HDC Project HNS 60:

A Review of the Biology and Control of Leaf and Bud Nematodes in Outdoor Ornamentals 1996

A Review of the Biology and Control of Bud and Leaf Nematodes in Outdoor Ornamentals

Final Report, 1996

HDC Project number:	**HNS 60**
Project leader:	**J E B Young** **ADAS Boxworth** **Boxworth** **Cambridge** **CB3 8NN** **Tel: 01954 267666** **Fax: 01954 267659** **E-mail: john_young@adas.co.uk**
Location of project:	**ADAS, Cambridge**
Project co-ordinator:	**Mr B E Humphrey** **Notcutts Nursery** **Woodbridge** **Suffolk** **IP12 4AF** **Tel: 01394 383344** **Fax: 01394 385460**
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Contract No: HNS 60

TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature..... Martin Heath ....

Position. ADAS ACCOUNT MANAGER FOR HDC

Date.................12/5/95..............

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Position..........CHIEF EXECUTIVE..........

Date..........24.4.94..........

1. SUMMARY

In the UK, the two main species of bud and leaf nematodes (eelworms) are *Aphelenchoides ritzemabosi* and *Aphelenchoides fragariae*. *A. ritzemabosi* is often referred to as the chrysanthemum nematode and *A. fragariae* as the leaf nematode. Bud and leaf nematodes are virtually invisible to the naked eye, their body length being in the range of 0.4 mm to 1.2 mm. The nematodes feed and reproduce in leaves or buds. Leaf tissue is invaded by nematodes entering via the stomata (leaf pores). Alternatively, the nematodes may feed externally between the layers of tightly folded bud tissue. The life cycle from egg to adult is completed in the plant in about 10 to 15 days, depending on temperature. The nematodes injure the plant by puncturing and sucking the contents of plant cells with their mouth spears. Symptoms of attack are visible typically as discoloured angular blotches on the leaves. Bud feeding damage can also cause stunting and distortion of leaves or flowers. Infested plants become unsaleable owing to varying degrees of leaf blotching, distortion or scarring. Bud and leaf nematodes have a large and varied host range, over 400 species of flowering plants from diverse families are listed. *A. fragariae* also attacks many species of fern.

Bud and leaf nematodes are dependent on water for survival and spread. The nematodes spread between buds, leaves or plants with an eel-like swimming motion in drops or films of water. Overhead irrigation systems or mist-propagation systems provide ideal conditions for the nematodes. Growing plants in dry conditions and spacing plants to avoid leaf contact between them can reduce the spread of infestation. Leaf and bud nematodes cannot survive away from a host plant for long periods. The most important means of transmission is through survival of the pest in the plant propagation chain and the subsequent use of infested propagating material. *A. ritzemabosi* can survive in a desiccated condition in dry plant debris for several years, highlighting the need for high standards of hygiene. In the soil, the nematodes are unlikely to survive for more than four months in the absence of a host plant. However, many common species of weed are attacked, which enables a longer term survival of the pest when infested weeds persist on used or disused ground.

A postal survey of outdoor ornamental nurseries indicated that leaf and bud nematode is a common and widespread problem in outdoor ornamentals. Of 138 respondents, 47 (34%) had at some time experienced bud and leaf nematode. Furthermore, 25% of respondents stated that bud and leaf nematode was currently active on their nursery. In 84% of cases, infestations were active for three or more years. The pest was frequently found in mother plants; 29% of respondents stated that the nematode was present in plants used for propagation purposes.

These findings confirm the difficulty of eradicating bud and leaf nematode, especially when propagation chains become infested. Plants species reported in the survey to be most frequently affected by bud and leaf nematode included *Anemone*, *Aster*, *Buddleia*, *Chrysanthemum*, *Hydrangea*, *Lamium*, *Philadelphus*, *Phlox*, *Ribes*, *Viburnum* and *Weigelia*. The most popular control measure was the use of Temik, followed by rogueing of infested plants and hygiene precautions. The control measures used were deemed to be only partially successful, with acceptable suppression being obtained in 65% of cases. 14% of respondents claimed their control to be poor or unacceptable.

The economic impact of bud and leaf nematode is potentially serious. In total, 76% of respondents stated that the pest hindered or prevented the sale of plants. Annual economic losses were estimated to be up to £5000 on 87% of participating nurseries and in excess of £10,000 in 4% of cases.

A range of control measures are discussed. Cultural hygiene is essential to ensure that the pest will not survive in the plant propagation cycle or re-infest clean plants. Hot-water treatment or tissue culture may be used to obtain pest-free mother plants. Chemical control, in the form of aldicarb (Temik) can be applied to suppress infestations and to prevent the appearance of symptoms. However, eradication of the pest is difficult to achieve with chemical alone when mother plants are infested. Control strategies to obtain long-term freedom from the pest should integrate all available forms of control, giving priority to obtaining healthy propagating material.

Greater emphasis should be placed on eradicating bud and leaf nematode from the plant propagation cycle by producing and maintaining pest-free mother plants. More use could be made of hot-water treatment or tissue culture techniques to achieve this objective. A series of recommendations are made for new research aimed at reducing the economic losses caused by bud and leaf nematode. They include: investigation of the use of avermectins to control bud and leaf nematode, improvement of hot water treatment techniques, screening of potentially useful bio-control agents, development of techniques to exclude nematodes from tissue culture and investigation of the varietal susceptibility of host plants.

2. INTRODUCTION

Nematodes are a large and diverse group of invertebrates which have colonised a wide range of environments. They are small, unsegmented, threadlike worms (nema – Greek for thread). A large number of nematode species are adapted as plant parasites and can damage cultivated plants. Some species also transmit plant virus diseases. About 5000 species of plant and soil nematodes are known and of these nearly 2000 belong to genera that harm plants (Hooper, 1978). Adults of plant and soil nematodes range from 0.2 mm to 1.5 mm long but most are in the 0.5 mm to 1.5 mm range and are difficult to observe without the aid of a microscope. One infested leaf is capable of harbouring several thousand individual nematodes. When viewed with a microscope, plant parasitic nematodes appear translucent and colourless and propel themselves through water, or water films, with an eel-like swimming motion, hence giving nematodes their alternative name – eelworms.

The bud and leaf nematodes belong to the genera *Aphelenchoides*. In the UK, the two main species of bud and leaf nematodes are: *Aphelenchoides ritzemabosi* (Schwartz) and *Aphelenchoides fragariae* (Ritzema Bos). The following review is confined solely to these two species and reference to bud and leaf nematodes in the following text refers collectively to both species. Other common names have been applied to the individual species: *A. ritzemabosi* is often named as the chrysanthemum nematode, and *A. fragariae* as the leaf nematode. *A. ritzemabosi* is well known to chrysanthemum growers as a serious threat to their crop, and much of our knowledge of this pest has been gained from chrysanthemum-based research. In contrast, *A. fragariae* is an acknowledged pest of strawberries, where it has also been implicated with 'spring dwarf' or 'spring crimp' disease.

Other pest species of *Aphelenchoides* indigenous to the UK include *A. blastopthorous*, the scabious bud nematode; *A. subtenuis*, an uncommon pest of narcissus and other bulbous plants; and *A. composticola*, a mushroom pest. Other noteworthy related species of major importance in warmer climates include the rice white-tip nematode (*A. besseyi*), the red ring nematode (*Rhadinaphelenchus cocophilus*) which causes red ring disease of coconut, and the pine wilt nematode (*Bursaphelenchus xylophilus*). The latter two species are carried and spread by insects. Fortunately for UK growers, the indigenous species of bud and leaf nematode are not spread by insects and they are not known to transmit harmful viruses.

Bud and leaf nematodes are well adapted to survival in outdoor ornamentals. Between them, both species have an enormous host range of wild and cultivated plants. Although neither species may survive for no more than a few months in moist soil without a living host plant, they can remain on contaminated ground by infesting many common species of weeds. Furthermore, *A. ritzemabosi* can withstand dry conditions in a dormant state and may remain viable for up to three years in their desiccated form. This mechanism permits survival of hostile conditions and can also allow spread by wind in dried-up plant debris, although in practice this is not considered to be an important source of infestation.

Bud and leaf nematodes are able to survive unchecked in the propagation cycle of many ornamental species. They are passed on in the leaves or buds of mother plants. The warm, humid propagation environment, often incorporating water misting or overhead irrigation, provides ideal conditions for the waterborne spread of the nematodes between plants. Symptoms of attack may go unnoticed for some time in young, vigorously growing, plants and may only become manifest when growth slows in cooler autumn or winter conditions.

The most common form of visible symptom caused by bud and leaf nematodes is the angular shaped leaf blotch. These blotches are caused by nematodes feeding within the leaf (endoparasitically) where their area of activity is restricted by the leaf veins. Alternatively, bud and leaf nematodes can feed externally (ectoparasitically) within the folded tissues of leaf or flower buds. This type of feeding results in distorted leaves or petals.

In recent years, bud and leaf nematodes have gained attention in outdoor ornamentals as their incidence appears to have increased. Infested plants become unsaleable owing to varying degrees of leaf blotching, distortion or scarring. More importantly, many growers find that bud and leaf nematodes are difficult to eradicate from the propagation cycle. The pests can be a continual threat to producing good quality plants once propagation lines become contaminated. Bud and leaf nematodes may linger for many years in infested stock and, when conditions allow, often re-appear after a period of apparently successful control measures.

This review aims to summarise for growers our existing knowledge of bud and leaf nematodes in relation to outdoor ornamentals in the UK. Life history, biology, host range and control measures are considered. Additionally, a grower survey has been done to establish the true extent and severity of bud and leaf nematodes in outdoor ornamentals. Strategies for controlling the pests are discussed and recommendations are made for future research of benefit to the horticultural industry.

3. LIFE HISTORY AND BIOLOGY

The bud and leaf nematodes have relatively simple life cycles (Fig. 1). Although both *A. ritzemabosi* and *A. fragariae* have been shown to be capable of feeding and reproducing on fungi (see below), both species are considered incapable of surviving long periods in a free-living state in the absence of host plants under natural conditions. Normally, the nematodes enter the leaves via the stomata (leaf pores) or feed externally by lodging themselves between tightly folded tissues within buds. The life cycle is completed within the leaf tissue where the nematodes feed and reproduce. Mating takes place here and eggs are laid in the spaces between plant cells. The life cycle from egg to adult nematode may be completed in about 10 to 15 days, depending on temperature (Siddiqi, 1974 & 1975). In keeping with many other pests, bud and leaf nematodes possess the capacity for a huge increase in numbers over a short time once a suitable host has been invaded. The following section describes in more detail aspects of the life history and biology of bud and leaf nematodes, with particular reference to features that affect the spread, survival and subsequent control of the pest.

3.1 Physical characteristics

Bud and leaf nematodes are almost invisible to the naked eye. Under the microscope they are visible as threadlike 'worms' with a translucent, colourless, body (Fig. 2). Their size varies according to species, development stage and sex. Body length ranges from 0.4 mm to 1.2 mm. At the anterior (head) end, there is a hollow, protrusable, mouth spear or stylet which is used to puncture plant cells during feeding. The stylet leads to a muscular oesophagus and then to a simple intestine. The gut is a simple tube running from the oesophagus to the rectum, exiting at the anus. The rest of the body comprises primarily of a muscular body wall, reproductive organs, digestive glands and nervous system. The body is unsegmented although the cuticle is annulated, giving the appearance of a series of thin, regular, circular ridges encircling the body.

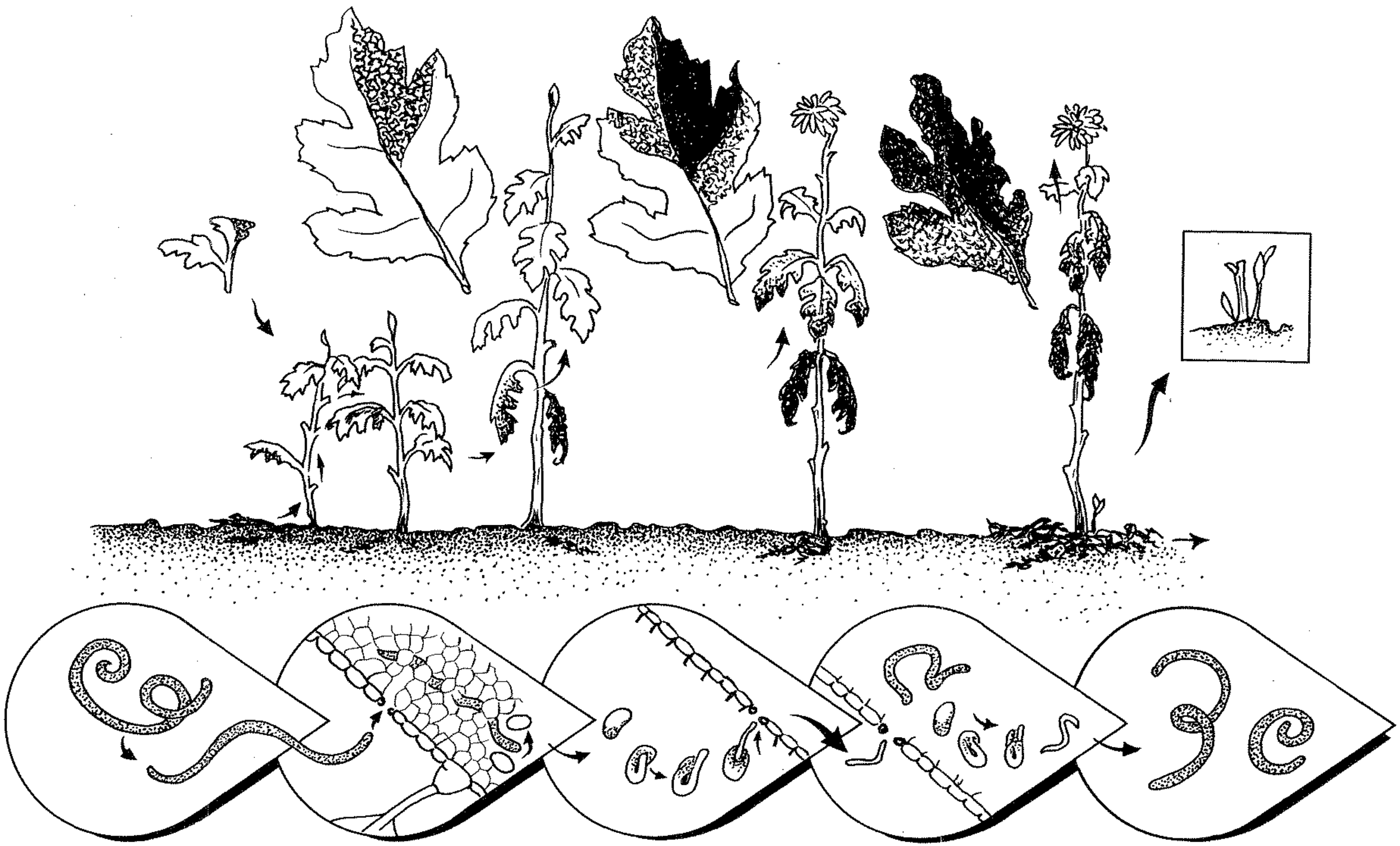


Figure 1. Life history of the bud and leaf nematode, *Aphelenchoides ritzemabosi*, on chrysanthemum

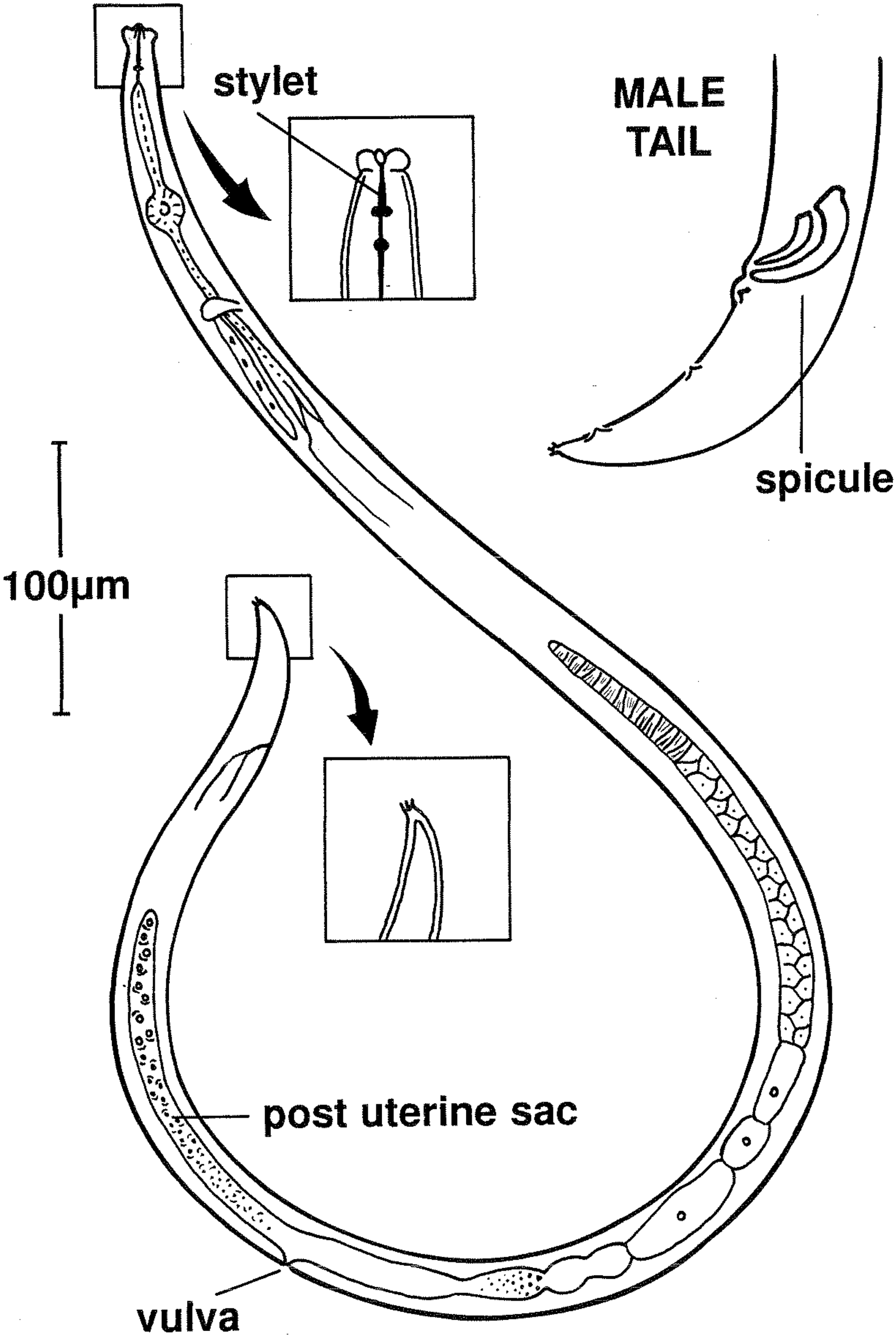


Figure 2. Body structure of the bud and leaf nematode,
Aphelenchoides ritzemabosi

Leaf and bud nematodes are bisexual; individual nematodes being either male or female. Male bud and leaf nematodes are identified by the presence at their posterior (tail) end of a pair of rose-thorn shaped spicules whose function is to grasp the female during copulation. The females have a vulva which is located towards the posterior of the body. The recognition and identification of the individual species of bud and leaf nematodes relies mainly upon body dimensions such as overall body length and stylet length. The appearance of the tail tip and the male spicules are also important diagnostic features. Further taxonomic details of use in identification procedures may be found in Siddiqi (1974 & 1975), Southey (1978) and Hunt (1993).

3.2 Movement and survival

3.2.1 Movement in water

Bud and leaf nematodes are highly dependent on water for survival and spread and they are, in consequence, energetic swimmers. The adults and larvae are able to propel themselves in an eel-like swimming action through moisture films or deeper water. The swimming movement of bud and leaf nematodes is responsible for the spread of infestation within and between plants.

Adult *A. ritzemabosi* naturally tend to move upwards, they can climb 15 cm (six inches) up a stem in damp conditions to locate younger, fresher, leaves (Hesling, 1962a). The process of emergence from the leaf, spread and re-invasion is almost continuous when the plants are wet for long periods, e.g. in overhead irrigation or mist propagation systems. The adult and pre-adult nematodes are responsible for most of the spread owing to their greater size and activity than the juvenile stages. The longer periods of wet and dampness encountered in the autumn and winter accounts partly for the increase in symptoms often observed during this period. Slower plant growth also contributes to the increase of attack symptoms in cooler conditions.

During rain or irrigation, the nematodes may be washed off the plant by water splash to infest lower leaves, adjacent plants or weeds. If the plants are tightly grouped, as is often the case in nursery standing areas, foliar contact assists the movement of nematodes between plants. Therefore, the speed at which an infestation spreads within a group of plants is dependent largely on water, environmental conditions and plant spacing. Hesling (1962b) considered that all chrysanthemums within about one metre of an infested plant would become infested in the outdoor conditions of September and October. However, in a wet year this distance could be greatly exceeded.

3.2.2 Survival in dry conditions

A. ritzemabosi is capable of surviving dry conditions. When infested leaves drop from the plant and conditions allow the detached leaves to dry out, the nematodes within the leaf may remain viable for a long period of time. Dry, infested leaves may also be carried by the wind to infest new areas. French & Barraclough (1962) found that in leaves kept dry for three years at 4° or 7° C, 33% and 8%, respectively, of nematodes of all stages could be revived. However, under normal outdoor conditions nematodes in leaves or soil in heavily infested plots did not survive the winter and had all disappeared by early April. Despite this, the 'dry' method of spread should not be entirely discounted as a threat. In some circumstances infested debris could remain dry for some time in polytunnels or glasshouses, highlighting the need for high standards of crop hygiene (Section 6.2).

3.2.3 Survival on fungi and in the soil

A. fragariae can reproduce readily on fungi (Hunt, 1993) and has been cultured on *Alternaria citri* (Southey, 1978). Hooper & Cowland (1986) also demonstrated that *A. ritzemabosi* may feed and reproduce on fungi, although the rate of reproduction was less than other species of *Aphelenchoides*. *A. fragariae* would appear to be better adapted to survive on fungi than *A. ritzemabosi*, which has implications on the ability of these bud and leaf nematodes to survive in the soil in the absence of host plants.

Szczygiel & Hasior (1971) found that the longest survival time for *A. fragariae* in the soil was three months in dry or fresh plants buried 15 cm in soil. If the nematodes in a water suspension were added to soil they persisted only four weeks. French & Barraclough (1962), working with chrysanthemums, found that very few *A. ritzemabosi* survived for more than 3-4 months in moist, fallow soil or moist leaves. They concluded that in nurseries where the ground is cleared of debris and ploughed in late autumn and kept fallow over winter, the nematodes are unlikely to survive long enough to infect chrysanthemums planted the following spring.

Despite the evidence that both *A. fragariae* and *A. ritzemabosi* were shown to survive on fungi in artificial conditions, the generally held view is that neither species are able to survive overwinter for more than four months in fallow soil devoid of host plants. However, many of the common weeds are hosts for bud and leaf nematodes, enabling long-term survival on infested ground (Section 3.2.4).

3.2.4 Survival in weeds

Many of the common weed species are hosts of *A. fragariae* and *A. ritzemabosi*. Buttercup, chickweed, cleavers, groundsel, sowthistle and speedwell are known hosts of *A. ritzemabosi* (Gratwick, 1992). Shepherd's purse, groundsel, black nightshade and speedwell are also noted as hosts of *A. fragariae* (Siddiqi, 1975). Ensuring fallow ground remains completely free of weed growth for up to four months is often difficult. Bud and leaf nematodes may, therefore, remain on infested land for long periods by surviving in weed hosts.

3.2.5 Survival in the propagation cycle

The most important source of re-infestation by bud and leaf nematodes is by transfer in infested plants or parts of plants used as propagation material. The survival of *A. ritzemabosi* in the buds of dormant chrysanthemum stools has been well documented (e.g. Hesling & Wallace, 1961a). In general, when mother plants are infested, the nematodes are transferred in the buds or leaves of cuttings. Symptoms of nematode attack may not always be visible when cuttings are taken or when plants are split for propagation. For example, a period of rapid growth prior to taking cuttings may reduce the numbers of nematodes in the new growth and hide the appearance of symptoms. Small numbers of nematodes may, therefore, be transferred in the propagation material and the appearance of symptoms can be delayed until the nematode population builds up when the new plants establish themselves.

The warm, wet and humid conditions of many propagation systems are extremely favourable for the nematodes. Overhead water irrigation or misting systems also greatly add to the potential for inter-plant spread of the pest between plants during propagation.

Seed-borne infestation of bud and leaf nematodes in the UK is rare and believed to be of little importance. However, Brown (1956) found that *A. ritzemabosi* was capable of transfer on the seed of annual aster (*Callistephus chinensis*). The only other species of *Aphelenchoides* known to be seed-borne is *A. bessyi*, the cause of white tip of rice (Cralley & French, 1952). Seed-borne infestation is, therefore, a risk that should not be completely dismissed. For this reason, seed from plants showing symptoms of attack, particularly in flowers or flower buds, should not be saved for further use.

3.3 Feeding behaviour

The bud and leaf nematodes may feed endoparasitically within leaf tissue or ectoparasitically within unopened buds. The nematodes are not attracted by host plants and their orientation is not affected by light or gravity (Siddiqi, 1974). The nematodes invade leaves via the stomata or surface wounds. Having gained entry, the nematodes move amongst the spaces between the spongy mesophyll cells.

The anterior (head) tip of the body is used to probe amongst the cells. Individual plant cells are selected for feeding; the nematode pushes the stylet (mouth spear) from the mouth and vibrates it back and forth in short strokes against the cell wall. Once the cell wall is penetrated, the stylet is fully extended into the cell where it remains for a few seconds while the nematode sucks out some of the cell contents. The stylet is then withdrawn and the nematode moves off in search of another cell. It is probable that the nematodes damage more cells than they feed on, as they probe at many cells before they remain to feed. Individual nematodes may, therefore, damage many hundreds of cells during the course of their life (Hesling, 1962a), often giving rise to the typical leaf blotching symptom of attack (Section 4.1).

When feeding ectoparasiticaly within buds, the nematodes damage the surface tissues of the unopened leaves or flower parts. When the buds break open, the expanding leaves or petals are subsequently scarred, deformed or destroyed (Section 4.1). The small intercellular spaces in young leaves are not large enough to permit nematode movement; in older leaves the spaces are large enough to allow the nematodes to move freely through the leaf tissue (Hesling & Wallace 1961b).

3.4 Reproduction

Bud and leaf nematodes are bisexual, individuals being either male or female. True bisexual reproduction takes place and is apparently obligatory as parthenogenesis is not known to occur (Siddiqi 1974; 1975). Fertilised females of *A. ritzemabosi* may go on reproducing for six months without re-fertilisation. This is due to the storage of sperms by fertilised females in a post-uterine sac. The sperms are subsequently carried forward into the anterior branch of the reproductive tract for fertilising the developing eggs.

In chrysanthemum leaves, *A. ritzemabosi* females lay about 25–30 eggs in a compact group . Eggs hatch in 3–4 days and the juveniles take 9–10 days to reach maturity; the life cycle takes 10–13 days at 14°–17°C (Wallace 1960). Strümpel (1967) gives an account of the life-history of *A. fragariae* in *Begonia* in which the generation time is 10–11 days at 18°C and females lay an average of 32 eggs. Therefore, bud and leaf nematode populations can build up rapidly in favourable conditions.

4. SYMPTOMS OF ATTACK AND HOST RANGE

4.1 Symptoms of attack

4.1.1 Leaf blotching

The most widespread and commonly recognised symptom of attack by bud and leaf nematodes is in the form of discoloured angular blotches on the leaf surface (Fig. 3). Leaf blotches are caused by nematodes feeding endoparasiticaly within the leaf (Section 3.3). As cells are killed by nematodes, brown necrotic areas develop which are angular in appearance at first as the spread of damage is limited by the veins (vascular tissue) within the leaf. In chrysanthemum, the cells around the main leaf veins are thicker-walled and not attacked until the later stages of an infestation, so the veins act a barrier to nematode spread within the leaf (Hesling 1962a).

Some of the most common outdoor ornamental hosts, including *Anemone*, *Buddleia*, *Viburnum* and *Weigelia* exhibit leaf blotch symptoms. Where leaf blotch symptoms are found, the same host may also develop leaf or flower distortion resulting from nematodes feeding within the buds or growing point.

Leaf blotches initially appear slightly pale and chlorotic, eventually becoming dark brown or black necrotic areas. Hesling & Wallace (1961b) observed that attacked cells gradually lost their chloroplasts and became brown. The formation of the brown substance in chrysanthemum leaf cells was attributed to the oxidation of polyphenols to quinones by the enzyme polyphenol oxidase, followed by polymerisation to brown substances. This is a well known defensive reaction of plant cells to invasion or injury.

Care should be taken in confirming that leaf blotch symptoms have been caused by bud and leaf nematodes. Several pathogens can also produce similar symptoms, for example, downy mildew of *Buddleia* and *Lamium* and bacterial blotch of *Begonia* and *Cheiranthus*.

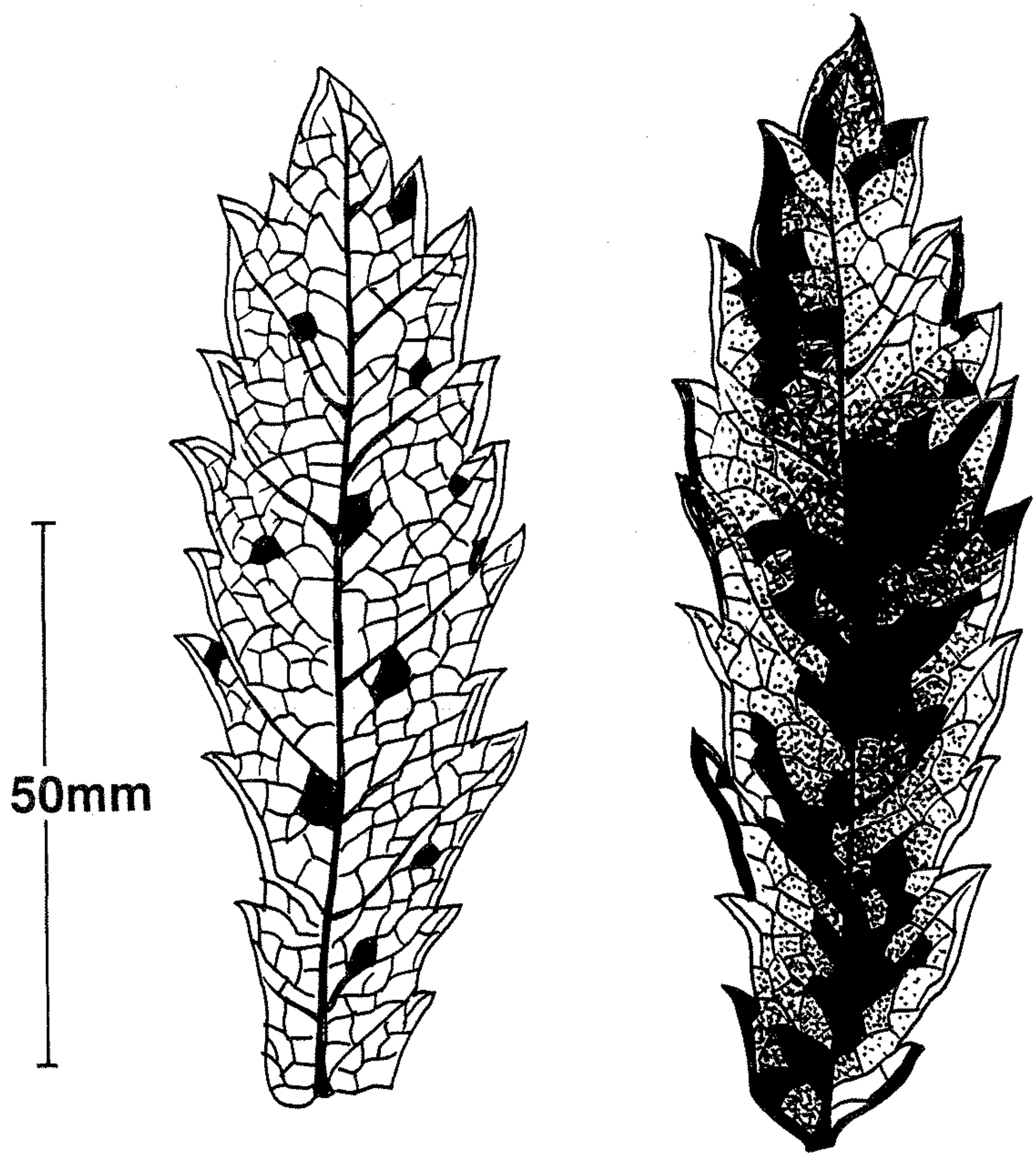


Figure 3. Leaf blotch symptoms caused by the bud and leaf nematode, *Aphelenchoides ritzemabosi*, on *Verbena vernosa*

4.1.2 Bud and growing point damage

The damage caused by bud and leaf nematodes feeding ectoparasiticaly within buds is not as widespread or as readily identified as leaf blotching symptoms. The nematodes feed on the surface of leaf or flower tissue within the bud. When apical buds are infested, the emerging leaves are often distorted or show signs of surface injury. When flower buds are damaged, the emerging flower may be small and malformed.

In strawberries and blackcurrants, bud feeding by *A. ritzemabosi* in the spring causes deformed leaves and flowers. *A. fragariae* can also damage strawberries in this way. In scabious (*Scabiosa caucasica*), *A. blastophthorous* causes death of young flowers and 'blind' plants by feeding within buds (Franklin 1952).

Hesling & Wallace (1961b) described a range a symptoms caused by bud infestation of *A. ritzemabosi* on infested chrysanthemum cuttings. These symptoms included stunting, distortion, brown scarring of leaves and petioles and puffiness and blistering of leaves.

Leaf distortion caused by *A. ritzemabosi* has been noted on *Anthemis*, *Artemisia*, *Buddleia*, *Helichrysum*, *Lavandula*, *Leucanthemum*, *Malvastrum*, *Rosemarinus*, *Salvia*, *Saponaria* and *Saxifraga* (Young, unpublished). Leaf distortion associated with *A. fragariae* has been found on *Androsace*, *Calceolaria*, *Mentha* and *Veronica* (Young, unpublished). Although leaf distortion is often found in association with leaf blotching, these two forms of symptoms do not always occur together.

4.1.3 Association with plant diseases

In strawberries, when *A. ritzemabosi* is present with the bacteria *Corynebacterium fascians* symptoms described as 'cauliflower disease' are produced in some cases. In this disease, there is proliferation of axillary buds with many of the leaves reduced to swollen petioles. The bacterial disease is initiated by bacteria that are carried into the buds by the nematodes and there stimulate growth of dormant meristems. The symptoms can be further modified by the feeding of the nematodes. In the field, *C. fascians* is almost universally present, there are many strains of which only a few can provoke cauliflower disease symptoms in strawberry (Pitcher 1965).

No important relationships are known to exist between bud and leaf nematodes and pathogens among outdoor ornamentals. However, Southey (1971) recorded *A. fragariae* in association with severe leafy gall symptoms (probably caused by *C. fascians*) on *Heuchera*. Given the wide host ranges of the species of nematode and bacteria involved, the possibility of similar gall-like disorders developing on other plant species cannot be dismissed.

4.2 Host range

The bud and leaf nematodes, *A. fragariae* and *A. ritzemabosi* have very large host ranges (Tables 1, 2 & Appendix I). Among the more well known hosts of *A. ritzemabosi* are *Aster*, *Anemone*, *Begonia*, *Buddleia*, *Calceolaria*, *Chrysanthemum*, *Dahlia*, *Delphinium*, *Doronicum*, *Fragaria*, *Lamium*, *Peonia*, *Ribes*, *Viburnum*, *Weigelia* and *Zinnia*. Hosts of *A. fragariae* include *Aster*, *Aconitum*, *Anthurium*, *Azalea*, *Begonia*, *Cornus*, ferns (Filicineae), *Fragaria*, *Hepatica*, *Heuchera*, *Hibiscus*, *Mentha*, *Primula*, *Saxifraga* and *Viola*. Many hosts of *A. ritzemabosi* are amongst the Compositae whilst most hosts of *A. fragariae* belong to the ferns, Liliaceae, Primulaceae and Ranunculaceae (Siddiqi 1975).

The host lists (Tables 1, 2 & Appendix I) compiled for the bud and leaf nematodes, *A. fragariae* and *A. ritzemabosi*, were based mainly on published scientific records. However, these lists should not be assumed as a complete or final definition of the host range of bud and leaf nematodes as new hosts are frequently reported. Host records up to 1963 were taken from Goodey *et al.* (1965). For the period 1963–1972, the *Helminthological Abstracts* were searched. For 1973–1991, the CAB International (Centre for Agriculture and Biosciences International) CD-ROM database (CABPESTCD) of crop protection research abstracts was consulted.

Table 1. Important hardy ornamental hosts of bud and leaf nematodes, *A. fragariae* and *A. ritzemabosi*. Host plants listed as generic names.

Host Plant	Nematode Species
Anemone hupehensis	*A. fragariae*
Anemone japonica	*A. fragariae*
Anemone sp.	*A. fragariae* & *A. ritzemabosi*
Aster novi-belgii	*A. ritzemabosi*
Aster sp.	*A. ritzemabosi*
Buddleia davidii	*A. ritzemabosi*
Buddleia globosa	*A. ritzemabosi*
Buddleia sp.	*A. ritzemabosi*
Choisya sp.	*Aphelenchoides* sp.
Choisya ternata	*Aphelenchoides* sp.
Chrysanthemum sp.	*A. fragariae* & *A. ritzemabosi*
Cistus sp.	*Aphelenchoides* sp.
Clematis heracleaefolia	*A. fragariae*
Dahlia sp.	*A. fragariae* & *A. ritzemabosi*
Fragaria sp.	*A. ritzemabosi*
Geranium sp.	*A. ritzemabosi*
Heuchera sp.	*A. fragariae* & *A. ritzemabosi*
Hydrangea sp.	*A. fragariae*
Lamium purpureum	*A. ritzemabosi*
Lavandula sp.	*A. ritzemabosi*
Mentha sp.	*A. fragariae* & *A. ritzemabosi*
Pentstemon sp.	*A. fragariae* & *A. ritzemabosi*
Phlox sp.	*A. fragariae* & *A. ritzemabosi*
Primula sp.	*A. fragariae* & *A. ritzemabosi*
Ribes sp.	*A. fragariae* & *A. ritzemabosi*
Salvia sp.	*A. fragariae* & *A. ritzemabosi*
Saxifraga sp.	*A. fragariae* & *A. ritzemabosi*
Scabiosa sp.	*A. fragariae* & *A. ritzemabosi*
Viburnum sp.	*A. ritzemabosi*
Weigelia sp.	*A. ritzemabosi*

Table 2. Fern hosts (Filicineae) of bud and leaf nematodes, predominantly *A. fragariae*. Host plants listed as generic names.

Acrostichum	*Ceropteris*	*Lygodium*	*Pityrogramma*
Adiantum	*Coniogramme*	*Marsilea*	*Polypodium*
Aneimia	*Cystopteris*	*Microlepia*	*Polystichum*
Aspidium	*Davallia*	*Neottopteris*	*Pteris*
Asplenium	*Diplazium*	*Nephrodium*	*Stenochlaena*
Athyrium	*Dryopteris*	*Nepholepis*	*Struthiopteris*
Blechnum	*Gymnogramme*	*Osmunda*	*Woodwardia*
Ceterach	*Lomaria*	*Phyllitis*	

The assistance of Mrs S Hockland of the MAFF Central Science Laboratory in compiling the host lists is gratefully acknowledged.

5. GROWER SURVEY

A grower survey was carried out from December 1995 until March 1996 to establish the relative extent and severity of bud and leaf nematodes as pests of outdoor ornamentals.

A questionnaire (Appendix 1) was sent to all recipients of the ADAS Horticulture Outdoor Ornamental Technical Notes, which is published at approximately monthly intervals.

The findings of the survey have been summarised in the following key points (Section 5.1) with associated tables and figures (Section 5.2).

5.1 Key point summary

- Response rate for the survey was 24%. Of the responses, 138 were analysed out of 580 sent.
- There was a wide range of nursery sizes among respondents. Around 27% of nurseries were up to one hectare in area. The average area was 14 ha (Fig. 4).
- A large majority (87%) of respondents grew general hardy container stock, with just over half (53%) growing herbaceous container stock (Table 3 & Fig. 5).
- Over 80% of nurseries propagate their own stock and are aware that bud and leaf bud nematodes are a pest of ornamentals (Table 4 & Fig. 6).
- Just over one third (35%) of respondents have had bud and leaf nematode at some time on their nurseries (Table 4).
- Overall, 25% of nurseries (35 respondents) currently have bud and leaf nematode infestation (Table 5 & Fig. 7).
- Of nurseries where the pest is no longer active, 60% of respondents (n = 10) stated the problem was last experienced in 1993 or 1994 (Fig. 8).
- Plants were infested with bud and leaf nematode for an average of five years amongst 31% of the respondents (Fig. 9).
- Pest diagnosis was undertaken by consultants in 54% of cases. Nursery personnel recognised the problem in 30% of cases (Table 6).
- In two thirds of cases, infestation was confirmed by microscopic examination (Table 7).
- General hardy shrubs most affected (Table 8).
  Weigelia (31.5%)
  Buddleia (18.4%)
  Philadelphus (10.5%) (unconfirmed host, see p. 40)
  Viburnum (6.5%)

- Herbaceous plants most affected (Table 9):

  Anemone (22.7%)

  Lamium (9%)

  Chrysanthemum (9%)

  Aster (9%)

- Alpines most affected (Table 10):

  Phlox (40%)

- In 42% of cases, it was suspected that the nematodes were brought onto the nursery in a batch of contaminated plants (Table 11 & Fig. 10).

- The pest was present in all stages of production. 29% of respondents indicated the pest was present in propagation plants, 30% in liners and 40% in final plants (Table 12 & Fig. 11).

- The most popular control measure was treatment with Temik, in both mother stock and production plants. Hygiene precautions and the destruction of infested plants were also commonly used as control measures (Table 13 & Fig. 12).

- Control measures were only partially successful: in 65% of cases the pest was suppressed to an acceptable level but control was poor in 14% of cases (Table 14 & Fig. 13).

- Not surprisingly, 76% of respondents believed that the pest hindered or prevented the sale or production of infested lines (Table 15 & Fig. 14).

- Annual economic losses amounted to less than £5,000 for 87% of nurseries. However, 4% of the respondents affected claimed losses from bud and leaf nematode exceeding £10,000 per annum (Fig 15).

5.2 Survey findings

Figure 4. Grower Survey Question 1: What is the size of your nursery in hectares? n = 138.

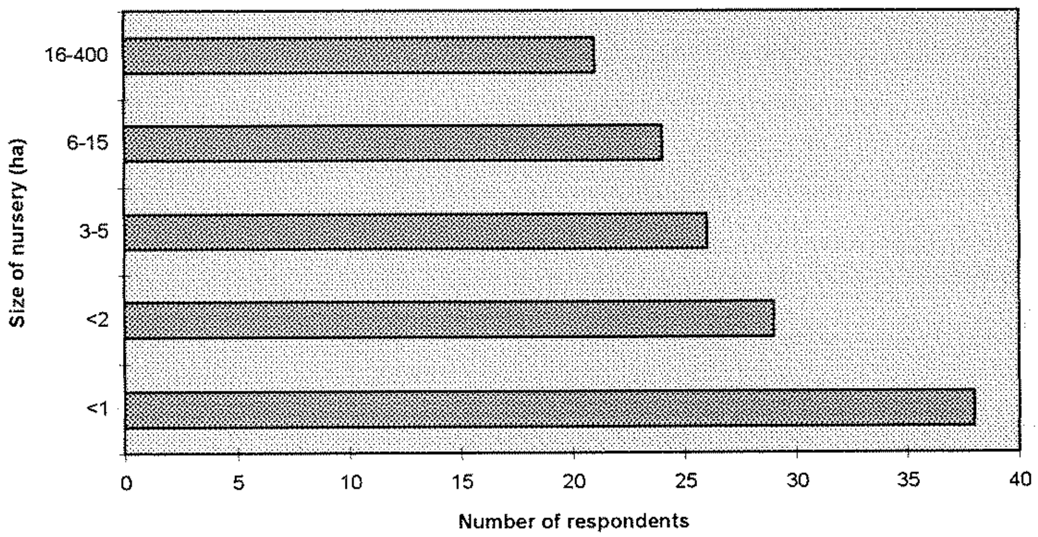


Table 3. Grower Survey Question 2: which of the following are grown on your nursery?

Stock type	Number of respondents	Percentage of respondents
General hardy container stock	120	87
Hebaceous container stock	74	53
Alpine container stock	27	19
Field grown trees and shrubs	40	29
Field grown herbaceous stock	14	10

Figure 5. Type of plants grown on surveyed nurseries.

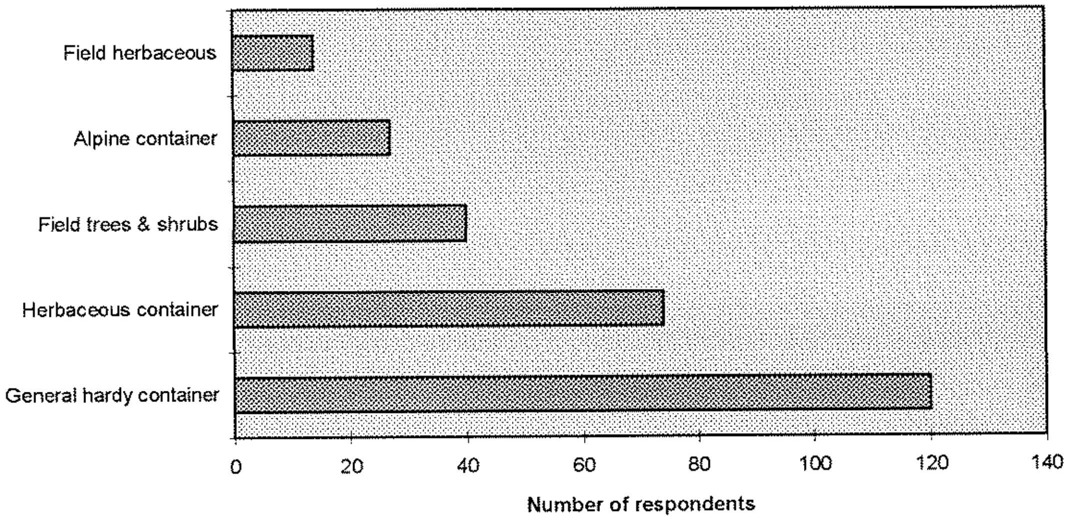


Table 4. Grower Survey Questions 3, 4 & 5: plant propagation and awareness of bud and leaf nematode.

Question	No. responding 'YES'	% responding 'YES'
Do you propagate your own stock?	117	85
Were you aware that bud and leaf nematode is a pest of ornamentals?	111	80
Has bud and leaf nematode been found at any time on your nursery?	47	35

Figure 6. Propagation of stock on surveyed nurseries.

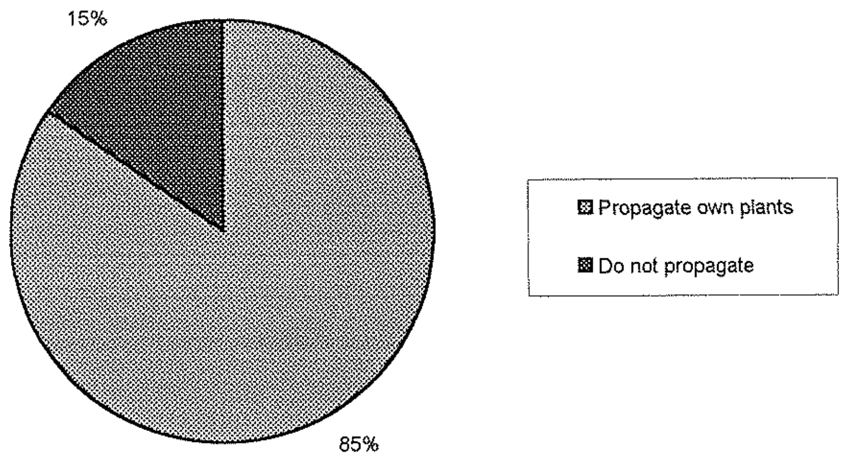


Table 5. Grower Survey Question 6: Is leaf and bud nematode currently active on your nursery?

Currently active	Number of respondents	% of respondents
Yes	35	52
No	32	48
Total	67	100

Figure 7. Current presence of bud and leaf nematode on surveyed nurseries.

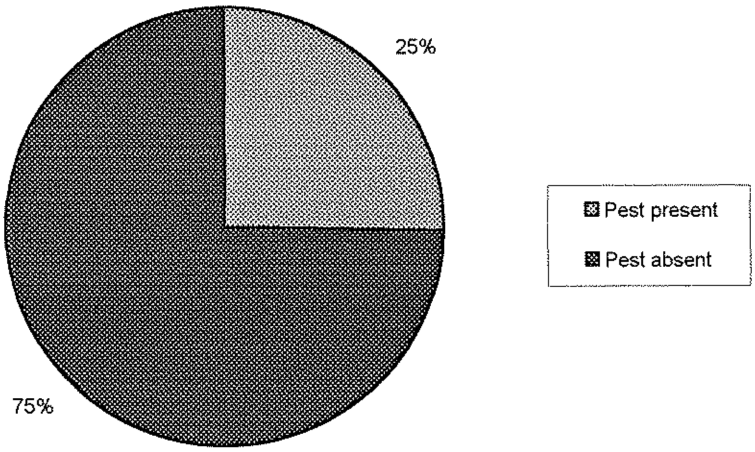


Figure 8. Year of last occurrence of bud and leaf nematodes on previously infested surveyed nurseries.

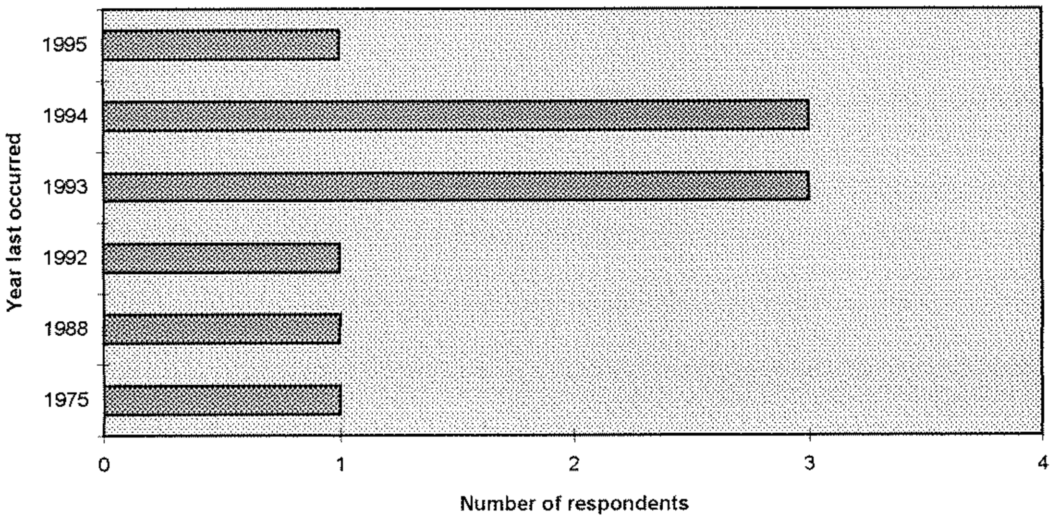


Figure 9. Duration of bud and leaf nematode infestation on surveyed nurseries.

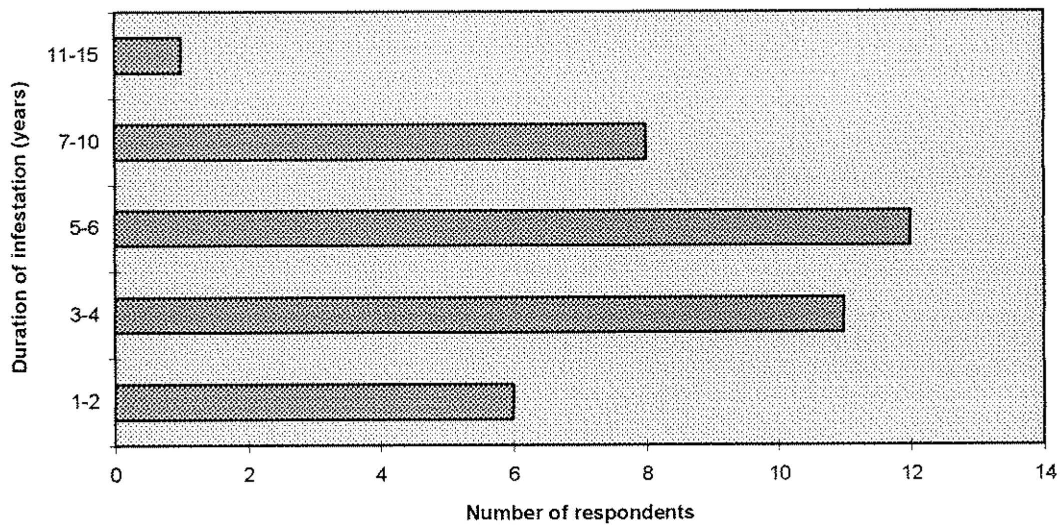


Table 6. Grower Survey Question 9: who first recognised or diagnosed bud and leaf nematode on your nursery?

Diagnosed by	Number of respondents	% of respondents
Nursery personnel	14	30
Consultant	25	54
Plant Health Inspector	4	9
Customer	0	0
Other	3	7
Total	46	100

Table 7. Grower Survey Question 10: was bud and leaf nematode confirmed by microscopic identification by a specialist.

Specialist confirmation	Number of respondents	% of respondents
'Yes'	30	65
'No'	16	35
Total	46	100

Table 8. Grower Survey Question 11: List the species of general hardy shrubs affected by bud and leaf nematode.

Plant species	Number of respondents	% of respondents
Weigelia	24	32
Weigelia cv. Florida	4	5
Weigelia cv. Variegala	3	4
Weigelia cv. Rubidor	1	1
Weigelia cv. Coraviieus	1	1
Weigelia cv. Bristol Ruby	1	1
Weigelia cv. Nubider	1	1
Buddleia	14	18
Buddleia cv. Royal Red	1	1
Buddleia cv. Black knight	1	1
Buddleia cv. Globosa	1	1
Buddleia cv. Claudii	1	1
*Philadelphus**	8	11
Viburnum	5	7
Hydrangea	3	4
Ribes	2	3
*Magnolia**	1	1
*Azalea**	1	1
*Cammelia**	1	1
*Cistus**	1	1
Choisya	1	1

* Unconfirmed. No previous host records (see p. 40)

Table 9. Grower Survey Question 11: List the species of herbaceous plants affected by bud and leaf nematode.

Plant species	Number of respondents	% of respondents
Anemone	5	23
Lamium	2	9
Chrysanthemum	2	9
Aster	2	9
Penstemon	1	5
Tradescantia	1	5
*Geum**	1	5
Potentilla	1	5
*Phygelius**	1	5
*Physostegia**	1	5
Phlox	1	5
Comfrey	1	5
Sages	1	5
Mints	1	5
Lavender	1	5

* Unconfirmed. No previous host record, see p40.

Table 10. Grower Survey Question 11: List the species of alpine plants affected by bud and leaf nematode.

Plant species	Number of respondents	% of respondents
Phlox	6	40
Phlox cv. Subulata	1	7
Phlox cv. Douglassi	1	7
Primula	1	7
Aster cv. Natalense	1	7
Prunella	1	7
Mimulus	1	7
Arabis	1	7
Saponaria	1	7
Dianthus	1	7

Table 11. Grower Survey Question 11: What was the suspected source of bud and leaf nematode infestation?

Suspected source	Number of respondents	% of respondents
Brought in on batch of contaminated plants	20	42
Natural infestation of own plants	11	24
Unknown	16	34
Total	47	100

Figure 10. Suspected source of infested plants on surveyed nurseries.

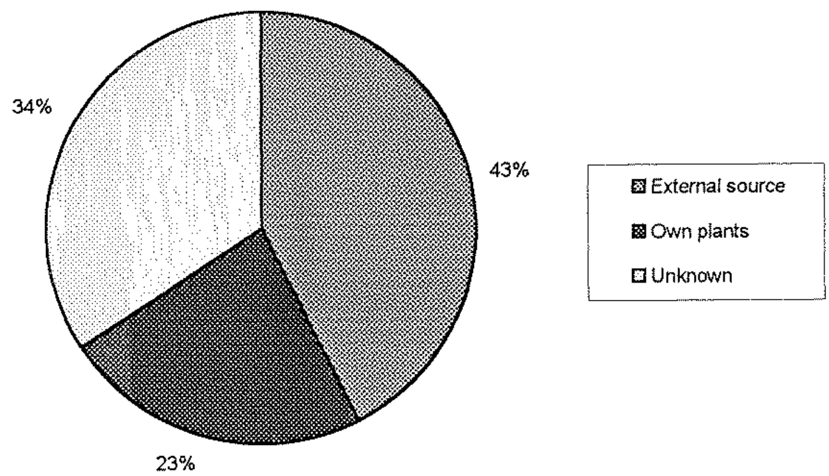


Table 12. Grower Survey Question 11: What stage of plant production is leaf and bud nematode present in?

Location of pest	Number of respondents	% of respondents
Stock plants used for propagation	20	29
Liners	21	30
Final plants	28	41
Total	69	100

Figure 11. The stages of plant production with bud and leaf nematode infestation on surveyed nurseries.

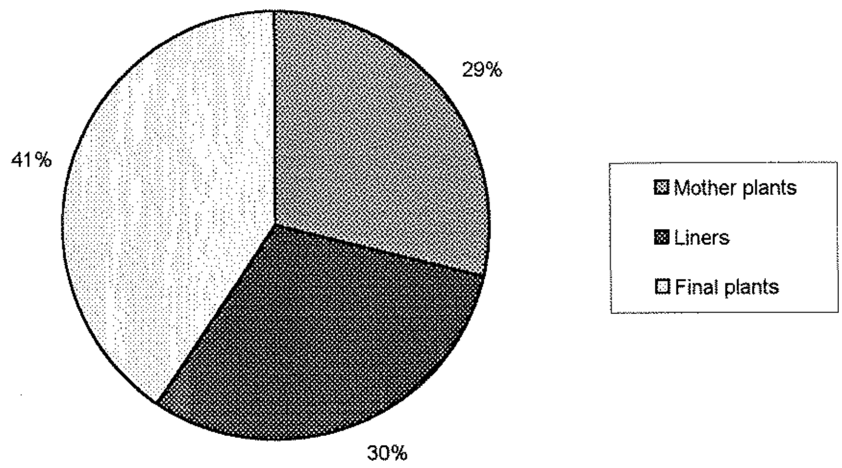


Table 13. Grower Survey Question 14: Which control measures have been adopted against bud and leaf nematode and in which stage of plant production?
n = number of respondents; % = percentage of respondents

Control measures		Stock plants	Production plants	None
Destruction of infested plants	n	17	17	3
	%	10	10	2
Hygiene precautions	n	18	18	2
	%	10	10	1
Quarantine precautions	n	4	0	5
	%	2	0	3
Chemical (Temik) treatment	n	26	33	2
	%	15	19	1
Hot water treatment	n	3	1	6
	%	2	0.5	3
Tissue culture	n	4	2	5
	%	2	1	3
Other	n	1	3	4
	%	0.5	2	2

Figure 12. Control measures used against bud and leaf nematode on surveyed nurseries.

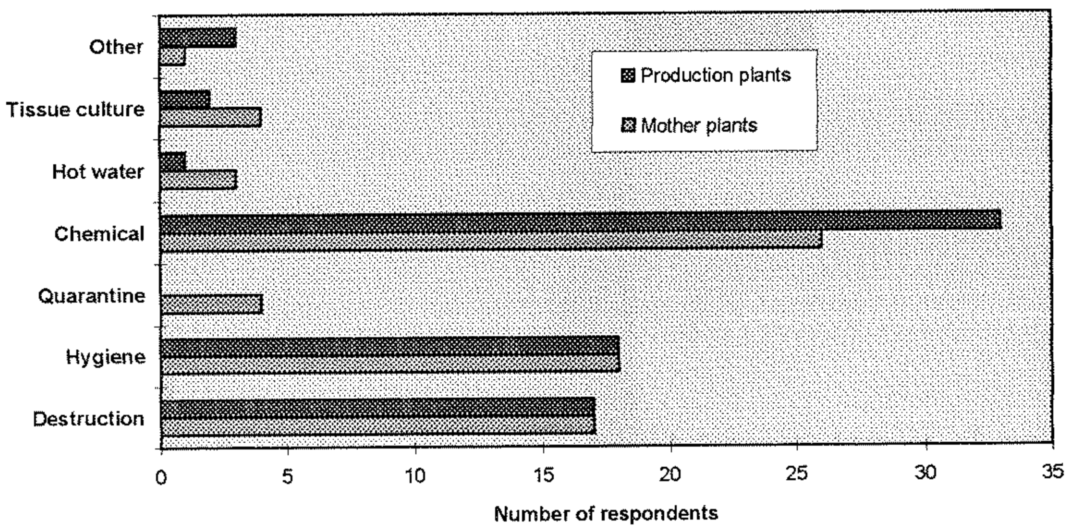


Table 14. Grower Survey Question 15: What have your control measures against bud and leaf nematode achieved?

Effect of control measures	Number of respondents	% of respondents
Pest eradicated	9	21
Pest suppressed to an acceptable level	28	65
Poor or unacceptable control	6	14
Total	43	100

Figure 13. Success of control measures against bud and leaf nematode on surveyed nurseries.

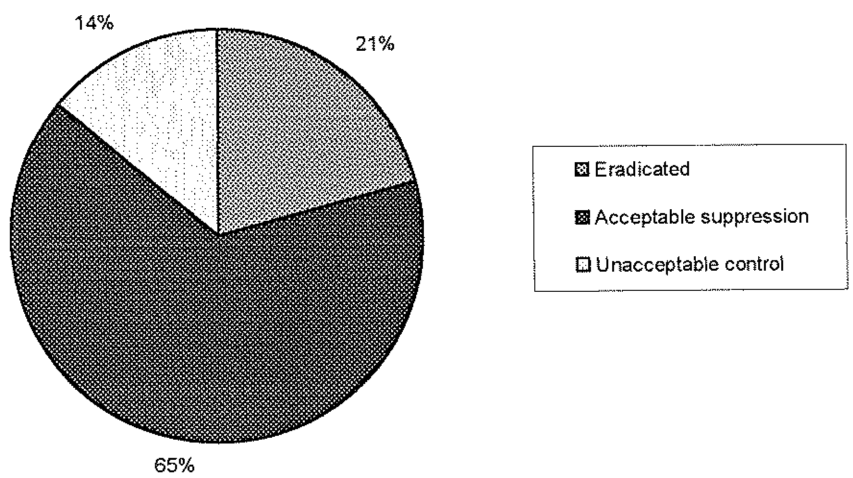


Table 15. Grower Survey Question 16: Has bud and leaf nematode infestation hindered or prevented the sale or production of infested lines?

	Number of respondents	% of respondents
Yes	35	76
No	11	24
Total	46	100

Figure 14. Effect of bud and leaf nematode on sale of infested plants.

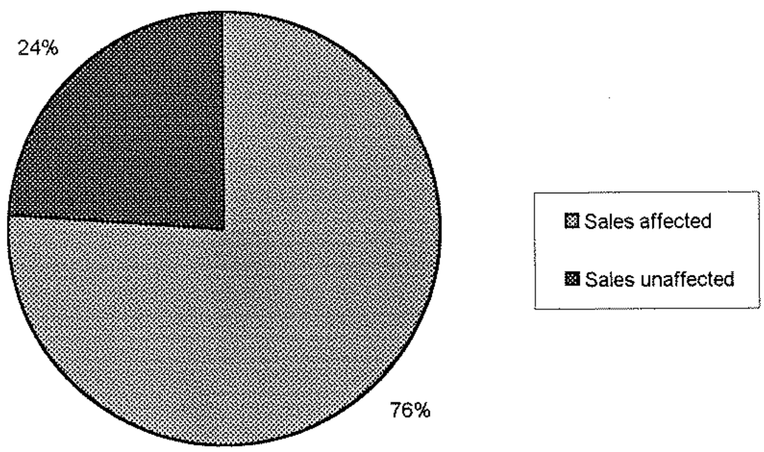
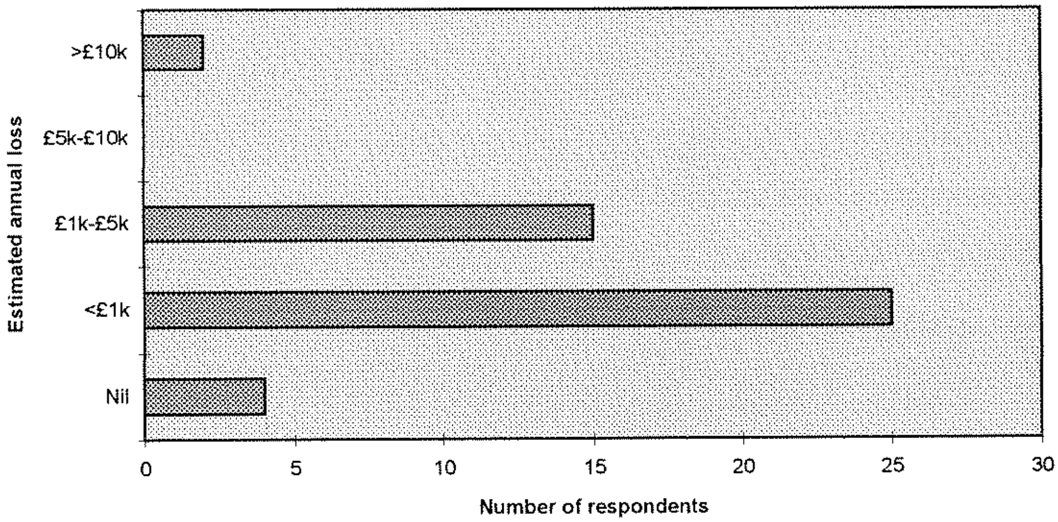


Figure 15. Estimated annual financial losses caused by bud and leaf nematode on surveyed nurseries.



The unconfirmed hosts reported in Tables 8 & 9 have not been laboratory tested to confirm their infestation by bud and leaf nematodes. These unconfirmed host records should, therefore, be regarded with caution. In particular, *Philadelphus* and *Magnolia* are prone to bacterial leaf spot, the symptoms of which may be confused with leaf blotching caused by nematodes.

5.3 Comments from survey respondents

1. We have a contract with you and presume you would have found it if it were present.

2. We are specialist conifer growers and as far as we are aware this pest is not a problem on this crop we hope

4. We are a new nursery business of 10 months standing. The nursery is being developed on a green field site. We have not found this pest to date but no doubt some other business in the trade will donate it to us - in the interests of fair shares for all.

5. If we have failed to recognise the symptoms and would find it difficult to locate this pest – colourless and 1mm long – we don't possess a microscope. Any suggestions would be welcome. Our main battle is vine weevil.

6. We have had a rigorous regime against plant problems. Choosing carefully all propagation materials, and inspecting all liners bought in. By our 3rd year we hope to be propagating all our shrub & herbaceous stock along with ferns & bamboos. We do not anticipate growing anything else at this stage.

7. Because we were unaware of leaf and bud nematode being a major problem, we have obviously not been looking for it - unlikely we would recognise symptoms of attack that easily - perhaps more info. regarding recognition would be beneficial

8. The only instance I am aware of where eelworm has been identified is on a batch of *Buddleias* from bought in lines – the problem no longer exists to best of our knowledge

9. Following information received I have thoroughly inspected all our mother plants, especially those bought in this year, shrubs bought in for resale as well as our own stock. I was not aware of anything on them but wanted to make sure. As most of our sales are from home produced stock I shall be monitoring bought in plants with extra care in future.

10. Even at £70 per hour MAFF Plant Health Inspectors have not found leaf and bud nematodes on this nursery. We do not believe it to be an economic nuisance on this nursery

11. So far, we are not aware of a leaf and bud nematode problem on our nursery.

12. We are growers of field-grown bush rose and have never seen any problems.

13. Infestation on *Buddleia* biggest problem, particularly in its association with over wintering finished plants and subsequent re-growth in spring.

14. Brought in on dutch *Hydrangea* in 1960s first recorded loose in UK.

15. We certainly treat this pest seriously and are unhappy about using Temik. Research into alternative control measures should be encouraged.

16. Only found on one batch of 100 plants.

17. It is now at a low level. This year it was not visible until the autumn.

18. Temik gives very good control on liners & 2-3 L plants. Usually one dose is sufficient. Stock plants have been dosed twice but control has not been achieved.

19. Eradicating this pest can be very time consuming - identifying and marking areas where it is suspected; treatment at the best time; and cleaning up leaf material etc. Any suspect liners are treated with Temik. Not a major pest, but a potential problem.

20. Although much less of a threat this problem has certain characteristics in common with vine weevil e.g. relatively immobile, constantly present, resistant to pesticides etc. Therefore, like that pest, it should be a good candidate for biological control methods if they could be developed.

21. Didn't know correct name only told last year in Holland eelworms. Help required to recognise and diagnose the problem, please forward the information.

22. Identified in stock plants which were then destroyed on eliminating this species from production for 2 years.

23. We would welcome research & development work into this pest, which is widespread in the industry, but little recognised and readily accepted.

24. If ever Temik is not allowed on horticultural ornamentals there could be serious problems in control of this in my opinion.

25. It has only really become a problem on outdoor chrysanths. in the last growing season so as yet control measures have not been implemented. We also grow dahlias on a large scale but have not observed problems on these, although we are aware that they are also susceptible.

26. We have not had this problem on this nursery. Not found by us or ADAS inspectors.

6. CONTROL METHODS

Control of bud and leaf nematode normally involves the adoption of an integrated policy, using cultural and chemical methods. Chemical control offers short-term alleviation of the symptoms of attack but is incapable of removing the pest from the propagation cycle when mother plants are infested. Cultural hygiene offers the most reliable means of eradicating bud and leaf nematode from infested lines. The following sections cover aspects of the various control techniques in more detail and indicate how individual techniques may be managed together as an integrated control strategy.

6.1 Cultural control

The selection of healthy propagating material, with strict attention to hygiene (Section 6.2) is vital to maintain freedom from bud and leaf nematode. Cultural control involves precautions to ensure that mother plants used in propagation are free of nematodes. Other methods such as tissue culture (Section 6.6) and hot water treatment (Section 6.5) can be employed to free mother stock from bud and leaf nematode infestation.

Mother plants showing any suspect symptoms of attack should always be immediately destroyed. When an infestation is discovered, plant debris from around infested plants should also be safely disposed of e.g. by burning. Neighbouring plants which may have been touching infested plants or within range of their water splash should also be destroyed where possible.

It is often advisable to have leaf samples from susceptible plant species periodically tested for the presence of leaf and bud nematode as symptoms may not be visible at all times of the year, e.g. during periods of rapid growth prior to taking cuttings. When infested mother plants need to be retained they should, of course, be well isolated from healthy stock.

The survival of bud and leaf nematodes in bare soil is such that maintaining previously infested ground free of weeds overwinter for at least four months should ensure no carry-over of the pest (Section 3.2.3). Infestation of healthy plants from debris or weeds is a greater risk. Many of the common weeds can harbour bud and leaf nematodes (Section 3.2.4). The standing ground for containerised stock should be kept free of weeds and plant debris. The plastic mulch commonly used in containerised stock is effective in eliminating weed growth. However, good control of weeds in field-grown stock is more difficult to attain without the use of herbicides.

When infested plants are found, watering should be minimised to reduce local spread of the nematodes. This is of great importance in the case of overhead sprinkler or misting systems which create wet leaves and cause splashing, providing ideal conditions for movement of nematodes within and between plants. Wider spacing of containers to minimise foliar contact between plants will also reduce the opportunity for spread of nematodes between plants.

Chrysanthemum growers have, in the past, been advised to apply grease bands (petroleum jelly or tree banding grease) to the lower stems of specimen plants to prevent the nematodes from gaining entry (Gratwick, 1992). None of the foliage should be in contact with the soil or touching other plants. The grease is applied early in the season and re-applied periodically as the stem girth expands. Frequent attention is necessary to ensure the grease remains effective throughout the season. This technique is seldom used today and is not of great relevance to containerised nursery stock provided it is standing on clean matting or staging. However, grease banding could remain of occasional use as a precaution to safeguard valuable field-grown mother plants where re-infestation from the ground may be possible.

6.2 Hygiene precautions

General hygiene precautions, although mostly a matter of common sense, should not be overlooked as an important part of bud and leaf nematode control. The main aim of hygiene measures is to prevent contamination of clean stock. Plant remains and debris should be removed from infested areas and destroyed or safely disposed of. Although the risk of bud and leaf nematodes surviving for any appreciable on plant containers or equipment is small, they should always be cleaned and sterilised after contact with infested plants. Contaminated soil or compost is not a common source of infestation in containerised stock but, nevertheless, should be of a high standard and stored free of contact with infested plant material or debris.

Quarantining or isolating plants brought onto the nursery from unknown or suspect sources should be adopted as a routine precaution. The isolated plants may then be observed for a period of a few weeks to ensure no symptoms of attack develop. The quarantine period can be shortened by testing leaf samples from newly arrived plants for the presence of bud and leaf nematodes.

6.3 Chemical control

6.3.1 Sprays, drenches and granules

Organophosphorus chemicals, notably parathion and thionazin, have been used in the past as dips or drenches to control *A. ritzemabosi* in chrysanthemum stools and cuttings (e.g. Bryden & Hodson, 1957). Studies carried out by B D Moreton and Margaret E John (1963) of NAAS (National Agricultural Advisory Service) demonstrated that parathion gave only partial control in outdoor chrysanthemums. This was considered useful in average seasons but inadequate in wet seasons. Thionazin was later found to give satisfactory control, equivalent to that of hot-water treatment, when applied as a drench to rooted cuttings. The use of hot water treatment of chrysanthemums declined with the introduction of effective chemical control measures, particularly that of aldicarb (Temik) granules.

Liquid formulations of pesticides such as parathion and thionazin were highly hazardous to use and required full safety precautions to protect users. Parathion and thionazin have since been withdrawn for use in the UK. Aldicarb (Temik 10G) is now the only post-planting chemical control measure currently available against bud and leaf nematode in the UK. Aldicarb is an oxime carbamate compound with the same anti-cholinesterase mode of action as organophosphorus chemicals and is available only as a granular formulation.

Temik originally carried a manufacturer's label recommendation for the use on protected and outdoor ornamentals against a range of pests, including bud and leaf nematode. This recommendation was recently withdrawn by the manufacturers. The HDC Hardy Nursery Stock and Protected Crops Panels decided that it was important to retain these uses of Temik and an application for a Specific Off-Label Approval (SOLA) was submitted to the Pesticide safety Directorate (PSD). An approval for the off-label use of Temik in outdoor and protected ornamentals was subsequently granted in 1995 (1325/95). The off-label approval includes the use of Temik against bud and leaf nematode in outdoor chrysanthemums, dahlias, herbaceous plants, nursery stock, trees and shrubs. Overall rates of 56 to 112 kg of product/ha are cited and a conversion table is given showing equivalent dose rates for treatment of individual plant containers of varying sizes. The approval document (1325/95, available from MAFF or ADAS) must always be consulted before use as a range of safety precautions must be implemented before using this potentially hazardous chemical. An HDC off-label update document (Project No. CP2, December 1995) also provides further details relating to the use of Temik on ornamentals.

Temik granules are applied to the soil or compost. Temik is a systemic chemical that is taken up by the plant roots once released from the granules in damp conditions. It is recommended that Temik be applied by broadcasting or spot application. Hand-held granule applicators (e.g. Kyoritsu Midget) or motorised knapsack applicators of low air output (e.g. Fontan) may be used for broadcasting the granules. Spot applications may also be applied to individual containerised plants using hand-held or knapsack dispensers (e.g. Horstine Farmery). Spot applications carry the advantage of being more precise and less wasteful. To speed the release and plant uptake of active ingredient, application should be made to a moist soil and followed immediately by thorough watering. The intensity of watering should be carefully regulated to avoid run-off onto paths or into drains. To gain maximum uptake and efficacy of Temik, it is also suggested that applications should be made to plants at the start of, or during, active vegetative growth and before infestations have built up.

Useful, short-term, control of bud and leaf nematodes may be obtained with Temik. Multiplication of the nematodes and the symptoms of attack are suppressed. The chemical mode of action is described at nematistatic as the nematodes are disorientated and immobilised rather than killed. Once the influence of the chemical has worn off, the capacity of the nematode to increase rapidly in numbers is such that a small number of survivors can quickly lead a resurgence of the nematode population. Symptoms of attack then re-appear with the return of favourable environmental conditions.

6.3.2 Soil treatments

Control of bud and leaf nematodes in the soil can be achieved through steam sterilisation or by using methyl bromide or methyl-isothiocyanate based (e.g. dazomet) soil fumigants. The soil nematicide dichloropropene (Telone II), although not approved specifically for use against nematodes in ornamentals, may also be used in outdoor soil.

Bud and leaf nematodes survive only for relatively short periods as free-living individuals in the soil. The transmission of nematodes through vegetative plant propagation or via survival in weeds on infested land are more important sources of infestation. However, soil treatment can be appropriate in some circumstances. Where host plants must be planted in previously infested ground which has been bare for less than four months, or where nematodes may have survived in weeds, soil sterilisation or fumigation is a useful precaution to prevent the carry-over of infestation.

6.3.3 Future developments

Abamectin (Dynamec) has recently been approved in the UK as an insecticide and acaricide for use in protected and outdoor ornamentals. The product is targeted mainly at two-spotted spider mite and leaf miners. Abamectin is able to exert residual control of spider mites and leaf miners because it is translaminar; the active ingredient penetrates leaf tissue and accumulates within the leaf structure. Abamectin has minimal impact on beneficial insects and mites that are not plant feeding and is compatible with integrated pest management (IPM) programmes.

Abamectin is part of a larger group of compounds known as avermectins. The avermectins are macrocyclic lactones which are naturally derived products of the soil microorganism *Streptomyces avermitilis*, an actinomycete. These compounds were originally discovered as antihelmintic (anti-worm) agents with activity against gastrointestinal worm parasites of sheep, cattle, dogs and poultry. Subsequent work demonstrated avermectin activity against various insect and mite plant pests as well as the root-knot nematode *Meloidogyne incognita*. When incorporated into the soil, avermectin B_{2a} was reported to exhibit excellent control of this nematode, superior to several unnamed contact nematicides (Putter *et al.*, 1981).

There are, to the author's knowledge, no published records of tests of avermectin against bud and leaf nematodes. The avermectins as a group, including those used in abamectin may, therefore, be of future use in controlling plant nematode pests such as bud and leaf nematode. An avermectin-based foliar spray with translaminar activity against nematodes could be of great value to the horticultural industry and warrants further investigation (Section 8).

6.4 Biological control

Bud and leaf nematode infestations are relatively persistent and immobile, which should make them amenable to biological control. However, the inaccessible nature of their habitat, feeding within the leaf or bud tissue, provides natural protection from contact with biological control agents.

There are numerous records of bio-control agents with potential use against plant parasitic nematodes (Jairajpuri *et al.*, 1990). They include pathogenic viruses, bacteria and fungi as well as predaceous protozoans, fungi, flatworms and nematodes. Higher organisms including tardigrades, springtails and mites have also been reported as nematode enemies.

The leaf and bud nematode is inaccessible to many natural enemies once it is feeding within leaf or bud tissue. To add to this difficulty, many of the bio-control agents described are active in the soil environment rather than the foliar environment of bud and leaf nematodes. The most accessible and vulnerable stage in the life cycle of bud and leaf nematode is during external migration in water films within or between plants to colonise new tissue. Pathogens have the opportunity to contact and infect nematodes on the plant surface during this stage. An ideal microbial-based biocontrol against bud and leaf nematodes would be applied as a foliar spray formulation. Once applied to the leaf surface the microbial agent would need to persist for some time and be resistant to periods of adverse temperature and humidity.

The spore forming bacteria *Pasteuria penetrans* (also referred to as *Bacillus penetrans*) has been noted (Ahmed, 1990) as a parasite of several species of plant parasitic nematodes including root-knot nematodes (*Meloidogyne* spp.). Spores of *P. penetrans* attach themselves to the nematode cuticle (body surface). Germination of the spores on the surface of *Meloidogyne incognita* (a root-knot nematode) is reported to start about eight days after the infected juvenile nematodes have entered the roots. The germinating spore penetrates the nematode body wall with a germ tube to give rise to vegetative cells which multiply within the nematode body. The life cycle of the host nematode and pathogen are closely synchronised; by the time the nematode matures its body is completely full with bacterial spores and is unable to reproduce.

At present, the biological control of bud and leaf nematodes has not been specifically investigated. If the spore stage of *P. penetrans* has the ability to survive for short periods on foliage, it may be capable of infecting bud and leaf nematodes during their migratory phase. The spread and increase of nematode populations could, therefore, be suppressed. Mankau and Prasad (1977) tested the infectivity of a population of *P. penetrans* on a range of nematode species. They reported that *Aphelenchoides* sp. were not infected by an isolate of *P. penetrans* taken from the root-knot nematode *Meloidogyne javanica*. However, they considered that a number of biotypes, races, or even species of *P. penetrans* probably exist. If this is the case, there may be a strain or closely related species of *P. penetrans* capable of infecting bud and leaf nematodes. The feasibility of using a strain of *P. penetrans* or other microbial pathogens against bud and leaf nematodes merits further investigation (Section 8).

6.5 Hot-water treatment

Hot-water treatment has been used extensively in the chrysanthemum industry against the bud and leaf nematode *A. ritzemabosi* and continues to be used in the bulb industry for control of stem nematode (*Ditylenchus dipsaci*). A comprehensive account of the theory and practice of hot-water treatment is given in the MAFF Reference Book 201: Hot-water Treatment of Plant Material (Gratwick & Southey, 1986).

The basic principle of hot-water treatment is to heat the affected plant material to such a temperature that the nematodes are killed while the plant tissue is undamaged. The margin between the two is usually small, so accurate control of the duration of the treatment and the temperature is essential.

The first record of hot-water treatment in the present century was in 1909 in Germany, where begonias and ferns were treated at 50°C for five minutes to control leaf nematode (Marcinowski, 1909). The technique was adopted with great effect in the early part of the century to save the UK bulb industry from destruction by stem nematode. Hot-water treatment was subsequently adopted widely for chrysanthemum stools, strawberry runners and mint, primarily against nematodes but also against tarsonemid mite, aphids and rust fungi.

Next to the control of stem nematode in bulbs, the hot-water treatment of dormant chrysanthemum stools against *A. ritzemabosi* was the second most important application of the process and became widespread amongst growers. A simple tank, often just a dustbin, was used and heated by a simple heater, such as a household oil-stove. Technical advancements made with hot-water treatment were driven mainly by the needs of the bulb industry to control stem nematode. Improvements in efficacy were gained through efficient pump-driven circulation of water, insulation and accurate thermostatic temperature control.

The temperature for killing nematodes varies with the species, e.g. *A. ritzemabosi* is easier to kill than *D. dipsaci*, the stem nematode (Woodville, 1964). There is a temperature below which each nematode species is virtually unharmed and a higher one at which death is practically instantaneous. Between these two temperatures there is a range of time and temperature combinations. Shorter immersion times are required at higher temperatures and longer times at lower temperatures.

The efficacy of hot-water treatment is entirely dependent on the ability to maintain the correct temperature throughout the treatment period. Practically all failures to control nematodes through this method have been traced to poor control of heat within the apparatus used (Gratwick & Southey, 1986). Too great a variation in the temperature can lead to partial failure of the process as a commercial treatment because of the small margin between killing the nematodes and damaging the plant tissue. A higher temperature or a longer time will damage the often valuable plant material, whereas a lower temperature or shorter time will not kill the pest.

Hot-water treatment of chrysanthemum stools for control of *A. ritzemabosi* has been established as 46°C for five minutes, or 43.5°C for 20–30 minutes (Gratwick, 1992). The shorter treatment is usually more convenient and involves less risk of damage to the more sensitive varieties. Gratwick & Southey (1986) also cite various other temperature/time combinations for use on other hosts of bud and leaf nematodes including *Fragaria, Gerbera, Hydrangea, Mentha, Paeonia, Phlox, Ribes, Saintpaulia* and *Viola*. In this instance, the technique was recommended specifically against bud and leaf nematodes only in the case of *Chrysanthemum, Fragaria, Saintpaulia* and *Viola*.

Hot-water treatment is used extensively by at least one large commercial nursery in the UK for the control of bud and leaf nematodes, stem nematode and root-knot-nematodes. The technique is used on a wide range of outdoor herbaceous and alpine plants including *Anemone, Aster, Chrysanthemum, Lamium, Phlox* and many other of the host species identified by the survey results in Tables 9 & 10. The water temperatures employed are in the range of 41–46°C. Immersion times are in the range of 6–15 minutes. The various time/temperature combinations have been developed gradually over many years of practical trial and error. The initial 'strike' temperature of the water immediately prior to treatment is normally a few degrees higher than that required to allow for initial cooling when the plants immersed.

The nursery in question uses the technique regularly on plant 'splits' bearing roots. Treatment is normally carried out in the spring on plants that have shown visual symptoms of attack. The plant splits are washed free of soil before immersion. The plants are held beneath the water in wire baskets of varying sizes. A wetter (e.g. Agral) is added to the water to improve wetting of the plant tissues. The hot-water treatment apparatus is based on a modified cattle drinking trough of approximately 50 gallon capacity. The container is well insulated with polystyrene foam on all external surfaces to minimise heat loss. A dividing plate partitions the heating element in a small chamber at one end of the tank to prevent direct contact with the plants. The electric heating element is of approximately 3 kW capacity. A large capacity electric pump provides rapid and turbulent circulation of water. Three thermostat sensors are located along the side wall of the water tank. The pump intake and heating element are protected from the ingress of plant debris by a wire mesh filter. This apparatus has been found to work well in practice, producing stable and accurately regulated water temperatures. At the end of the treatment period the plants are immediately cooled by plunging into cold water.

The nursery using the hot-water treatment detailed above comments that the technique has the disadvantage of being labour intensive, requiring experienced operators to work successfully. Treated plants also require careful weaning and nurturing to survive the shock of hot-water treatment. Although only partial control is sometimes obtained when incorrect time/temperature combinations are used, the method has demonstrated the potential to give extremely high standards of control. Furthermore, the method is favoured by the nursery as it has good operator safety and minimises the potentially hazardous use of Temik.

There is scope to expand the use of hot-water treatment in the horticultural industry amongst propagators of outdoor ornamentals for the control of bud and leaf nematodes. Future development work would be useful in refining optimum temperature/time combinations for various host plants. The feasibility of using hot-water treatment for the control of bud and leaf nematodes in woody shrubs should also be investigated (Section 8).

6.6 Tissue culture

The process of tissue culture normally involves removing small amounts of bud or meristem tissue from mother plants. This explant (source) tissue is usually surface sterilised in a dilute solution of sodium hypochlorite and then transferred onto agar-based growing media in aseptic (sterile) conditions. The tissue is then cultured in environmentally controlled growth rooms and manipulated to produce vigorous plants suitable for final growth under normal nursery conditions.

Tissue culture can be used to great effect to free infested plant lines of bud and leaf nematodes. There is, however, a danger that the nematodes could survive in tissue culture if contaminated tissue was taken from infested mother plants. The moist, warm, environment of tissue culture favours the survival of nematodes on host tissue.

Webster & Lowe (1966) successfully cultured *A. ritzemabosi* on a range of aseptically cultured callus tissue, including red clover and lucerne, to study the effect of a plant growth substances on the host-parasite relationship. There are, apparently, no records of bud and leaf nematode surviving in commercial tissue culture. However, tissue culture contamination problems have been known to occur with other pests such as mites and thrips.

Therefore, it seems reasonable to assume that bud and leaf nematodes could survive all stages of the tissue culture process including 'heat therapy'. During this process the mother plants are subjected to high temperatures to produce a flush of disease-free growth, the meristems of which are taken for culturing.

To ensure tissue cultured plants are not contaminated by bud and leaf nematode, steps should be taken to check that the mother plants are free of the pest. When a line of plants with a history of nematode problems are to be cultured, healthy plants clear of any symptoms of attack should be selected. As small numbers of bud and leaf nematode are capable of surviving for periods in host plants without causing the appearance of attack symptoms, mother plants should initially be tested for the presence of nematodes. The extraction technique normally used to test plant tissue for the presence of harmful nematodes is known as the Baermann method (Southey, 1986). In this technique, a finely chopped plant sample is suspended in water for about 24 hours. The nematodes swim free of the plant tissue and are collected in water at the base of a glass funnel. The technique is easy to use, relatively sensitive and capable of detecting small numbers of nematodes. Representative sampling of the test plants is vital for reliable results.

The technique of meristem dissection (T Marks, HRI, pers. comm.) offers another opportunity to minimise the risk of nematodes entering tissue culture. In this method, meristem explants are subjected to microscopic dissection. Small, healthy portions of meristem are removed for tissue culture. Bud and leaf nematodes are not able to colonise the small intercellular spaces of meristem tissue. They are, however, capable of surviving between the folds of tightly compressed bud tissue. When dissecting meristems under the microscope tissue fragments as small as 0.1 mm may be removed. Meristem tissue could, therefore, be searched for motile bud and leaf nematodes (adult body length 0.4–1.2 mm) during the dissection process prior to culturing. Nematode eggs remain a possible threat as they are far smaller, so meristems containing motile nematodes should be discarded.

Methods to reduce or eliminate the risk of nematodes surviving in tissue culture merit further investigation (Section 8).

6.7 Varietal susceptibility

Differences in susceptibility between chrysanthemum varieties to *A. ritzemabosi* were investigated by Hesling & Wallace (1961c) and Wallace (1961) but have not been put to practical use due to the wide and constantly changing range of commercially available cultivars.

Strawberry varieties have also been noted to have differing susceptibility to *A. fragariae* but this has not been put to commercial use in the UK. It is thought that the varietal susceptibility of strawberries is linked to the level of phenolic compounds in the leaves (Szczygiel & Giebel, 1970).

No recent work has been done to quantify the varietal susceptibility of ornamental plants to bud and leaf nematodes. Less susceptible varieties are unlikely to be entirely immune to invasion by the nematode, although the appearance of symptoms may be less severe. If reliable differences in varietal susceptibility could be found, there may be scope to exploit them commercially, (Section 8).

7. DISCUSSION

The grower survey conducted as part of this review has highlighted the pest status and economic losses caused by bud and leaf nematode in outdoor ornamentals. Furthermore, the difficulty of obtaining satisfactory long-term control of the pest has been confirmed. Bud and leaf nematode is a widespread and long-term problem within the industry but it is little recognised and often readily accepted.

If the incidence of bud and leaf nematode is to be reduced and the quality of plants improved, steps should be taken to eradicate the pest from the propagation cycle. Higher standards of plant health must be applied in the propagation and production of plants. General awareness of the bud and leaf nematode problem in the ornamental plant industry needs to be heightened to ensure that the problem is contained and the trade of infested plants is minimised.

Integrated control strategies, making use of all available methods of control, offer the best long-term prospect of eliminating bud and leaf nematodes from the chain of plant propagation and production. Integrated control involves the adoption of a range of control measures. Cultural control techniques and hygiene precautions are basic requirements to prevent re-invasion of the pest. Aldicarb granules (Temik) are commonly used against the pest and commercially acceptable control is often obtained. Aldicarb is often used in a reactive way to suppress infestations as soon as they are found. However, eradication of the pest is difficult to achieve through chemical treatment alone as nematode populations often build up again when the residual effect of treatment diminishes.

Further development of new nematicides, as they become available, should not be dismissed. Despite the shortcomings of chemical treatment, the current use of Temik is clearly a popular and convenient option for many growers. The activity of the avermectins against bud and leaf nematodes requires investigation as a future prospect.

The varietal susceptibility of host plants has not been studied. It may be possible to exploit varietal differences, if they exist, to commercial advantage.

Tissue culture or hot-water treatment should be used more widely to obtain nematode-free mother plants. Both techniques merit further development and promotion. Visual symptoms of attack may be slow to develop and are often difficult to recognise. Quarantine procedures and the routine testing of plants for the presence of nematodes could also be deployed more widely to safeguard nurseries from inadvertently buying or producing contaminated plants.

Biological control of invertebrate pests has been adopted with great success in many sectors of the horticultural industry. Although nematodes are now in use to control insect pests such as vine weevil, the use of bio-control agents against bud and leaf nematodes has not been explored. Microbial organisms probably offer the best prospect against nematodes. However, many of the candidate organisms currently identified are soil-based organisms, which may pose difficulty in the control of foliar species such as bud and leaf nematodes. Fundamental studies are required to screen and identify prospective bio-control agents.

A great depth of information already exists in relation to the biology and control of bud and leaf nematodes. This review has attempted to summarise the scope of our existing knowledge and has identified several areas of research with potential future value to the horticultural industry (Section 8).

8. RECOMMENDATIONS FOR FUTURE RESEARCH

The following topics have been identified as warranting further research:

- Investigation of the efficacy of avermectins, primarily abamectin (Dynamec), for the control of bud and leaf nematode, (Section 6.3.3).

- Development and improvement of the efficacy of hot-water treatment against bud and leaf nematodes in susceptible species of outdoor ornamentals, including a feasibility study for use of hot-water treatment on woody shrubs, (Section 6.5).

- Screening and assessment of microbial bio-control agents for potential use against bud and leaf nematode, (Section 6.4).

- Development of methodology to prevent the survival and transmission of leaf and bud nematodes in tissue culture, (Section 6.6).

- Investigation of host plant varietal susceptibility to bud and leaf nematode, (Section 6.7).

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11. APPENDIX

11.1 Appendix I

Flowering plant (Phanerogamae) hosts of bud and leaf nematodes, *A fragariae* and *A. ritzemabosi.* Host plants listed as generic names.

Host Plant	Nematode Species
Achillea filipendulina	*A. ritzemabosi*
Aconitum lycoctonum	*A. fragariae*
Aconitum napellus	*A. ritzemabosi*
Aconitum sp.	*A. fragariae*
Acrostichum flagelliferum	*A. fragariae*
Actaea spicata	*A. fragariae*
Adenostyles alpina	*A. ritzemabosi*
Aegopodium podagraria	*A. ritzemabosi*
Ageratum conyzoides	*A. fragariae*
Ageratum houstonianum	*A. ritzemabosi*
Ageratum mexicanum	*A. ritzemabosi*
Allium flavum	*A. ritzemabosi*
Allium sativum	*A. ritzemabosi*
Allium sikkimense	*A. ritzemabosi*
Ampelopsis quinquefolia	*A. ritzemabosi*
Anacyclus pyrethrum	*A. ritzemabosi*
Anchusa caespitosa	*A. fragariae*
Anchusa myosotidiflora	*A. fragariae & A. ritzemabosi*
Androsace sarmentosa	*A. fragariae*
Anemone alpina	*A. fragariae*
Anemone angulosa	*A. fragariae*
Anemone coronaria	*A. fragariae & A. ritzemabosi*
Anemone flaccida	*A. fragariae*
Anemone halleri	*A. fragariae*
Anemone hepatica	*A. fragariae & A. ritzemabosi*
Anemone hupehensis	*A. fragariae*
Anemone japonica	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Anemone nemorosa	*A. fragariae*
Anemone ranunculoides	*A. fragariae*
Anemone silvestris	*A. fragariae & A. ritzemabosi*
Anemone vitifolia	*A. fragariae*
Anthemis nobilis	*A. ritzemabosi*
Anthemis pedunculata	*A. ritzemabosi*
Anthemis sp.	*A. ritzemabosi*
Anthemis tinctoria	*A. ritzemabosi*
Anthiscus sylvestris	*A ritzemabosi*
Anthurium andraeanum	*A. fragariae*
Antirrhinum majus	*A. ritzemabosi*
Apium dulce	*A. ritzemabosi*
Aquilegia longissima.	*A. ritzemabosi*
Aquilegia sp.	*Aphlenchoides* sp.
Arabis aubrietioides	*A. ritzemabosi*
Arisaema amurense	*A. fragariae*
Arisaema ringens	*A. fragariae*
Artemisia spp.	*A. ritzemabosi*
Aster alpinus	*A. fragariae & A. ritzemabosi*
Aster caucasicus	*A. ritzemabosi*
Aster dumosus	*A. ritzemabosi*
Aster novi-belgii	*A. ritzemabosi*
Aster pattersoni	*A. fragariae*
Aster sp.	*A. ritzemabosi*
Aster tradescanti	*A. ritzemabosi*
Astrantia biebersteinii.	*A. fragariae*
Astrantia carniolica	*A. fragariae*
Astrantia major	*A. fragariae*
Atragene alpina	*A. fragariae & A. ritzemabosi*
Begonia fuchsoides	*A. fragariae*
Begonia rex	*A. fragariae*
Begonia semperflorens	*A. fragariae*
Begonia sp.	*A. fragariae & A. ritzemabosi*
Bellis perennis	*A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Bergenia delavayi	*A. fragariae*
Bergenia pacifica	*A. fragariae*
Bergenia sp.	*A. ritzemabosi*
Bletia hyacinthina	*A. fragariae*
Bletia striata	*A. fragariae*
Bouvardia sp.	*A. fragariae*
Boykinia aconitifolia	*A. fragariae*
Brassica oleracea	*A. fragariae*
Buddleia davidii	*A. ritzemabosi*
Buddleia globosa	*A. ritzemabosi*
Buddleia spp.	*A. ritzemabosi*
Buddleia variabilis	*A. ritzemabosi*
Bunias ovientalis	*A. ritzemabosi*
Calamintha nepeta	*A. fragariae*
Calceolaria	*A. fragariae* & *A. ritzemabosi*
Calendula officinalis	*A. ritzemabosi*
Callistephus chinensis	*A. ritzemabosi*
Callistephus sp.	*A. ritzemabosi*
Calonyction aculeatum	*Aphlenchoides* sp.
Campanula rapunculoides	*A. ritzemabosi*
Capsella bursa-pastoris	*A. fragariae* & *A. ritzemabosi*
Centaurea jacea	*A. ritzemabosi*
Centaurea montana	*A. ritzemabosi*
Cerastium vulgatum	*A. ritzemabosi*
Ceratostigma willmottianum	*A. ritzemabosi*
Chelidonium majus	*A. ritzemabosi*
Chenopodium album	*A. ritzemabosi*
Choisya sp.	*Aphelenchoides* spp.
Chrysanthemum balsarnita	*A. ritzemabosi*
Chrysanthemum cinerariifolium	*A. ritzemabosi*
Chrysanthemum coccineum	*A. ritzemabosi*
Chrysanthemum hortorum	*A. fragariae*
Chrysanthemum indicum	*A. fragariae* & *A. ritzemabosi*
Chrysanthemum koreanum	*A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Chrysanthemum leucanthemum	*A. fragariae & A. ritzemabosi*
Chrysanthemum maximum	*A. ritzemabosi*
Chrysanthemum morifolium	*A. ritzemabosi*
Chrysanthemum parthenium	*A. ritzemabosi*
Chrysanthemum rubellum	*A. ritzemabosi*
Chrysanthemum sp.	*A. fragariae & A. ritzemabosi*
Cirsium arvense	*A. ritzemabosi*
Clematis heracleaefolia	*A. fragariae*
Clematis tangutica	*A. ritzemabosi*
Clematis vitalba	*A. fragariae & A. ritzemabosi*
Cochlearia officinalis	*A. ritzemabosi*
Colchicum sp.	*A. fragariae & A. ritzemabosi*
Coleus hybridus	*A. ritzemabosi*
Coleus sp.	*A. fragariae*
Cornus canadensis	*A. fragariae*
Cornus florida	*A. fragariae*
Convallaria majalis	*A. fragariae & A. ritzemabosi*
Convolvulus sp.	*A. ritzemabosi*
Crassula sp.	*A. fragariae*
Crassula coccinea	*A. ritzemabosi*
Crossandra undulifolia	*A. fragariae*
Cyclamen giganteum	*Aphelenchoides* sp.
Cyclamen persicum	*A. fragariae & A. ritzemabosi*
Cyclamen sp.	*A. fragariae & Aph.* sp.
Cyperus alternifolius	*A. fragariae*
Cypripedium sp.	*A. fragariae*
Cypripedium spectabile	*A. fragariae*
Dahlia sp.	*A. fragariae & A. ritzemabosi*
Dahlia variabilis	*A. fragariae & A. ritzemabosi*
Delphinium sp.	*A. ritzemabosi*
Dianthus caryophyllus	*A. ritzemabosi*
Diervilla sp.	*A. ritzemabosi*
Digitalis purpurea	*A. fragariae*
Doronicum caucasicum	*A. fragariae & A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Doronicum columnae	*A. ritzemabosi*
Doronicum cordifolium	*A. ritzemabosi*
Doronicum orientale	*A. ritzemabosi*
Doronicum plantagineum	*A. fragariae*
Doronicum sp.	*A. fragariae & A. ritzemabosi*
Echinacea purpurea	*A. ritzemabosi*
Echium sp.	*A. ritzemabosi*
Elsholtzia cristata	*A. ritzemabosi*
Endymion hispanicus	*A. fragariae*
Epildoium montanum	*A. ritzemabosi*
Epipactis palustris	*A. fragariae*
Episcia chontalensis	*A. fragariae*
Eremurus stenophyllus	*A. ritzemabosi*
Erigeron glabellus	*A. ritzemabosi*
Erigeron uniflorus	*A. ritzemabosi*
Erigeron villarsii	*A. ritzemabosi*
Eryngium alpinum	*A. ritzemabosi*
Erysimium perofskianum	*A. ritzemabosi*
Ficus bengalis	*A. fragariae*
Ficus comosa.	*Aphelenchoides* sp.
Ficus elastica	*A. fragariae*
Ficus radicans	*Aphelenchoides* sp.
Ficus religiosa	*A. fragariae*
Ficus macrophylla	*A. fragariae*
Ficus rubiginosa	*A. fragariae*
Ficus sp.	*A. fragariae*
Ficus stipulata	*Aphelenchoides* sp.
Forsythia suspensa	*A. ritzemabosi*
Fragaria xananassa	*A. fragariae & A. ritzemabosi*
Fragaria sp.	*A. ritzemabosi*
Fragaria vesca	*A. ritzemabosi*
Fuchsia sp.	*A. fragariae*
Gaillardia grandiflora	*A. ritzemabosi*
Galium aparine	*A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Gardenia jasminoides	*A. fragariae*
Geranium macrorrhizum	*A. fragariae*
Geranium sp.	*A. ritzemabosi*
Geranium subcaulescens	*A. fragariae*
Gerbera jamesoni	*A. fragariae*
Glechoma hederacea	*A. fragariae*
Gomphrena globosa	*A. fragariae*
Gunnera chilensis	*A. fragariae*
Gymnostachyum ceylanicum	*A. fragariae*
Gypsophila cerastoides	*A. fragariae*
Helenium autumnale	*A. ritzemabosi*
Helenium sp.	*A. ritzemabosi*
Helianthus anuus	*A. ritzemabosi*
Helianthus decapetalus	*A. ritzemabosi*
Helianthus tuberosus	*A. ritzemabosi*
Helichrysum ambiguum	*A. ritzemabosi*
Helichrysum angustifolium	*A. ritzemabosi*
Helichrysum sp.	*A. fragariae*
Heliopsis scabra	*A. ritzemabosi*
Helleborus abchasicus	*A. fragariae*
Helleborus antiquorum	*A. fragariae*
Helleborus cyclophyllus	*A. fragariae*
Helleborus foetidus	*A. fragariae*
Helleborus intermedius	*A. fragariae*
Helleborus niger	*A. fragariae*
Helleborus olympicus	*A. fragariae*
Helleborus orientalis	*A. fragariae*
Helodea sp.	*Aphelenchoides* sp.
Hemigraphis colorata	*A. fragariae*
Heuchera sanguinea	*A. fragariae & A. ritzemabosi*
Heuchera sp.	*A. fragariae & A. ritzemabosi*
Hibiscus rosa-sinensis	*A. fragariae*
Horminum pyrenaicum	*A. fragariae*
Hosta sp.	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Hydrangea hortensia	*A. fragariae*
Hydrangea sp.	*A. fragariae*
Hydrophyllum canadense	*A. fragariae*
Impatiens balfouri	*A. ritzemabosi*
Impatiens balsamina	*A. fragariae & A. ritzemabosi*
Impatiens sultani	*Aphelenchoides* sp.
Incarvillea delavayi	*A. ritzemabosi*
Incarvillea sp.	*A. ritzemabosi*
Ipomoea purperea	*A. ritzemabosi*
Iris sp.	*A. fragariae & A. ritzemabosi*
Isatis tinctoria	*A. ritzemabosi*
Kalanchoe coccinea	*A. fragariae*
Knautia arvensis	*A. fragariae & A. ritzemabosi*
Knautia macedonica	*A. fragariae*
Lactuca sativa	*A. ritzemabosi*
Lamium album	*A. ritzemabosi*
Lamium purpureum	*A. ritzemabosi*
Lantana sp.	*A. fragariae*
Lavandula vera	*A. ritzemabosi*
Lavandula sp.	*A. ritzemabosi*
Leucanthemum hosmariense	*A. ritzemabosi*
Lewisia sp.	*A. ritzemabosi*
Ligustrum vulgare	*A. fragariae*
Lilium henryi	*A. fragariae & A. ritzemabosi*
Lilium hollandicum	*A. fragariae*
Lilium humboldtii	*A. fragariae*
Lilium longiflorum	*A. fragariae & Aph. sp.*
Lilium pardalinum	*A. fragariae*
Lilium phillippinese	*A. fragariae*
Lilium pumilum	*A. fragariae*
Lilium regale	*A. fragariae & A. ritzemabosi*
Lillium sargentiae	*A. fragariae*
Lilium speciosum	*A. fragariae*
Lilium sulphurgale	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Lilium tennifolium	*A. ritzemabosi*
Limonium sinuatum	*A. fragariae*
Limonium vulgare	*A. ritzemabosi*
Limnophila sp.	*A. fragariae*
Lobelia erinus	*A. fragariae*
Lupinus sp.	*A. ritzemabosi*
Lycopersicon esculentum	*A. ritzemabosi*
Lycoris radiata	*A. fragariae*
Malvasterum lateritum	*A. ritzemabosi*
Maranta leuconeura	*A. fragariae*
Medicago sativa	*A. ritzemabosi*
Melandrium elisabethae	*A. fragariae*
Mentha piperita	*A. ritzamabosi*
Mentha spicata	*A. fragariae*
Mentha sp.	*A. fragariae & A. ritzemabosi*
Mimulus guttatus	*A. ritzemabosi*
Morina longifolia	*A. ritzemabosi*
Narcissus pseudonarcissus	*A. fragariae*
Nerine sp.	*A. fragariae*
Nicotiana affinis	*A. ritzemabosi*
Nicotiana rustica	*A. ritzemabosi*
Nicotiana sp.	*A. fragariae*
Nicotiana tabacum	*A. ritzemabosi*
Nicotiana virginica	*A. fragariae*
Ocimum sp.	*A. ritzemabosi*
Odontoglossum sp.	*A. fragariae*
Omphalodes verna	*A. fragariae*
Oryza sativa	*Aphelenchoides* sp.
Paeonia albiflora	*A. fragariae*
Paeonia lutea	*A. fragariae*
Paeonia moutan	*A. fragariae*
Paeonia officinalis	*A. fragariae*
Paeonia sp.	*A. fragariae & A. ritzemabosi*
Paeonia wittmanniana	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Papaver ovientale	*A. ritzemabosi*
Papaver sp.	*A. ritzemabosi*
Paphiopedilum sp.	*A. fragariae*
Pelargonium sp.	*A. fragariae*
Peltiphyllum peltatum	*A. fragariae*
Pentas lanceolata	*A. fragariae*
Pentstemon barbatus	*A. fragariae & A. ritzemabosi*
Pentstemon gentianoides	*A. fragariae & A. ritzemabosi*
Pentstemon hirsutus	*A. fragariae & A. ritzemabosi*
Pentstemon laevigatus	*A. ritzemabosi*
Pentstemon neomexicanus	*A. fragariae*
Peperomia caperata	*A. ritzemabosi*
Peperomia glabella	*A. ritzemabosi*
Peperomia griseo-argentea	*A. ritzemabosi*
Peperomia magnoliaefolia	*A. fragariae*
Peperomia sp.	*A. fragariae & A. ritzemabosi*
Peplis sp.	*A. fragariae*
Phaseolus vulgaris	*A. ritzemabosi*
Philadelphus sp.	*Aphelenchoides* sp.
Phlox amoena	*A. ritzemabosi*
Phlox douglasii	*A. ritzemabosi*
Phlox drummondii	*A. ritzemabosi*
Phlox paniculata	*A. fragariae & A. ritzemabosi*
Phlox subulata	*A. ritzemabosi*
Phyllocactus sp.	*A. fragariae*
Pimpinella diversifolia	*A. ritzemabosi*
Pinus palustris	*A. fragariae*
Plantago major	*A. ritzemabosi*
Poa annua	*A. ritzemabosi*
Podophyllum peltatum	*A. ritzemabosi*
Potentilla alpina	*A. fragariae*
Potamogeton sp.	*A. fragariae*
Prenanthes alba	*A. ritzemabosi*
Primula anisiaca	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Primula auricula	*A. fragariae*
Primula beesiana	*A. fragariae*
Primula denticulate	*A. fragariae*
Primula denticulata	*A. fragariae*
Primula helenae	*A. fragariae*
Primula japonica	*A. fragariae*
Primula luteola	*A. fragariae*
Primula malocoides	*A. fragariae*
Primula obconica	*A. fragariae*
Primula polyantha	*A. fragariae* & *A. ritzemabosi*
Primula pulverulenta	*A. fragariae*
Primula rosea	*A. fragariae*
Primula sp.	*A. fragariae*
Primula wanda	*A. ritzemabosi*
Primula wilsoni	*A. fragariae*
Prunus cerasus	*A. ritzemabosi*
Pulmonaria officinalis	*A. fragariae*
Pyrethrum sp.	*Aphelenchoides* sp.
Pyrus sp.	*A. fragariae*
Ranunculus acer	*A. ritzemabosi*
Ranunculus alpestris	*A. fragariae*
Ranunculus auriconius	*A. ritzemabosi*
Ranunculus montanus	*A. fragariae*
Ranunculus repens	*A. ritzemabosi*
Ranunculus speciosus	*A. fragariae*
Ranunculus sp.	*A. fragariae*
Rhododendron sp.	*A. ritzemabosi*
Rhynchospermum verticillatum	*A. ritzemabosi*
Ribes nigrum	*A. ritzemabosi*
Ribes sanguineum	*A. ritzemabosi*
Ribes uva-cripsa	*A. fragariae* & *A. ritzemabosi*
Rochea coccinea	*Aphelenchoides* sp.
Rodgersia podophylla	*A. fragariae*
Rodgersia purdomii	*A. fragariae*

Appendix I. Continued

Host Plant	Nematode Species
Rodgersia sambucifolia	*A. fragariae*
Rosemarinus sp.	*A. ritzemabosi*
Rubens idaeus	*A. ritzemabosi*
Rudbeckia fulgida	*A. ritzemabosi*
Rudbeckia laciniata	*A. ritzemabosi*
Rudbeckia newmani	*A. fragariae & A. ritzemabosi*
Rudbeckia nitida	*A. ritzemabosi*
Rudbeckia sp.	*A. ritzemabosi*
Rumex alpinus	*A. fragariae*
Rumex sp.	*A. ritzemabosi*
Ruscus hypophyllum	*A. fragariae*
Saintpaulia ionantha	*A. fragariae & A. ritzemabosi*
Saintpaulia sp.	*A. fragariae & A. ritzemabosi*
Saxil reticulata	*A. ritzemabosi*
Salvia farinacea	*A. fragariae & A. ritzemabosi*
Salvia officinalis	*A. ritzemabosi*
Salvia pratensis	*A. ritzemabosi*
Salvia sp.	*A. fragariae & A. ritzemabosi*
Salvia splendens	*A. fragariae*
Salvia sylvestris	*A. ritzemabosi*
Sambucus racemosa	*A. ritzemabosi*
Saponaria olivana	*A. ritzemabosi*
Saxifraga crassifolia	*A. fragariae*
Saxifraga decipiens	*A. fragariae*
Saxifraga ligulata	*A. fragariae*
Saxifraga rotundifolia	*A. fragariae*
Saxifraga sarmentosa	*A. fragariae & A. ritzemabosi*
Saxifraga superba	*A. fragariae*
Scabiosa caucasica	*A. fragariae & A. ritzemabosi*
Scabiosa columbaria	*A. fragariae & A. ritzemabosi*
Scabiossa lucida	*A. fragariae & A. ritzemabosi*
Scabiosa silenifolia	*A. fragariae*
Scilla sp.	*A. fragariae*
Scindapsus aureus	*A. fragariae & A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Scrophularia vernalis	*A. fragariae*
Sedum maximum	*A. ritzemabosi*
Senecio clivorum	*A. fragariae*
Senecio cruentus	*A. ritzemabosi*
Senecio nemorensis	*A. fragariae*
Senecio vulgaris	*A. fragariae & A. ritzemabosi*
Silene schafta	*A. ritzemabosi*
Sinningia hybrida	*A. fragariae*
Sinningia sp.	*A. fragariae & A. ritzemabosi*
Sinningia speciosa	*A. fragariae*
Solanum nigrum	*A. fragariae & A. ritzemabosi*
Solidago rupestris	*A. ritzemabosi*
Sonchus arvensis	*A. ritzemabosi*
Sonchus oleraceus	*A. ritzemabosi*
Spilanthes acmella	*A. ritzemabosi*
Spiraea arunaus	*A. fragariae*
Stachys alopecuros	*A. fragariae*
Stachys longifolia	*A. fragariae*
Stachys officinalis	*A. fragariae*
Stachys palustris	*A. fragariae*
Stachys sylvatica	*A. ritzemabosi*
Statice latifolia	*A. ritzemabosi*
Statice speciosa	*A. ritzemabosi*
Stellaria media	*A. ritzemabosi*
Stenoglottis longifolia	*A. fragariae*
Strobilanthes dyerianus	*A. fragariae*
Symphytum asperum	*A. fragariae*
Symphytum sp.	*Aphelenchoides* sp.
Taraxacum officinale	*A. ritzemabosi*
Tellima grandiflora	*A. fragariae*
Teucrium arduini	*A. fragariae*
Teucrium chamaedrys	*A. fragariae*
Tradescantia virginiana	*A. fragariae*
Trifolium pratense	*A. ritzemabosi*

Appendix I. Continued

Host Plant	Nematode Species
Trifolium repens	*A. fragariae*
Trillium grandiflorum	*A. fragariae*
Triosteum fargesii	*A. fragariae*
Ulmus sp.	*A. fragariae*
Urtica dioica	*A. ritzemabosi*
Urtica urens	*A. ritzemabosi*
Valeriana montana	*A. ritzemabosi*
Vanda sp.	*A. fragariae*
Verbena sp.	*A. ritzemabosi*
Verbena tenera	*A. fragariae*
Verbena venosa	*A ritzemabosi*
Veronica arvensis	*A. fragariae*
Veronica agrestis	*A. ritzemabosi*
Veronica grandis	*A. ritzemabosi*
Veronica incana	*A. ritzemabosi*
Veronica sp.	*A. ritzemabosi*
Veronica spicata	*A. ritzemabosi*
Veronica stelleri	*A. fragariae*
Viburnum sp.	*A. ritzemabosi*
Viola sp.	*A. fragariae*
Viola uliginosa	*A. fragariae*
Weigelia sp.	*A. ritzemabosi*
Wulfenia carinthiaca	*A. fragariae*
Xanthium canadense	*A. fragariae*
Zebrina pendula	*A. fragariae*
Zinnia elegans	*A. fragariae & A. ritzemabosi*
Zinnia haageana	*A. ritzemabosi*
Zinnia sp.	*A. fragariae*

11.2 Appendix II

Leaf and bud nematode survey questionnaire (over page).

Leaf and Bud Nematode Survey

ADAS

FOOD, FARMING, LAND & LEISURE

The Horticultural Development Council
is greatfully acknowledged for funding this work.

The object of this questionnaire is to establish the distribution and severity of leaf and bud nematodes as pests of hardy ornamental nursery stock.

We do not need to know your name and addresses, this will ensure that all respondents to the survey will remain anonymous.

Please refer to the article on leaf and bud nematode biology and symptom recognition in the current issue (No. 15) of Outdoor Ornamental Technical Notes before you complete the questionnaire.

1 What is the size of your nursery in hectares? [ ] ha

2 Please indicate which of the following are grown on your nursery.

- General hardy container stock [ ] 1
- Herbaceous container stock [ ] 1
- Alpine container stock [ ] 1
- Field grown trees and shrubs [ ] 1
- Field grown herbaceous stock [ ] 1

3 Do you propagate you own stock? Yes [ ] 1 No [ ] 2

4 Were you aware that leaf and bud nematode is a pest of ornamentals? Yes [ ] 1 No [ ] 2

5 Has leaf and bud nematode been found at any time on your nursery? Yes [ ] 1 No [ ] 2

If yes, please complete the rest of the questionnaire.
If no, please return the questionnaire, because it is important to know the number of nurseries that are free of this pest.

6 Is leaf and bud nematode currently active on your nursery? Yes [ ] 1 No [ ] 2

7 For how many years has the pest been active on your nursery? [ ] yrs

8 If the pest is no longer present on your nursery but was a problem in the past, please give the year in which it last occurred. | 1 | 9 | | |

[✓] 99

9 Who first recognised or diagnosed the problem on your nursery?

- Nursery personnel ☐ 1
- Consultant ☐ 2
- Plant Health Inspector ☐ 3
- Customer ☐ 4
- Other ☐ 5

Please describe other: ☐

10 Was the problem confirmed by microscopic examination by a specialist? Yes ☐ 1 No ☐ 2

11 Please list the plant species affected by leaf and bud nematode on your nursery under the following headings:

General hardy shrubs		Herbaceous plants		Alpines	

12 What was the suspected source of the pest?

- Brought in on a batch of contaminated plants ☐ 1
- Natural infestation of own plants ☐ 2
- Unknown ☐ 3

13 Is the pest present in?

- Stock plants used for propagation ☐ 1
- Liners ☐ 2
- Final plants ☐ 3

14 Which control measures have been adopted against the pest and in what stage of plant production? ☑ 99

	Stock plants	Production plants	None
Destruction of infested plants	☐ 1	☐ 2	☐ 3
Hygiene precautions	☐ 1	☐ 2	☐ 3
Quarantine procedures	☐ 1	☐ 2	☐ 3
Chemical (Temik) treatment	☐ 1	☐ 2	☐ 3
Hot water	☐ 1	☐ 2	☐ 3
Tissue culture	☐ 1	☐ 2	☐ 3
Other	☐ 1	☐ 2	☐ 3

Please describe other: ☐

15 What have your control measures achieved?

- Pest eradicated ☐ 1
- Pest suppressed to an acceptable level ☐ 2
- Poor or unacceptable control ☐ 3

16 Has the pest hindered or prevented the sale or production of infested lines? Yes ☐ No ☐

17 Please estimate your average annual economic losses from this pest including the costs associated with control.

- Nil ☐ 1
- Less than £1000 ☐ 2
- £1000 - £5 000 ☐ 3
- £5 000 - £10 000 ☐ 4
- More than £10 000 ☐ 5

Please add any further relevant comments or information if you wish.

Thank you for completing this questionnaire. Please return it in the envelope provided to:
ADAS Market Research Team, 98 Epsom Road, Guildford, Surrey, GU1 2LD

11.3 Appendix III

Copy of HDC contract for project HNS 60 (over page).

Contract between ADAS (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called the "Council") for a research/development project.

1. TITLE OF PROJECT

Project No: HNS 60
Contract date: 24.4.95

HARDY ORNAMENTAL NURSERY STOCK: A REVIEW OF THE BIOLOGY AND CONTROL OF LEAF AND BUD NEMATODES

2. BACKGROUND AND COMMERCIAL OBJECTIVE

The increasing prevalence and awareness of problems caused by the leaf and bud nematode (*Aphelenchoides* spp.) in nursery stock has given rise to concern. This insidious pest is often difficult to eradicate. Chemical control only gives short-term suppression of the problem. The nematodes often go undetected in the propagation cycle owing to unhealthy stock plants which do not always exhibit obvious external symptoms of attack. The proposed review will provide an up-to-date summary of all existing knowledge concerning this increasingly important pest.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

The horticultural industry will benefit immediately by having all available knowledge of the topic summarised and interpreted for immediate use. The study will also serve to identify possible gaps or weaknesses in our existing knowledge, the future study of which would benefit the industry by offering improved methods or strategies for the control of this pest.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

The author intends to look comprehensively at the subject by reviewing, summarising and interpreting the value and use of our current knowledge of the pest. As mentioned above, the review will also help identify problems which might be solved by further research, which may be funded by industry and/or government, in relation to improving control of the pest.

5. CLOSELY RELATED WORK - COMPLETED OR IN PROGRESS

To our knowledge, there is no work in progress on leaf and bud nematode. However, much knowledge already exists from earlier studies. It would be valuable to summarise the current status of our knowledge by reviewing previous work on what is, to some extent, a "forgotten" pest.

6. DESCRIPTION OF THE WORK

The proposed review will cover the following issues;

- Biology and life history
- Host range and symptoms of attack

- Grower survey (postal) to determine the scale, distribution and awareness of the problem.

- Control methods - chemical, cultural and physical - past and present

- Control strategies - suggested options for future control and recommendations for future research.

This study will be based largely upon a wide-ranging review of the published international literature. The services of ADAS, MAFF and (possibly) external libraries will be essential to undertake comprehensive literature searches. On-line computer based literature searches will be done. However, it is likely that manual searching will be required as many references to early work could pre-date the literature data-bases.

7. COMMENCEMENT DATE, DURATION AND REPORTING DATES

Start date 01.04.95; duration 1 year.

The final report will be produced by the end of March 1996.

8. STAFF RESPONSIBILITIES

Project leader - John Young, Senior Research Consultant at ADAS Boxworth.

No other staff directly involved apart from consultation with ADAS hardy nursery stock consultants and key growers.

9. LOCATION

ADAS Boxworth