Indian Journal of Nematology* 32, 16–19.

Sundararaju, P. and Sudha, S. (1998) Nematode management in arecanut and arecanut based farming system. *Proceedings of the Third International Symposium of Afro-Asian Society of Nematologists (TISAASN), Nematology: Challenges and Opportunities in 21st Century*. Sugarcane Breeding Institute (ICAR), Coimbatore, India, 16–19 April 1998, pp. 190–192.

Sundararaju, P., Sosamma, V.K. and Koshy, P.K. (1984) Additional host records of root knot nematode, *Meloidogyne incognita*. *Indian Journal of Nematology* 14, 183–184.

Sundararaju, P., Koshy, P.K., Banu, J.G., Rethnakaran, K. and Sosamma, V.K. (1995a) Plant parasitic nematodes associated with oil palm (*Elaeis guineensis* g.). Abstracts of papers presented in the National Symposium, *Nematode Problems of India – An appraisal of the Nematode Management with Eco-friendly Approaches and Bio-components*, 24–26 March 1995, IARI, New Delhi, India.

Sundararaju, P., Sosamma, V.K., Koshy, P.K., Rethinam, P., Sukumaran, S. and Suja, C.P. (1995b) Occurrence and distribution of *Radopholus similis* in coconut nurseries in South India. Abstracts of papers presented in the National Symposium, *Nematode Problems of India – An Appraisal of the Nematode Management with Eco-friendly Approaches and Bio-components*, 24–26 March 1995, IARI, New Delhi, India.

Troccoli, A., Lamberti, F. and Greco, N. (1992) *Pratylenchus* species occurring in Algeria (Nematoda, Pratylenchidae). *Nematologia Mediterranea* 20, 97–103.

Tsang, M.M.C., Hara, A.H. and Sipes, B. (2003) Hot-water treatments of potted palms to control the burrowing nematode, *Radopholus similis*. *Crop-Protection* 22, 589–593.

Van Hoof, H.A. and Seinhorst, W. (1962) *Rhadinaphelenchus cocophilus* associated with little leaf of coconut and oil palm. *Netherland Plant Pathology* 68, 251–256.

Van Weerdt, L.G., Birchfield, W.R. and Esser, R.P. (1959a) Observations on some subtropical plant parasitic nematodes in Florida. *Proceedings of the Soil Crop Science Society of Florida* 19, 443–451.

Van Weerdt, L.G., Martinez, A.P. and Esser, R.P. (1959b) Results of a survey designed to determine the etiology of lethal yellowing of *Cocos nucifera*. *Proceedings of the Florida State Horticultural Society* 72, 421–430.

Villanueva, A. and Gonzalez, A. (1988) Importancia ecónomica del Anillo Rojo en Palmerasde la Costa S.A. y medidas de control practicadas. *Palmeras de la Costa*.

Webster, B.N. and Gonzalez, J. (1959) Investigaciones sobre la enfermedad 'anillo rojo' en cocas y palma de aceite. *9th Convencion de la Asociacion Venezolana el Avance de la Ciencia*, Servicio Shell para el Agricultor, Estado Arajua, Venezuela.

Weischer, B. (1967) Report to the Government of India on plant parasitic nematodes. PL 24/52 *Report No TA 2332*, FAO, Rome.

Youssef, M.M.A. and Eissa, M.F.M. (1994) Population dynamics of certain nematodes associated with date-palm in Egypt. *Afro Asian Journal of Nematology* 4, 68–72.