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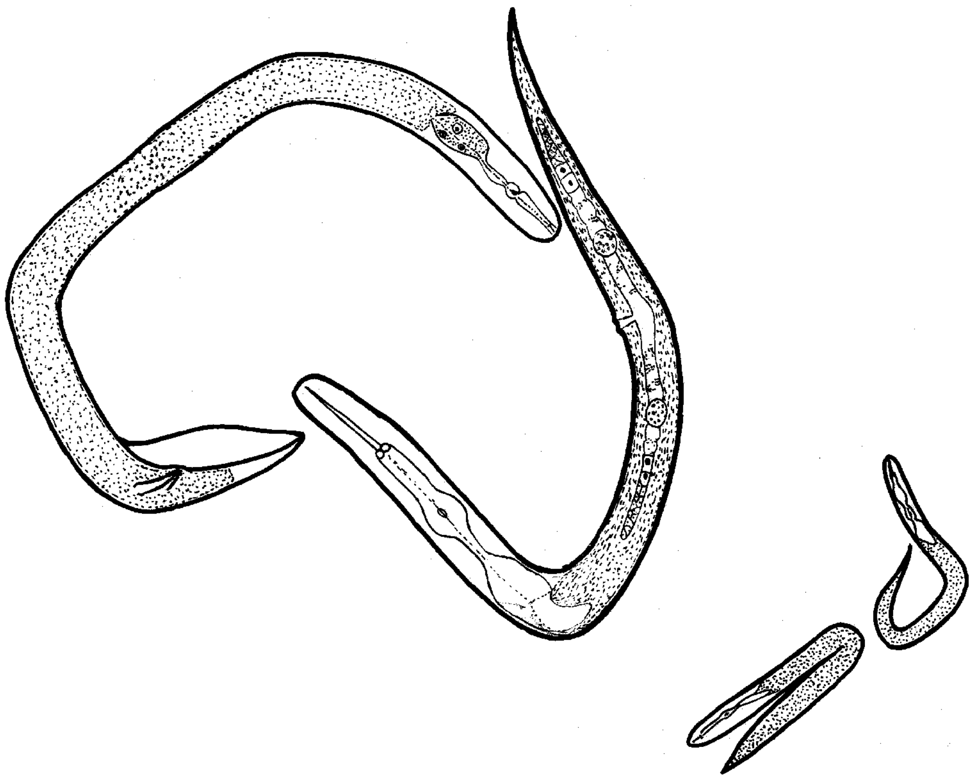
AUSTRALASIAN NEMATOLOGY NEWSLETTER



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From the Editor

Thank you to all those who made contributions to this newsletter.

July Issue

The deadline for the July issue is June 15th. I will notify you a month in advance so please have your material ready once again.

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Association News

FROM THE PRESIDENT

The joint meeting of the 8th International Congress of Plant Pathology and Australasian Plant Pathology Society in Christchurch has crept up remarkably quickly after the memorable meeting at Cairns less than 18 months ago. Let's hope there are no more surprises involving Air New Zealand this time. (That last provocative statement thrown in for the benefit of our Kiwi members: we have not forgotten you.)

Because of the relatively short time since Cairns, and because it is also the International Congress of Plant Pathology, myself and the Secretary decided that a formal biennial meeting of the AAN will not be held at the APPS meeting as is usual. There will be an informal meeting of AAN held during one of the breaks in the busy schedule, probably over lunch on Thursday after the nematology session chaired by David Bird. John Marshall has agreed to organise this meeting so please get in touch with John to find out when it will take place. I will probably not be present, but Ian Riley will be there. We decided that more members may be present if the formal biennial meeting was held in conjunction with the Soilborne Diseases Symposium in Adelaide early in 2004, which is a little later than usual. Please mark the meeting in your diaries.

I have had only one comment so far regarding the suggestion for holding the 5th International Congress of Nematology in Australasia, which was in favour with some qualifications. Please give some thought to this proposal, because, although it seems a long way off, planning for such an event starts a long time ahead

Regional News

NEWS FROM NEW ZEALAND

Some crumbs from considering cereal grains, soil particles and soil biology

I attended the GRDC-sponsored workshop 'Root/Soil Biology in Agriculture: Towards a New Conceptual Framework III' held at CSIRO Plant Industry 30 October – 2 November 2002 and came away stimulated.

This series of workshops, under the GRDC Soil Biology Initiative, is intended to develop soil biology as an integral part of sustainable farming systems and is organised by Dr Margaret McCully. Of the 15 oral papers three were invited contributions concerning nematodes. They were set among diverse contributions including gas relations of roots, the impacts of and solutions to water logging, crop residues and root development, the role of soil algae, function of actinomycetes, and ideas of optimising the architecture of root systems. Gregor Yeates described 'How nematodes make a positive contribution to soil processes', Ian Riley gave an account of 'Plant parasitic nematodes in Australian agricultural soils' and Graham Stirling explained 'Manipulating soil biology: Biological control of plant parasitic nematodes'.

A late afternoon poster session included some with nematological themes. Even those which did not mention nematodes raised relevant questions – ranging from variability of *Phylloxera* on grape roots to the growth of grass roots under elevated carbon dioxide and temperature.

There was a marvellous flow of information and receptive minds no doubt went home with many questions which will influence their work and future interactions with others working on, what they can now see as, related topics. Up to 60 attended the two days of lectures, with the second two days of practical workshops being targeted at 20 research students and post-docs. Ian provided a range of infested plant material which participants stained and then examined nematodes. Graham (and Marcelle) brought fungal cultures with trapped nematodes, and we all helped with identifying a wide range of soil nematodes. Explanation of the workings of a drawing tube, which happened to be on one of the microscopes, was an unexpected bonus.

It was great to see nematologists including Vivien Vanstone, Rachael Hutton, Tony Pattison, Marcelle Stirling, Loothfar Rahman, Nicki Seymour, Rod McLeod, Jackie Nobbs, Mike Hodda and Zhao Zeng Qi for all or part of the workshop.

From the nematode angle, I was reminded of:

a) the importance of nematophagous fungi, *Pasteuria* and mites in influencing nematode populations,

b) the importance of root tip feeding,

c) the idea that rapid root elongation may help roots evade some pathogens (this presumably needs to be thought of in terms of pathogen multiplication because rarely will a root be moving through a pathogen naïve soil; many nematodes actively seek out zones of root elongation),

d) the need to focus on those propagules of plant parasites present at the end of the growing season – they are the organisms that will attack young roots next season, often before their parasites and predators can respond, and

e) the possible importance of root structure, including modifications to overcome water logging, in reducing nematode access to a large resource.

Overall, there does seem to be a growing appreciation of the importance of C:N ratios in both soils and organic matter. At higher N contents, bacterial-based foodwebs seem more important than fungal-based webs; at lower N contents the reverse seems true. These differences must greatly influence not only those organisms which we associate with nutrient turnover but also the largely unknown organisms involved in influencing populations of others regarded as 'good' and 'bad'.

For grain producers who use 'good' soil management techniques, when major local limitations to yield (e.g., moisture, local major pathogens) have been overcome, it seems that soil biology needs to aid in understanding and then finding practical ways of utilizing

a) the impact of the increasing C:N ratio from prey to predator which leads to increasing excretion of nitrogen (which may then be taken up by plants – if the release and roots are coincident),

b) the turnover of essential nutrients is more important for crop growth than total nutrients because when turning over they may be taken up by plants (grazing or predation by nematodes on soil microbes is now acknowledged as contributing significantly to this turnover), and

c) breeding for roots which reduce pathogen damage, while exploring all useful resources in the soil, and optimising uptake of both nutrients and water to deliver better economic yield (which, in grains, is aboveground).

As nematologists we should be able to contribute to understanding these ecological processes. We are still plainly ignorant of basic facts such as the relationships of Tylenchidae and Hoplolaimidae to root growth and root hairs, and how these groups contribute to the nutrient flux from roots to soil microbial biomass. Perhaps many Tylenchidae (and *Cephalenchus*) may be (facultative) fungal feeders. There is room to keep the nematological flag flying among the soil particles.

Gregor Yeates
Landcare Research, Palmerston North, New Zealand

NEWS FROM SOUTH AUSTRALIA

Imelda Soriano's paper on phytoecdysones in plant defence against nematodes was received well at the 15th International Ecdysone Workshop in Crete in July. We were told the food was great, the beaches beautiful and the mozzies thick but she still had time to make some useful contacts with scientists working on ecdysones.

Ian Riley gave presentations at two workshops, the root/soil biology workshop in Canberra (supported by GRDC) and an annual ryegrass toxicity workshop at Wallaroo, WA (supported by Australian Meat and Livestock). Nematologists from Adelaide and elsewhere were out in force at the Canberra meeting (Gregor Yeates provides more details elsewhere in the newsletter).

Kerrie Davies continues to be irrepressible in her hunt for new *Fergusobia*/*Fergusonina* associations and has recently completed a successful field trip to Tasmania.

Zhao Zeng Qi is preparing himself to commence the study of *Bursaphelenchus* and closely related taxa in Australia conifers, supported by the Forest and Wood Products Research and Development Corporation, in February 2003.

Shin Hae Soo, a Masters student from the University of Western Australia is about to embark on a nematology project and spent December visiting Adelaide to get to know the nematologists and how we do things.

Transformed from a sedentary to a migratory nematologist, Vivien Vanstone left the comforts of university life for the rigours of civil service in WA. Our loss is the West's gain, but they should be warned, there is no standing in the way of progress. We look forward to strengthening links between the States as Vivien becomes established in her new role with the WA Department of Agriculture, South Perth. Following in the footsteps of three other Waite escapees, Stynes, Stanton and Riley, Vivien is bound to be haunted by old samples lurking unloved in the damp, dark places of the B block cold room and bearing names of those long departed.

Siwi Indarti (Gadjah Mada University, Indonesia) completed her Crawford Fund traineeship with the Adelaide nematology groups. She enjoyed the experience and looks forward to returning one day. Siwi undertook some work on bacterial adhesion to *Anguina*, which resulted in the submission of a short paper for publication.

Sadly Caroline Versteeg withdrew from studies at Adelaide, but we congratulate her on appointment to a position with Yates in Narromine, NSW.

Motiul Quader has departed from Adelaide and will be job hunting from a Sydney base. Motiul finished his thesis on grapevine nematodes before leaving. He was farewelled with a lunch at the Eagle on the Hill and we wish him well in the examination of his thesis and with future prospects.

Speakers at our campus-wide nematode discussion group for second semester were John Heap, SARDI, on precision agriculture and DNA testing for soil nematodes, Siwi Indarti on nematology in central Java, John Lewis on CCN tolerance screening and Diana

Walter, CSIRO, on her PhD project on the effect of BT-producing transgenic cotton on soil organisms including nematodes.

Ian Riley, University of Adelaide, Waite Campus

MORE NEWS FROM SOUTH AUSTRALIA

SARDI

Field trials were sown in 2002 to assess tolerance/yield loss and resistance to cereal cyst nematode (*H. avenae*), root lesion nematode (*P. neglectus*) and stem nematode (*D. dipsaci*). While dry conditions have certainly stressed these trials, all except one should be harvested. For *P. neglectus*, field trials were in their second year, with differing levels of nematodes established following resistant and susceptible varieties in 2000. Varieties of wheat, barley oat, triticale and medic were oversown across these sites this season and large differences were seen in growth between plots which should be reflected in yield differences. For stem nematode the news was not so good (from a nematologist's point of view!) with little or no multiplication seen in the field in the last two seasons as a result of drier, warmer winter conditions.

The screening season for *P. neglectus*, *P. thornei*, stem nematode and CCN has just been wrapped up with about 16,000 plants processed for the first three species and over 120,000 plants processed for CCN in field, glasshouse, growthroom and outdoor "terrace" tests. This concerted effort has been handled admirably by the Prat and Dit team (Sharyn Taylor, Danuta Szot, Michelle Russ, Brett Malic, Irena Dadej and Sue Pederick) and the CCN team (John Lewis, Tony Debicki and Milanka Matic).

Jackie Nobbs, Nematode Taxonomist Extraordinaire, has been kept busy with numerous distress calls from Vivien Vanstone (newly ensconced in the West) and records of stem nematode in clover and canola from both Victoria and South Australia. *Ditylenchus* and *Pratylenchus* are certainly causing identification concern!

Sharyn Taylor attended the 4th International Nematology Congress in Tenerife where she caught up with the exciting world of international nematodes and nematologists. The congress was well worth the 40 hours travel time (including the obligatory loss of posters upon arrival at Tenerife airport). Following the congress, Sharyn visited Roger Rivoal (INRA, France), Carolien Ziljstra (Wageningen, Netherlands) and spent 3 weeks with Julie Nicol, now based with CIMMYT in Ankara, Turkey. Julie has been given the unenviable job of defining nematode problems in wheat in Turkey and the west Asia/ North Africa region and has already identified *H. filipjevi*, *H. latipons* and *P. thornei* as being of major concern in these areas.

Julie's work currently linking with other research occurring in Europe (highlighted within posters, papers and colloquia at the Congress) to understand the cereal cyst nematode complex, which is now believed to comprise up to 12 *Heterodera* species (including many pathotypes). This may affect Australian research, as little work has been done on Australian *H. avenae* for many years to define whether this is the only species or pathotype here.

Other highlights of the trip to Turkey were the food, the scenery and the very crazy Turkish driving (to which both Julie and her husband Duncan have definitely become acclimatised!!).

NEWS FROM THE OTHER SIDE OF THE WORLD IN TURKEY

Greetings fellow Nematologists from a lost Australian now residing in Turkey. I thought it would be useful to give a brief update of the activities that I am involved in. Since leaving Australia in 1998 I have worked for CIMMYT International – the International Wheat and Maize Improvement Centre. CIMMYT principally is involved in developing both wheat and maize germplasm for developing countries through an active breeding program (including breeders, agronomists, pathologists and molecular tools). We also have a major role in training and empowering developing country scientists. More information about CIMMYT can be found at www.cimmyt.org

I was based at CIMMYT headquarters in Mexico from 1998-2000 on a GRDC funded Post-Doctoral Fellowship working on root diseases on wheat. During this time I worked on my PhD pet nematode Root Lesion Nematode (*Pratylenchus thornei*) and also with Root Rots (*Fusarium spp* and *Bipolaris sorokinana*). We conducted yield loss trials in the north of Mexico and identified under limited irrigation that *P. thornei* significantly reduced wheat yield. I was actively involved in establishing an active screening program to identify disease resistance to these soil borne pathogens and subsequently incorporate these into high yielding adapted wheats for both developing countries and Australia.

In June 2001 I was transferred to the CIMMYT outreach posting as Pathologist in Turkey which is involved principally in developing winter wheat for developing countries working through West Asia, North Africa and Central Asia. I now work with the IWWIP (International Winter Wheat Improvment Program), a combined effort of CIMMYT, MARA (Turkish Agricultural Minstry of Rural Affairs) and ICARDA (International Centre Arid Research in Dryland Areas). I am the soil disease pathologist for the region and I have definitely embarked on a serious challenge. As many of you may know the centre of origin of cereals is the Middle-East and we may have a lot of genetic diversity for cereals here, but also for the pathogens (hence the problem!!).

I am working with Turkish National Scientists on a multitude of tasks including;

a. <u>Surveying</u>: identifying the extent and diversity of the root disease problem. To date we have found both Lesion (*Pratylenchus thornei* and *P. neglectus*) and Cyst (*Heterodera filipjevi* and *H. latipons*) in approximately 80% of soil samples assessed. Over 60% of soil samples contained root rot pathogens (including *Fusarium spp*. and/or *Bipolaris*).

b. <u>Nematode Yield Loss and Population Dynamic Studies</u>: as with all the hard work that has occurred in Australia over many years with both Cyst and Lesion we are doing the same here in Turkey. We have several yield loss trials accross the country where we are monitoring the yield loss, plant susceptibility and trying to understand the population dynamics of the nematodes (especially the cyst species *H.filipjevi* and *H. latipons* where very little information is known in the world).

c. Root Rot Yield Loss and Screening Nurseries: We have over 5000 field plots where we are actively screening for root rot resistance and measuring the loss that root rots have on winter wheat in the region. A number of agronomic factors are also being assessed. We are particularly interested in learning how nematode resistant germplasm performs for root rots with the view to breed 'root disease' resistant germplasm.

d. Nematode Screening Program: we have set up a nematode screening laboratory in the West of Turkey (Eskisehir) and we have started to screen germplasm with root lesion nematode, *P. thornei*. We are currently conducting basic biology experiments with *Heterodera* to understand its hatch with the intention of establishing an active screening program.

e. Breeding: we are actively incorporating known sources of resistances to Root Rots and Nematodes into winter wheat. Furthermore we are testing advanced spring wheat lines from Mexico with known sources incorporated to validate their effectiveness.

f. Application of Molecular Tools : we are currently optimizing MAS (Marker Assisted Selection) procedures for different known genes of Cereal Cyst Nematode Resistance and using PCR-RFLP based techniques to identify species of *Heterodera*. We also have an Australian GRDC Project working with Lesley Research Centre, University of Southern Queensland and CSIRO Brisbane on developing molecular markers in resistant germplasm for *P. thornei*.

g. Training: The IWWIP program is training Turkish Scientists and Scientists from the region in the field of soil disease cereal research. This includes postgraduate training and special courses such as the course planned for next June in Turkey which several Australian Pathologists will attend to provide their expertise and knowledge base. The Training course is called 'Soil Borne Pathogens of Cereals" and will occur from June 14-28th in Turkey under my coordination. It is aimed at teaching and training developing country scientist from this region about working with both nematodes and root rots. We are highly grateful to our sponsors, principally lead by the ATSE Crawford Fund, CIMMYT, MARA, ICARDA, GRDC, ACIAR and the Kirkhouse Trust.

I hope this has given a little insight what I have been up to and I can definitely say that my job is a can of worms!!! Please feel free to contact me if you have any questions/suggestions. From my PhD days at the dear Waite Institute, I think it is fair to say the old Toad Team (meeting group at the Waite for Nematode specialists) has now jumped into a larger research area than before and I would be more than happy to interact with any of you!!

My contact details are;

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All the best with your research and wishing you a lovely warm Christmas in the Great Southern Land as the snow is falling outside!!

NEWS FROM CANBERRA

I have been given an ABRS contract to expand the electronic interactive keys available free on the web to cover a range of other nematodes. The keys currently cover about 50 genera of aquatic nematodes from the Murray-Darling Basin and coastal freshwaters of southeastern Australia, as well as most of the species of *Pratylenchus* known from Australia. The contract is to add several families of Dorylaimida to the key, with the intention of facilitating recognition of this important order, which are present in the vast majority of terrestrial soils in large numbers. (They are the big ones with short, broad spears in their mouth and often with short tails.)

PhD student from the University of Western Sydney Farming Systems Research Centre, Emma Broos submitted her thesis in August entitled “Responses of soil biological parameters to contrasting farming systems”. Nematodes figure quite prominently in the soil biological parameters, including – you guessed it – a lot of those Dorylaimids which are present in large numbers. There were a lot of Tylenchid plant parasites as well to keep the officionados happy. The thesis is still being examined, but I will be encouraging Emma to present an abstract in a subsequent edition of the newsletter.

I have another PhD student from the University of Western Sydney who has just started, this time from the Centre for Horticulture and Plant Sciences. Sosamma Pazhavarical will be working on the mechanisms of plant parasitic nematode invasion of roots, most probably using the contrasting nematodes *Pratylenchus* and *Meloidogyne*. The former of course is highly damaging directly, while the latter damages the plant indirectly through induction of giant cells. The project is still being developed, and I will encourage “Susie” to write an update on her project for the newsletter as it progresses.

The nematode collection has received a steady stream of specimens. I recently even managed a correct identification from a description given over the phone on the basis that we had some specimens of the particular species from that area. The collection is there and maintained for just such a purpose, and as it grows the value increases. It is only through building a collection including as much geographic, host crop and seasonal variation as possible, that the systematics and identification of nematodes can advance. Likewise it is the only way that we can recognise previously undiagnosed problems, and identify new threats. It is always very useful when I am dealing with quarantine enquiries. So when you are doing a study of any particular nematode problem, send us some specimens, so that we can add them to the collection where they will add to the data that will be the basis of future nematode systematics, identification, host and geographic records. As a specialist collection, we have the best possible curation equipment, expertise and a special purpose building for biological collections. We also have a separate unit creating specialist collection management software to ensure that the specimens are as accessible as possible. If you want to donate material, in whatever form (fixed or unfixed, mounted on slides or not, in pure or mixed culture), please contact me.

Nematodes in Cropping Systems: Identification and Techniques

An intensive training course on "Nematode Identification and Techniques" will be held under the joint auspices of ANIC and The Waite Institute, University of Adelaide. The course will be held in December 2003 at The Waite Institute, University of Adelaide, under co-ordinators Dr Mike Hodda and Dr Kerrie Davies. The course will cover identification of plant, soil and insect nematodes, together with techniques for sampling, extraction, experimentation and analysis. The course is aimed at professionals in plant and insect pathology, pest management, soils and other disciplines dealing with nematodes. Sufficient background will be presented to enable those with limited experience to benefit fully from more advanced aspects. Details of course content will be varied to suit the interests of the participants: please contact the co-ordinators to discuss any specific needs. Anticipated cost is $1200 (+GST) for 1 week, including all course materials. A minimum of 8 participants is required for the course to proceed.

Web site: http://www.ento.csiro.au/research/natres/nematode.html

To register your interest or discuss specific needs please contact Dr Kerrie Davies at The University of Adelaide:

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Research

VARIABILITY IN HOST RANGE AND PATHOGENICITY OF AUSTRALIAN *RADOPHOLUS* SPP. ON MUSA CULTIVARS

Jennifer Cobon, Queensland Horticulture Institute, Indooroopilly and Tony Pattison, Centre for Wet Tropics Agriculture, South Johnstone

INTRODUCTION

Radopholus similis is the most important plant-parasitic nematode on bananas. *R. similis* is found in most banana producing areas in the world (Gowen and Queneherve 1990). The nematode feeds on the cortical cells of roots forming large reddish-lesions that reduce the efficiency of the root system. The lesions reduce the plant's ability to take up nutrients; plants appear stunted with smaller bunch weights, slower cycling time and bunching pseudostems may topple. *R. similis* is endemic in the tropical Queensland production area and commonly found in the subtropical areas of Queensland and in New South Wales growing areas.

A wide diversity of *R. similis* has been reported throughout the world in tail shape, optimum temperature, multiplication rate and pathogenicity (Fogain and Gowen 1994; Fallas *et al*. 1995) and RAPD analysis (Hahn *et al*. 1993; Elbadri *et al*. 2002). Furthermore, Elbadri *et al*. (2002), found two distinct groups of *R. similis* with differing pathogenicity on bananas cv. Grand Naine. This suggests that pathotypes of the nematode may exist. The investigation of possible pathotypes has led to the description of a new species of *Radopholus, R. musicola* found near Darwin (Stanton *et al*. 2001). If pathotypes or new species exist in the Australian population of *R. similis,* it will become more difficult to recommend resistant banana cultivars and rotations to control this nematode.

Pisang jari buaya (*Musa acuminata* genome group AA)(Pjb) is a diploid with confirmed resistance to *R. similis* (De Waele and Elsen 2002; Elsen *et al*. 2002). Pjb has been used in the breeding program of Fundación Hondureña de Investigación Agrícola (FHIA), which has resulted in the *R. similis* resistant diploid AA hybrid SH-3142 (De Waele and Elsen 2002). SH-3142 was crossed with the triploid AAB cultivar Prata Anã to produce the tetraploid AAAB hybrid FHIA-01 (Goldfinger) which was partially resistant to *R. similis* when 28 week old plants were tested (Stanton 1999; De Waele and Elsen 2002).

It is the aim of this study to determine if there are any differences in the pathogenicity and reproductive fitness of Australian *R. similis* isolates and *R. musicola* sampled from commercial banana plantations on *Musa* cultivars.

MATERIALS AND METHODS

Nematodes isolated and cultured from eight sites.

Isolates of burrowing nematode (*Radopholus* spp.) from throughout the major banana growing areas of Australia, were collected from the roots of 8 separate banana crops (Table 1). There were two isolates of *R. similis* from north Queensland (Tully and Bartle Frere), 3 isolates from south-east Queensland (Pimpama, Tallabudgera and Cudgen) and 2 isolates from northern NSW (Crossmaglen and Red Hill) and one isolate of *R. musicola* from the Northern Territory (Darwin).

Table 1. Nematode species and location where isolates were originally sampled.

Species	Location	Longitude (east)	Latitude (south)
R. musicola	Darwin, Northern Territory	130.84006	-12.46105
R. similis	Tully, north Queensland	145.92172	-17.93107
R. similis	Bartle Frere, north Queensland	145.87513	-17.46276
R. similis	Pimpama, south-east Queensland	153.29891	-27.81265
R. similis	Tallabudgera, south-east Queensland	153.41764	-28.15987
R. similis	Cudgen, south-east Queensland	153.55000	-28.26667
R. similis	Crossmaglen, northern NSW	152.98450	-30.36510
R. similis	Red Hill, northern NSW	153.13753	-30.31319

To extract the nematodes from bananas the roots were washed thoroughly and placed in a misting chamber for seven days to collect the nematodes (Hooper 1986). After backwashing nematodes from a 25 ì m sieve, the nematodes were picked from the solution under the microscope and a single mature female placed on a sterile carrot. After the single nematode had reproduced, inoculum of up to 20 females for each carrot was washed repeatedly in sterile water and used to inoculate further carrots. Each month all nematode isolates were renewed onto new carrots and maintained at 26°C in monaxenic cultures (Moody *et al.* 1973).

Host range and pathogenicity determined for eight nematode isolates.

Experiment 1

Tissue culture plants of the banana varieties of Goldfinger (AAAB, breeding line FHIA-01), Ladyfinger (AAB), Pjb (AA), SH-3142 (AA) and Williams (AAA) were tested with the nematode populations from Cudgen (SEQ), Tallabudgera (SEQ), Darwin (Northern Territory), Bartle Frere (NQ), Pimpama (SEQ) and Tully (NQ).

Thirteen weeks after deflasking, the banana plants were repotted into 175 cm pot of standard UC mix. Two days later the pots were inoculated with 300 nematodes per pot. Treatments were replicated five times and pots were kept in a glasshouse. Ten weeks after inoculation, plants were harvested and nematodes were extracted from the roots over 7 days in a misting chamber and counted.

Experiment 2
Tissue culture plants of the banana varieties of Goldfinger, Ladyfinger, Pjb, SH-3142 and Williams were tested with the nematode populations from Pimpama (SEQ) and Tully (NQ).

Thirteen weeks after deflasking, the banana plants were repotted into 175 cm pot of standard UC mix. A total of 8 months after deflasking the pots were inoculated with 300 nematodes per pot. Treatments were replicated five times and pots were kept in a glasshouse. Ten weeks after inoculation, plants were harvested and nematodes were extracted from the roots over 7 days in a misting chamber and counted.

Experiment 3
Tissue culture plants of the banana varieties of Goldfinger, Ladyfinger, Pjb and Williams were tested with the nematode populations from Cudgen (SEQ), Tallabudgera (SEQ), Darwin (Northern Territory), Bartle Frere (NQ), Pimpama (SEQ), Tully (NQ), Red Hill (NSW) and Crossmaglen (NSW).

Thirteen weeks after deflasking, the banana plants were repotted into 175 cm pot of standard UC mix. Two days later the pots were inoculated with 300 nematodes per pot. Treatments were replicated five times and pots were kept in a glasshouse. Ten weeks after inoculation, plants were harvested and nematodes were extracted from the roots over 7 days in a misting chamber and counted.

Experiment 4
Tissue culture plants of the banana varieties of SH-3142 and Williams were tested with the nematode populations from Cudgen (SEQ), Tallabudgera (SEQ), Darwin (Northern Territory), Bartle Frere (NQ), Pimpama (SEQ), Tully (NQ), Red Hill (NSW) and Crossmaglen (NSW).

Thirteen weeks after deflasking, the banana plants were repotted into 175 cm pot of standard UC mix. Two days later the pots were inoculated with 300 nematodes per pot. Treatments were replicated five times and pots were kept in a glasshouse. Ten weeks after inoculation plants, were harvested and nematodes were extracted from the roots over 7 days in a misting chamber and counted.

Data analysis
The data were analysed using Genstat. All nematode counts were $\ln(x+1)$ transformed prior to analysis to allow data to be normally distributed before being subject to analysis of variance (ANOVA). If a statistical difference ($P \leq 0.05$) was observed means of treatments were separated using the least significant difference (LSD) method.

RESULTS

Experiment 1
All banana varieties were as equally susceptible as Williams to the Tully isolate of *R. similis* (Table 2). This suggested that no banana cultivars were resistant to this isolate of *Radopholus*. In contrast either Pjb, SH-3142 or both, were resistant to

multiplication of other isolates of *Radopholus* spp. relative to Williams (Table 2). The cultivar SH-3142 demonstrated resistance to all *Radopholus* isolates except the Tully isolates. Pjb, the parent to SH-3142, exhibited resistance to the *Radopholus* isolates from Tallabudgera, Cudgen and Bartle Frere (Table 2). Partial resistance was observed in Ladyfinger to the Tallabudgera and Bartle Frere isolates of *Radopholus* spp (Table 2). Partial resistance to the Bartle Frere isolate was also observed in Goldfinger (Table 2).

Table 2. Mean number of six *Radopholus* spp. isolates in 100g roots from *Musa* cultivars Williams, Goldfinger, Ladyfinger, Pjb, and SH-3142 inoculated 13 weeks after deflasking and harvested 10 weeks later.

Variety	Darwin	Tully	Pimpama	Cudgen	Bartle Frere	Tallabudgera
Goldfinger	8.79 (6560) b	8.86 (7015) a	9.30 (10970) c	7.92 (2737) c	7.10 (121) c	6.24 (511) bc
Ladyfinger	8.18 (3582) b	8.81 (6720) a	8.82 (6794) c	9.04 (8467) d	7.45 (1771) c	4.43 (83) b
Pjb	8.43 (4558) b	8.60 (5414) a	7.91 (2734) b	4.61 (100) b	4.44 (84) b	1.64 (4) a
SH-3142	4.72 (111) a	8.57 (5259) a	4.64 (102) a	2.77 (15) a	2.66 (13) a	2.17 (8) a
Williams	8.71 (6087) b	8.93(7554) a	9.16(9527) c	8.41 (4468) cd	8.97(7878) d	6.66 (777) c

These figures are log means ln(*x*+1) with the back transformed means in parenthesis. Means in columns with the same subscript are not significantly different *(P<0.05)*

Pathogenicity of the *Radopholus* spp. isolates was reflected in the reduction in root weights at harvest. The *R. similis* population from Tully was the most pathogenic isolate, significantly reducing root weight below all other isolates except for the isolate from Pimpama (Table 3). The isolate from Tallabudgera was the least pathogenic with a significantly heavier root system than all other isolates (Table 3).

The pathogenicity of the nematodes appears to be correlated to the multiplication rate of the nematode isolates. Isolates that had the highest number of nematodes recovered from the roots also had the lowest root weight (Table 3).

Table 3. Mean root weight of *Musa* cvs. Williams, Goldfinger, Ladyfinger, Pjb and SH-3142 inoculated with six different *Radopholus* spp isolates 13 weeks after deflasking and harvested 10 weeks later.

***Radopholus* sp**	**Location**	**Root weight (g)**
R. musicola	Darwin, NT	46.00 c
R. similis	Tully, NQ	40.24 a
R. similis	Pimpama, SEQ	42.06 ab
R. similis	Cudgen, SEQ	44.40 bc
R. similis	Bartle Frere, NQ	45.54 bc
R. similis	Tallabudgera,SEQ	50.76 d

Means with the same subscript are not significantly different (*P<0.05)*

Experiment 2

The Tully isolate of *R. similis* was, once again able to multiply on all cultivars equally as well as on Williams (Table 4). Ladyfinger showed partial resistance in this trial, with better resistance than Goldfinger, Pjb and SH-3142 to nematode multiplication (Table 4). SH-3142 and Pjb were both significantly more resistant than Williams to multiplication of the Pimpama isolate (Table 4).

There appears to be no difference in susceptibility of the banana cultivar with the age of the plant after deflasking. The reaction of the cultivars to *Radopholus* spp., deflasked after 13 weeks (Table 2) and 8 months (Table 4) appears to correlate. The isolate of nematode tested, not the age of the plant, determines the effect on the cultivar.

Table 4. Mean number of two *Radopholus* spp. isolates in 100g roots from *Musa* cultivars Williams Goldfinger, Ladyfinger, Pjb and SH-3142 inoculated 8 months after deflasking with 300 nematodes/pot with 2 isolates of *Radopholus* spp. and harvested 10 weeks later.

Variety	Tully	Pimpama
Goldfinger	7.01 (1109) b	7.45 (1715) c
Ladyfinger	5.02 (150) a	6.65 (773) bc
Pjb	7.04 (1145) b	4.97 (143) ab
SH-3142	7.63 (2056) b	4.37 (78) a
Williams	5.97 (391) ab	7.37 (1582) c

These figures are log means ln(x+1) with back transformed means in parenthesis. Means in columns with the same subscript are not significantly different ($P<0.05$)

Experiment 3

Similar to the previous experiments, the different isolates behaved differently on the different banana cultivars. Pjb again reduced the multiplication of all nematode populations except for the isolate from Tully (Table 5). The isolate from Cudgen again had a high multiplication rate on Goldfinger, Ladyfinger and Williams but low multiplication on Pjb. The population from Bartle Frere had a very low multiplication rate on Pjb but an extremely high multiplication rate on Williams.

Table 5. Mean number of eight *Radopholus* spp. isolates in 100g roots on *Musa* cultivars. Williams, Goldfinger, Ladyfinger and Pjb inoculated 13 weeks after deflasking and harvested 10 weeks later.

Variety	Darwin	Tully	Pimpama	Cudgen	Bartle Frere	Tallabudgera	Red Hill	Crossmaglen
Goldfinger	9.03 (8382) b	9.49 (13252) a	10.12 (24809) a	10.49 (36025) bc	8.73 (7136) b	10.28 (29201) a	9.10 (8954) a	9.36 (11648) a
Ladyfinger	3.44 (30) a	8.77 (6611) a	8.44 (4604) a	9.39 (12003) ab	9.85 (18976) bc	8.94 (7653) a	8.49 (4870) a	10.29 (29318) a
Pjb	9.45 (12758) b	10.77 (47714) a	9.37 (11777) a	8.77 (6457) a	6.71 (816) a	8.01 (3009) a	7.01 (1109) a	8.26 (3873) a
Williams	9.34 (11383) b	9.67 15802) a	9.84 (18731) a	10.86 (51999) c	10.61 (40456) c	9.92 (20393) a	9.90 (19989) a	9.67 (15866) a

These figures are log means ln(*x*+1) with the back transformed means in parenthesis. Means in columns with the same subscript are not significantly different

The rate of multiplication of the nematode isolates differed on the same banana cultivars. The nematode isolate from Darwin was reduced on Ladyfinger but the isolates from Bartle Frere, Crossmaglen and Cudgen were all high on Ladyfinger.
The isolates from Darwin, Pimpama and Tallabudgera were significantly less pathogenic than all other isolates as determined by the reduction in root weight of banana plants (Table 6). This was a similar response to root weight reduction from Experiment 1 (Table 2) where Tallabudgera and the Darwin isolate had significantly higher root weights than plants inoculated with the other isolates. Only the Pimpama isolate differed in pathogenicity reaction. The Pimpama isolate was significantly less pathogenic than the Tully isolate in Experiment 3 (Table 6) but had equal pathogenicity to Tully in Experiment 1 (Table 2).

Table 6. Mean root weight of *Musa* cultivars Williams, Goldfinger, Ladyfinger and Pjb inoculated with 8 isolates of *Radopholus* spp. isolates 13 weeks after deflasking and harvested 10 weeks later.

***Radopholus* sp.**	**Location**	**Root weight (g)**
R. musicola	Darwin, NT	72.0 b
R. similis	Pimpama, SEQ	69.1 b
R. similis	Tallabudgera, SEQ	63.4 b
R. similis	Red Hill, NSW	56.3 a
R. similis	Tully, NQ	54.2 a
R. similis	Crossmaglen, NSW	52.5 a
R. similis	Cudgen, SEQ	52.4 a
R. similis	Bartle Frere, NQ	49.0 a

Means with the same subscript are not significantly different ($P<0.05$)

Experiment 4
SH-3142 reduced nematode numbers in all isolates tested (Table 7). However, SH-3142 only demonstrated partial resistance to the Tully isolate, as there was a large number of nematodes recovered from the roots of banana plants relative to all other nematode isolates (Table 7). All eight nematode isolates had a high multiplication rate on Williams.

Table 7. Mean number of eight *Radopholus* spp. isolates in 100g root from *Musa* cultivars Williams and SH-3142 inoculated 13 weeks after deflasking and harvested 10 weeks later.

Variety	Darwin	Tully	Pimpama	Cudgen	Bartle Frere	Tallabudgera	Red Hill	Crossmaglen
SH-3142	4.48 (87) a	7.40 (1633) a	3.22 (24) a	1.78 (5) a	1.62 (4) a	2.84 (16) a	1.54 (4) a	3.51 (32) a
Williams	7.90 (2696) b	8.03 (3070) b	8.85 (6980) b	8.15 (3452) b	9.19 (9778) b	8.89 (7272) b	8.85 (6980) b	9.47 (12950) b

These figures are log means ln(x+1) with the back transformed means in parenthesis. Means in columns with the same subscript are not *($P<0.05$)*

DISCUSSION

The high level of pathogenicity of the *Radopholus* spp. isolate from Tully to the *Musa* cultivars tested in this trial suggested that this isolate is a different pathotype of *Radopholus similis* compared to those found elsewhere in the Australian production area. The Tully isolate was able to overcome the resistance reported by other researchers in Pjb and SH-3142 (De Waele and Elsen 2002; Elsen *et al*. 2002). All *Musa* cultivars used in this trial were equally susceptible to the Tully isolate. There were no obvious morphological difference between the Tully isolate to the other *R. similis* isolates. Elbadri *et al*. (2002) suggested that pathogenicicty of *Radopholus* may be detected by examining RFLP of the ITS region with *Alu*I and *Tru*9I. This warrants further investigation as the Tully isolate *R. similis* may be distinguishable with a PCR-based diagnostic test. This type of PCR test would help to confirm the similarity between the different isolates and may explain some of the differences measured by banana cultivar reaction.

A taxonomic sub-division of *R. similis* in Australian banana growing regions is not suggested. However, differences in host susceptibility need to be easily identified, if new banana cultivars are going to be used to manage nematode losses. Banana growers who have isolates of *R. similis*, other than the Tully isolate, would benefit from varieties with resistance based on Pjb. A PCR-based diagnostic test would help banana growers to determine if their local isolates of *R. similis* would react the same way to banana varieties as the Tully isolate.

While the resistance of Pjb and SH-3142 to most isolates of *Radopholus* spp., including *R. musicola* has been confirmed, other resistance genes are also required for effective resistance to all isolates. This would require further screening of banana varieties and also a better understanding of the resistance mechanisms that Pjb or other banana cultivars use to reduce nematode multiplication. Yangambi KM5 (triploid AAA) has been reported as having resistance to *R. similis* (De Waele and Elsen 2002). However, Yangambi KM-5 is not being used in *Musa* breeding programs because the progeny produce abnormal leaves and erect bunch characteristics (De Waele and Elsen 2002).

The time from deflasking to inoculation with nematodes had little influence in the reaction of tissue culture bananas to *Radopholus* isolates. Elsen *et al*. (2002) found that in vitro banana plants inoculated with nematodes had the same reaction of susceptibility and tolerance as plants inoculated later in the crop cycle. This contrasts the findings of (Stanton 1999) who found that Goldfinger had improved resistance 28 weeks after deflasking. Goldfinger showed only partial resistance to the Bartle Frere isolate in two experiments and was as equally susceptible as Williams to all other isolates of *R. similis*. Therefore, Goldfinger would not be recommended as a cultivar in a nematode management program.

The pathogenicity of *Radopholus* isolates was related to their reproductive fitness (Fallas, *et al*. 1995). That is, the higher the reproductive fitness, the greater the pathogenicity in the roots and reduction in plant growth. This was confirmed in this trial, where high reproduction of the nematode isolate on the roots was associated with lower root weight of the cultivar. Therefore, it appears important to select banana cultivars that are able to reduce the multiplication of nematodes within the roots to minimize losses and maintain banana productivity.

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HOSTS OF THE *FERGUSONINA* FLY/*FERGUSOBIA* NEMATODE ASSOCIATION

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The *Fergusonina* fly/*Fergusobia* nematode association produces galls on the growing shoot tips, leaves and flower buds on Myrtaceous plants (Currie 1937; Giblin-Davis *et al.* 2002). It seems that the nematode induces gall development (Currie 1937, Giblin-Davis *et al.* 2001b), used by both developing fly larvae and the nematodes for food and shelter. *Fergusobia* has a complex life cycle, with a parthenogenetic generation in the gall followed by an amphimictic one, that begins in the gall and 'ends' in the fly. Pre-parasitic female nematodes are inseminated in the gall, and then move into the haemolymph of mature female fly larvae. How this is achieved, and how they are able to avoid the fly's immunological system and distinguish between male and female fly larvae is unknown. In the fly, the nematode undergoes apolysis, losing its cuticle and stylet, the gut degenerates, and the epidermis becomes much thickened with enormous development of microvilli (Giblin-Davis *et al.* 2001a). The nematode's gonad undergoes hypertrophy, and it becomes a sausage-shaped 'bag' of developing eggs. Nutrients apparently are absorbed from the fly's haemolymph through the epidermis. The nematode deposits eggs into the haemolymph in the abdomen of the developing fly, and by the time the adult female fly emerges from the puparium these have hatched and developed into 'normal'-looking tylenchid J2's. They then move to the fly's ovaries, and when she deposits her eggs into fresh plant material some of the nematodes are also deposited. Thus, the fly/nematode association is a mutualistic association, with the fly needing the nematode for gall initiation, and the nematode needing the fly for dispersal.

We are collaborating with staff at the University of Florida, CSIRO Entomology and the USDA, investigating the systematics, biology, distribution, and specificity of the *Fergusonina/Fergusobia* association. We are also looking at its potential for biocontrol of *Melaleuca quinquenervia* in the Florida Everglades. The galls support complex communities of insect parasitoids (mostly wasps) and inquilines (wasps, beetles, moth larvae, and thrips). Interactions between the gall organisms are little known, but provide potential model systems for ecological and biodiversity studies.

There is clear morphological evidence for co-evolution and speciation between flies and nematodes, and their myrtaceous hosts (Taylor 2003, Davies & Giblin-Davis 2003). Particular fly and nematode associations are monophagous or have narrow host ranges with closely related plant species (Goolsby *et al*. 2000, Giblin-Davis *et al.* 2002, Taylor 2003, Davies & Giblin-Davis 2003, unpub. data from Waite Insect and Nematode Collection (WINC) accessions). Molecular analysis of the cytochrome oxidase I mitochondrial gene for *Fergusonina* flies (Scheffer *et al.*, unpubl. data) and of D2/D3 rDNA sequences (expansion segment of the 28S rRNA gene) for corresponding species of *Fergusobia* nematodes (Giblin-Davis *et al.*, unpubl. data) support the occurrence of species specific one to one associations between respective species of flies and nematodes.

Following extensive collecting, the WINC currently contains about 170 accessions of fly/nematode associations from NSW, Queensland, Victoria, Tasmania, South Australia and Western Australia. Data from these accessions, other museum collections and published records (Table 1) suggests that radiation of the *Fergusonina /Fergusobia* association has largely occurred in Australia, probably in parallel with the radiation of the Myrtaceae. On the basis of various combinations of fly larval, puparial and adult morphotypes, gall types, nematode morphotypes and host associations, there is evidence for the existence of about 85 species (mostly undescribed) for both *Fergusonina* flies and *Fergusobia* nematodes. It is probable that not all species of *Eucalyptus* are hosts, as galls have not been collected from many species, despite repeated sampling. Given that many species of *Angophora, Corymbia*, *Eucalyptus*, *Melaleuca* and *Syzygium* have not yet been sampled, there is potential for several hundred new species.

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Table 1. Plant host records for the *Fergusonina* fly/*Fergusobia* nematode association on Myrtaceae.

Host	**Location**	**Reference**
Myrtoidea		
Syzygium cumini	India	5, 6
Leptospermoidea		
Angophora		
A. apocynifolia	Queensland	4, 11
A. floribunda	New South Wales	12
A. subvelutina	Queensland	4
Corymbia		
C. abbreviata	Western Australia	12
C. intermedia	Queensland	4, 12
C. maculata	New South Wales, Queensland	2, 3, 12
C. papuana	New Guinea	10
C. ptychocarpa	Queensland	12, 13
C. tesselaris	Queensland	4
C. trachyphloia	Queensland	12
Eucalyptus		
(*Monocalyptus*)		

E. acmenoides	Queensland	4
E. amygdalina	Tasmania , Victoria (ID??)	2, 12
E. baxteri	South Australia, Victoria	12, 13
E. delegatensis	Tasmania	12
E. diversifolia	South Australia	12, 13
E. macrorrhyncha	Australian Capital Territory, New South Wales, South Australia, Victoria	2, 11, 12, 13
E. marginata	Western Australia	12, 13
E. nitida	Tasmania	12
E. obliqua	South Australia, Tasmania, Victoria	11, 12, 13
E. pauciflora	New South Wales, Tasmania	2, 12
E. planchoniana	Queensland	12
E. racemosa	Queensland	12, 13
E. tenuiramis	Tasmania	12
(*Symphyomyrtus*)		
E. albens	New South Wales, South Australia, Victoria	2, 3, 12
E. aromaphloia	South Australia, Victoria	12, 13
E. blakelyi	Australian Capital Territory	2, 3
E. brevifolia	Western Australia	12, 13
E. bridgesiana *(E. Stuartiana)*	Australian Capital Territory	2

E. camaldulensis	New South Wales, South Australia, Queensland, Victoria, Western Australia	2, 10, 12, 13
E. coolabah	South Australia	12, 13
E. confluens	Western Australia	12
E. cosmophylla	South Australia	13
E. crebra (incl. *E. drepanophylla)*	Queensland	2, 3, 4
E. dalrympleiana	South Australia	12
E. dealbata	New South Wales	12
E. deglupta	Papua New Guinea, Philippines	7
E. fasciculosa	South Australia	13
E. gomphocephala	Western Australia	2, 3, 12
E. interstans	South Australia	13
E. johnstonii	Tasmania	12
E. laeliae	Western Australia	12
E. largiflorens	South Australia	13
E. lesouefi	Western Australia	12
E. leucoxylon	South Australia, Victoria	8, 12, 13
E. lockyeri	South Australia	13
E. loxophleba	Western Australia	12

E. mannifera (*E. maculosa*)	Australian Capital Territory, New South Wales, Victoria	2
E. melanophloia	Australian Capital Territory	2, 3
E. melliodora	Australian Capital Territory, New South Wales, Victoria	2, 3, 12
E. microcarpa	South Australia, Victoria	12, 13
E. moluccana (*E. hemiphloia*)	Victoria, Queensland	2, 3, 4
E. occidentalis	Western Australia	12
E. odorata	South Australia	2, 13
E. oleosa	South Australia	13
E. platypus	Western Australia	12
E. polyanthemos	Australian Capital Territory	2, 3
E. polybractea	Australian Capital Territory	10
E. populnea	New South Wales, Queensland	4, 12
E. porosa	South Australia	12, 13
E. pruinosa	Western Australia	12, 13
E. robusta	New South Wales	12
E. rudis	Western Australia	2, 3
E. siderophloia	Queensland	12, 13
E. sideroxylon	Australian Capital Territory, New South Wales	2

E. tereticornis	Queensland, Victoria	2, 3, 12
E. viminalis	South Australia, Tasmania, Victoria	12, 13
E. yalatensis	Western Australia	12
E. zopherophloia	Western Australia	12
Eucalyptus sp.	Queensland	6
Eucalyptus sp.	South Australia	12
Melaleuca		
M. armillaris	New South Wales	9
M. cajuputi	Queensland	9
M. dealbata	Queensland	9
M. fluviatilis	Queensland	9
M. leucadendra	Queensland, Western Australia	9
M. nervosa	Queensland, Western Australia	9
M. quinquenervia	New South Wales, Queensland	9
M. stenostachya	Queensland	9
M. viridiflora	Queensland	9

1, Morgan (1933); 2, Currie (1937); 3, Tonnoir (1937); 4, Colbran (1964); 5, Harris (1982); 6, Siddiqi (1986); 7, Siddiqi (1994); 8, Davies and Lloyd (1996); 9, Taylor (2003); 10, Australian National Insect Collection, Canberra; 11, Australian Museum Collection, Sydney; 12, K. Davies, pers. obs.; 13, G. Taylor, pers. obs. Material collected by Davies (12) and Taylor (13) is deposited in the Waite Insect and Nematode Collection, The University of Adelaide.

Review

Preamble

It is with some qualms that I present this, the written paper of the invited talk I gave at the recent International Congress of Nematology. However, as I promised this in the last newsletter, I thought I had better deliver.

Please bear in mind that this is a vast simplification of a large amount of research, which had to be delivered within a strict time and word limit, so undoubtedly there are some areas where details which some may consider important are omitted or subsumed within a bigger generalisation. It is larger trends and patterns which were the subject for the talk, rather than details. One person could not hope to present the subtleties of nematode management across the entire region in any detail. Nevertheless, I hope that a look at the trends in areas outside one's own specific interests may trigger some thought or new insight.

That said, I thought that Australasian nematology stood up very well to international comparison, given the limited expertise and resources allocated to nematology in the region.

It is always useful to attempt to stand back and take stock by looking at the larger picture. If people have constructive comments or additions, I am always happy to hear them. If nothing else, if the paper encourages debate and communication among Australasia's nematologists, and those with interests in the subject, it will have served a useful purpose.

NEMATODE MANAGEMENT IN THE AUSTRALASIAN REGION

An invited seminar for the Fourth International Congress of Nematology, Tenerife, 8th June 2002

Abstract

The Australasian region—including Australia, New Zealand, the Islands of the South Pacific, and Papua New Guinea—encompasses a huge range of agricultural systems, from subsistence to highly mechanised commercial farms, from very small holdings to some of the largest farms in the world, from tropical to temperate and from very wet to some of the driest farmed lands and large areas of irrigation. Within this enormous range of conditions, there are many different nematode pests and management strategies, but similar approaches in broad agricultural systems. Until relatively recently, Cyst Nematodes (*Heterodera* spp.) were the major pest of broad acre low intensity farming of grains in the region, but this has been successfully managed to date

by crop rotation and resistance. More recently Root-Lesion Nematodes (*Pratylenchus* spp.) have become the major pest of this cropping system. Much of the effort in management has been in resistance. Several genera are potential threats in this system, but have been largely ignored to now. In pasture, different species in the same genera are the main problems, with management effort directed largely towards resistance, and lesser efforts in agronomic practices. In intensive horticulture, Root-Knot (*Meloidogyne* spp.), Cyst (*Heterodera* spp., and in NZ *Globodera* spp.) and Burrowing Nematodes (*Radopholus* spp.) are managed by phytosanitary controls, chemical methods, and a range of "alternative" techniques including mulching and soil amendments. In woody crops (fruit, grapes, citrus etc), Root-Knot (*Meloidogyne* spp.), Citrus (*Tylenchulus* sp.), Dagger (*Xiphinema* spp.) and Ring Nematodes (criconematids) are all important, and controlled mostly chemically. "Alternative" nematode management techniques are, however, increasing in importance. In small-scale horticulture Root-Knot (*Meloidogyne* spp.), Burrowing (*Radopholus* spp.) and Root-Lesion Nematodes (*Pratylenchus* spp.) are most important, and controlled by enforced crop rotations. In all of the agronomic systems of the region, identification and diagnosis of nematode problems remain as major issues. Quarantine and phytosanitation are also common themes in nematode management because a number of pest species common in the rest of the world are absent from countries or certain areas. The efficiency and profitability of the current measures are generally moderate to high, but I believe that several initially divergent trends will ultimately converge to produce a different pattern of nematode management in the region in the future. One trend is an increasing use of plant resistance to manage nematodes. Another trend is increasing use of "alternative" techniques. A third trend is a decrease in chemical control. In the longer term I believe these trends will converge towards a more integrated approach utilising elements of all three strategies. This integrated strategy will emerge as all approaches face threats from, for example, resistance-breaking races, changes in soil microbial populations, and enhanced biodegradation of chemicals, as well as increased regulatory and consumer demands. Such longer term changes in nematode management in the region will depend critically on improved identification and diagnosis of nematode problems in the context of the whole soil system.

INTRODUCTION

This paper presents a necessarily broad overview of nematode management in the Australasian Region. The aims are to review the recent past, to assess the current situation, to identify gaps, to highlight particular successes or failures, to point out apparent trends, and to make predictions as to where nematode research may be directed most productively in future. In doing this, comparisons of the experiences in other regions and for organisms other than nematodes will be compared with the situation in nematodes. Some cases where nematode management seems to be successful and less successful will also be compared.

The Australasian region covers a large area of land of diverse climate, agricultural types and crops, including Australia, New Zealand, the Islands of the South Pacific, and Papua New Guinea (Figure 1). It encompasses a huge range of agricultural systems, from subsistence to highly mechanised commercial farms, from very small holdings to some of the largest farms in the world, from tropical to temperate and from very wet to some of the driest farmed lands and large areas of irrigation. Within this enormous range of conditions, there are many different nematode pests and management strategies, but similar approaches in broad agricultural systems. Hence an overview of general trends is presented rather than details of specific crops, geographic areas or agricultural management regimes. A few more specific examples are discussed to illustrate how nematode management may work – or not work – in specific conditions. One of the conclusions of this review is that many of the issues involving nematode management in Australasia involve specific geographic areas, soils, crops or nematode species, and that application of general approaches across a wide range of conditions may be of limited value.

The nematodes in the broad agricultural systems and their management are reviewed first. A few specific examples of apparently successful and less successful nematode management are then presented. The examples were chosen because of their familiarity to the author. Apparently common features of nematode management from the different agricultural systems are summarised. Finally, the future is discussed, focussing on current gaps and trends in the region, particularly in comparison to the situation in other regions.

Definitive data on nematodes and their management is not available for many crops and parts of the region. Hence, this review is based heavily on discussions with people working in various areas of nematology and plant pathology within the region, as well as specimens and records in the National Nematode Collection. Because of the sources of data, statements are not formally referenced.

Entomophilic or helminth nematodes are not considered.

NEMATODES AND THEIR MANAGEMENT IN BROAD AGRICULTURAL TYPES

Grains

Wheat is the major grain crop grown in the region, with lesser amounts of barley, oilseeds, grain sorghum, oats and rice. Grains are grown mainly in warm temperate areas of Australia in farms which are large in area, use few chemical inputs, have low-productivity per unit area, and are commercially oriented. (As stated above, within these broad generalizations, there are exceptions: wheat production in New Zealand – only 1% of that in Australia – operates on much smaller areas, and is much more intensive with higher inputs and production per unit area.)

The major nematodes of concern in grain cropping are Cyst Nematodes (particularly the Cereal Cyst Nematode *Heterodera avenae*) and Root Lesion Nematodes (*Pratylenchus* spp.) Concern in both cases is centred on wheat. Much less is known about nematodes in other cereals. Losses to *H. avenae* were as high as 60% as recently as the 1970's, and most severe in south-eastern Australia. The average loss to *H. avenae* was estimated at about 20%. Following a considerable research programme, *H. avenae* is now largely controlled through a combination of soil testing, crop rotation, and plant resistance. Chemical control at planting was also used some years ago, but this option has now been largely phased out. High losses still occur occasionally, but the combination of lack of knowledge about abundance of *H. avenae* in the soil, high abundance at planting, and highly susceptible cultivars is very rare. Losses were most recently estimated as very low. The management of this species has, on the whole, been successful. This success has been aided by the presence of only 1 pathotype or race in the region, which has considerably simplified designing soil testing, design of rotations, and development of resistance.

Following the large degree of success in management of Cereal Cyst Nematode, *Pratylenchus* spp. have emerged as the major nematode issue in wheat. Unlike the situation with Cereal Cyst Nematode, there are multiple species involved, some of which have only been identified recently. *Pratylenchus* spp. have a much wider host range than Cereal Cyst Nematode, and so concern with these nematodes extends across a number of grain crops. Although concern is more widespread, crop losses seem lower: losses between 0 and 30% have been recorded. As with Cereal Cyst Nematode, the situation in wheat has been most studied because it is the grain crop covering the largest area and having the highest value, and in wheat losses are estimated to average about 10%.

There are at least 9 species involved: *P. brachyurus*, *P. coffeae*, *P. hexincisus*, *P. neglectus*, *P. penetrans*, *P. pinguicaudatus*, *P. thornei*, *P. zeae* and a species which has been recorded as *P. teres* Not all species are regarded as equally damaging, but the distributions and differences between them are still being investigated.

Root Lesion Nematodes are managed through a combination of soil testing, crop rotation if abundance is high, and resistance. The current emphasis is heavily weighted towards developing resistant cultivars. How successful this strategy will prove given the complexities of the species involved and their distribution is yet to be seen, but so far there seems to have been little change.

Ditylenchus dipsaci is of concern in Oats, with losses of up to 100% in the past. Current losses are, on average, small. Testing of soil or plants and resistant varieties are the principal management strategies. Testing is less extensive than for *H. avenae* or *Pratylenchus* spp., so economic losses still occur occasionally. Resistance particularly has proven successful, possibly because it appears that there are relatively few of the many races of *D. dipsaci* present in Australasia.

There are a fourth group of nematodes which seem very common in grain crops in the north of Australia: the Stunt Nematodes (*Tylenchorhynchus* spp.). They are not perceived as warranting concern or special management at the moment, but they may be very abundant under grain crops and have been recorded elsewhere as causing crop losses either alone or together with other genera of nematodes. Should Root Lesion Nematodes be controlled to the same extent that Cereal Cyst Nematode has been, one may speculate that Stunt Nematodes will be the next pest to emerge. The current knowledge of taxonomy and distribution of this group in Australia is very poorly understood.

Commercial horticultural crops

Included in this category are tomatoes, cucurbits such as melons, cucumbers, squash and pumpkin, ginger, onion and relatives, carrots, hops, cut flowers, and other crops grown intensively on areas which are very small relative to broad acre grains. Production is spread geographically over most humid areas of the region, with some in irrigated areas as well (but irrigated agriculture is covered in a separate section below).

The main nematodes causing concern in this agricultural system are Root Knot Nematodes (*Meloidogyne* spp.). In cooler areas various Cyst Nematodes (*Heterodera* spp.) are of concern. Of lesser concern are Root Lesion Nematodes (*Pratylenchus* spp., but often different species to those of concern in grains). In some cases the species present on a particular crop in a particular region are known, but, often management is based on genus, rather than species.

The results of nematode management are extremely variable, with losses ranging up to 50% in the past. Currently losses are variable but probably in the range 5 to 15% (but there have been very few studies of losses in many horticultural crops).

A range of strategies are employed for management of nematodes, and these differ somewhat between the many different crops collected under this agricultural type. Physical methods, such as soil sterilization, are used where the scale of the growing unit makes it feasible. Chemical control with organophosphates or carbamates is used where the value of the crop is sufficiently high to justify the cost. Soil hygiene – clean planting material, avoiding introduction of foreign materials and using land not previously cropped – is also a major strategy used. There is also a trend to soil-less culture which has so far resulted in total disease management. However, methods such as this are only being used on very high value crops.

Probably the fastest growing area of nematode management in this agricultural system is what may be collectively termed "novel biological" methods. Included under this term are the use of soil amendments from a variety of sources, intercropping or rotations with plants which fumigate the soil, and management of plant residues. Within each of the above categories, there are many alternatives which have been applied with success in certain situations but not others. There is added impetus to switch to biological methods from the deleterious environmental effects and unsustainability of some of the more traditional methods. The use of these "novel biological" methods will be discussed further below.

A common characteristic of nematode management in commercial horticulture is that it is relatively untargeted. The physical, chemical, hygiene-centred, and "novel biological" methods all aim to reduce or eliminate all plant-parasitic nematodes, and in some cases all other types of nematodes as well. This may be a reason that nematode management fails sometimes, as evidenced by the patchy variation in losses to nematodes. Economics also plays a large role in the success or otherwise of nematode management in this agricultural system: where crop values are high enough, the generally expensive methods for nematode control are used successfully, but this is not so where crop values are lower. (An interesting comparison may be made with sports turf, which is a very high value “crop”, where economics does not seem to have any

Broad acre tropical commercial crops

Included in this category are banana and sugar cane, which are grown on relatively large scales in warm temperate and tropical Australia, Papua/New Guinea, and Fiji. Plantain is only a very small proportion of the total area.

By contrast with the situation in many other agricultural systems, the plant-parasitic nematodes associated with banana are well known at species level. *Radopholus similis* is probably the major nematode of concern, with losses to bananas of up to 30% in Australia. (Australia seems to be the geographic centre of species radiation in the genus *Radopholus*, with over 20 species known, but most are not thought to be of economic importance.) Spiral Nematode (*Helicotylenchus multicinctus* is also of concern in bananas. The closely-related *H. dihystera* is often present, either alone or in combination with *H. multicinctus*, but is not regarded as being of particular concern. Also of concern are *Pratylenchus* spp., particularly *P. goodeyi*, and *Meloidogyne* spp. (*M. arenaria, M. incognita* and *M. javanica*).

The nematodes associated with sugar cane are much less well known, but include a similar suite of genera to those of concern in banana, albeit with a different rank order in terms of level of concern. The level of concern is based mainly on distribution and abundance data, as details of the effects of the nematodes on production are still incomplete and subject to continuing research. *Pratylenchus zeae* are seen as warranting most attention, followed by *Meloidogyne javanica*, *Paratrichodorus minor*, *Helicotylenchus* spp. and *Tylenchorhynchus* spp.. *Radopholus* spp. are present but of little concern.

Losses in the absence of nematode management are estimated at up to 20% for bananas and 20-30% for sugar cane in Australia. In both crops, chemical control has been used extensively, and has reduced losses considerably. There have been some attempts at “novel biological” approaches using soil amendments, but these have been rather limited and of uncertain success. Fallow and crop rotation have been shown effective at reducing nematode damage, but use of these methods of nematode management has been relatively low. Overall, current nematode management seems to reduce nematode damage to acceptable levels, based perhaps on the good knowledge of the fauna allowing targeting of chemical use. However, whether this situation will continue into the future is less certain with the environmental and economic pressures to reduce pesticide use.

Irrigated crops

Grown principally in arid or semi-arid Australia, very few nematode issues have been reported in this cropping system. However, this may be related to the relatively recent expansion of these areas, and their geographical isolation from both humid agricultural areas and from each other. Many plant-parasitic nematode species may be absent from irrigation areas, or the ones which are there may be undergoing evolution and selection for genotypes which suit the conditions. Under these conditions, quarantine will clearly be important.

Tropical non-commercial

Included in this category are all the tropical crops grown on small plots for essentially local consumption. This type of agriculture is primarily carried out in Papua/New Guinea and the Pacific Islands, but there are some farms in Australia and New Zealand which share many of the characteristics of this type of agriculture as well.

The main nematodes associated with the large number of crops in this agronomic type are Root Knot Nematodes (*Meloidogyne* spp.). Root Lesion Nematodes (*Pratylenchus* spp.) and Burrowing Nematodes (*Radopholus* spp.) are also important. Spiral Nematodes (*Helicotylenchus* spp.) and Cyst Nematodes (*Heterodera* spp.) are significant in particular crops and areas. The species within these genera which are most important for crop losses are known in a few cases, but in many cases management is based on the genus of nematodes only. In some cases management systems have evolved which are clearly directed at managing nematodes, without explicit recognition that nematodes are the pathogen involved.

Losses are highly variable, and have been up to 100%, but are now generally much less than this. The main methods used for nematode management are crop rotation (either deliberate or enforced), fallow and hygiene (clean planting material). These methods have reasonable success given the very limited detail of knowledge about the nematodes present in any particular situation, but often management is reactive to obvious problems with crops, rather than proactive.

Potato

This crop has been treated separately from other intensively grown horticultural crops because there is a divergence of approaches in the region, based on the distribution of Potato Cyst Nematodes (*Globodera* spp.). Both *G. rostochiensis* and *G. pallida* are present in New Zealand, but *G. rostochiensis* has only been found in small areas in Australia. Apart from the Potato Cyst Nematodes, the main nematode pests are Root Knot Nematodes (*Meloidogyne* spp., mainly *M. hapla* but recently *M. fallax* has raised concern), and Root Lesion Nematodes (*Pratylenchus* spp.).

In New Zealand, management of Potato Cyst Nematodes is a complicated combination of testing, recording the history of every field, restrictions on the use of potatoes based on the results of testing and history, plant resistance, and application of chemicals, although this method is used relatively infrequently. These strategies have been reasonably successful, based on a PCR-based diagnostic protocol, a history of a previous strict containment regime which has provided a combination of information on extensive testing of potato fields, infrastructure for and a culture of thinking about Potato Cyst Nematodes, and locally developed resistance to most local nematode pathotype. The current management regime was only developed within the last decade, and about 20 years after the first detection of Potato Cyst Nematodes in New Zealand in 1972.

In Australia, the emphasis has been on quarantine, with strict regulations on what can be grown everywhere Potato Cyst Nematodes have been detected, and in large buffer zones around. These measures have proven successful so far, as no new areas have been found infected. Only 1 pathotype of only 1 species (*G. rostochiensis*) is present in the infested areas of Australia. Plant resistance is also under investigation.

The other nematodes of concern in potato are controlled mainly by chemical means.

The direct losses in crop production to nematodes are not very great under the current management techniques. However, the total costs, including foregone production and regulatory regimes, are substantial. Nematode pests of potato – particularly Potato Cyst Nematodes – are difficult pests to manage right around the world, and whether their management is better or worse where Potato Cyst Nematodes are present in Australasia is difficult to quantify. In the large areas of Australia which do not have Potato Cyst Nematodes, management is undoubtedly easier and more profitable than most of the rest of the potato growing areas of the world where Potato Cyst Nematodes are present.

Pasture

Pasture here refers to relatively intensively managed pastures, rather than the low-intensity grazing lands which cover very large areas of northern and central Australia. Little is known about the nematodes in extensive grazing lands and little management is practiced. By contrast, nematodes are a major concern in the intensively managed grazing lands in temperate Australia and New Zealand. Forage grasses and clovers are the main pastures.

The main nematodes of concern in this system are Cyst, Root Knot, Stem and Root Lesion Nematodes (*Heterodera trifolii*, *Meloidogyne* spp., mainly *M. trifoliophila, Ditylenchus dipsaci* and *Pratylenchus* spp.). The former 2 taxa are more important than the latter 2. Losses to these nematodes are difficult to quantify because a common result of nematode damage on pasture is reduced persistence, but losses may have been as high as 33% in the past. Presently losses are lower, but are still substantial.

The main management response has been development of plant resistance. Crop rotations have also been used. Perhaps the range of nematodes involved has meant that neither has been particularly successful. There have been some moves towards an approach involving increased diagnosis of nematode species, management of grazing intensity, and management of pasture composition, which have yet to yield conclusive reductions in pasture losses to nematodes.

Turf

This has been included as a separate section in this review because it will be used as a specific example below. It is grown as a crop for harvest (as turf rolls including the entire above and below ground plant with some soil), and as a substrate (for playing fields and landscape). The areas covered are small relative to many of the other crops, but the value in terms of expenditure per unit area is high. The areas involved range from very small, to medium sized sports fields to large areas of landscape turf. Turf is grown right across the region.

The nematodes of concern in turf are Stubby Root Nematodes (*Paratrichodorus* spp.), Dagger Nematodes (*Xiphinema* spp.) and Sheath Nematodes (*Hemicycliophora* spp.). However, Root Lesion, Sting, Spiral, Root Knot, Ring and Stunt Nematodes are also often present in large numbers, either alone or, more frequently, in combination (*Pratylenchus* spp., *Belonolaimus (sensu lato)* spp., *Helicotylenchus* spp., *Meloidogyne* spp., Criconematina including *Criconemella* spp., *Criconemoides* spp. or *Hemicriconemoides* spp., and *Tylenchorhynchus* spp., respectively). Species have mostly not been identified. Likewise distributions are mostly unknown, except that Dagger Nematodes and Sting Nematodes seem mostly restricted to warmer areas.

Losses to these species can be effectively 100% (as where an entire surface must be replaced). Less severe losses are more common, but the effect of nematodes is currently substantial. Testing is used, but mainly to diagnose problems after symptoms are already apparent. Overwhelmingly the management technique is application of chemicals (mainly organophosphates). This technique has some success, but failures are also common. Enhanced biodegradation after repeated application, vertical migration by nematodes and the use of nemastatic, rather than nematoxic, compounds are possibly implicated.

There is also a small movement towards "novel biological" management techniques involving soil amendments from various sources. Those based on seaweeds have been popular. Success has been very mixed.

Woody crops

In this category are grape, olives, citrus and fruit trees. At least one type of woody crop is grown in most regions of Australia and New Zealand.

Major nematodes of concern in this category are Dagger Nematodes (*Xiphinema* spp.), Citrus Nematode (*Tylenchulus semipenetrans*), Root Knot Nematodes (*Meloidogyne* spp. mainly *M. javanica*), Stubby Root Nematodes (*Paratrichodorus* spp. often *P. lobatus*) and various Ring Nematodes (*Criconemella* spp. mainly *C. xenoplax*). Nematodes are not viewed as major pests in this system, hence there is little nematode sampling and infrequent reports of nematode damage to woody crops. This has fed back into the perception that nematodes are not major pests in this agricultural system. The nematode damage which is reported seems to be patchy in most crops; however this is based on symptoms present. Replant disorders are reasonably frequent. They are often caused by nematodes elsewhere in the world, but they have not been associated with nematodes on a large scale in Australia. This may be because nematodes have not been investigated in many cases of replant problems.

An exception to this rule is hops, which may be associated with hop cyst nematode (*Heterodera humuli*) and *Coslenchus costatus*. These nematodes are managed by use of chemicals. Another situation which is relatively well known is citrus, where Citrus Nematode is common. Management most frequently involves chemicals, often using compounds also in use for insect pests (carbamates). Resistant rootstocks are also used. The situation in grapes is less clear. Citrus nematode is known to cause losses and is controlled chemically as above. Dagger Nematodes also seem important in grape vines, but research in this area is at an early stage.

Woody crops are another category where "novel biological" methods are being increasingly used. Grazing by various animals around the bases of the plants (for example, geese or pigs), biofumigation using *Brassica* cvv., pure organic mulches of *Pinus* spp. and/or *Eucalyptus* spp. or mulches mixed from many sources, and biological antagonists involving plant extracts and manures have all been tried. These methods have also been combined with various levels and techniques of incorporation into the soil. Results have been variable, but *Brassica* cvv seem most effective at reducing abundance of plant-parasitic nematodes. The reduction in nematodes was, however, associated with a higher incidence of *Pythium* spp.. Some treatments have increased nematode abundance but not losses.

An unusual feature in this system has been the use of chemical and mulching strategies together. Considerable success has been achieved in trials by adding a mulch and a low concentration of nematicide. This technique has yet to be taken up by farmers.

Losses are difficult to estimate in crops such as these, but are estimated at 5 to 10%.

SOME SPECIFIC EXAMPLES

In this section more detail is presented on 3 areas where nematode management seems to work well, work moderately well, and works poorly. The choice of illustrations is partly from areas with which the author is personally familiar and partly from areas about which most is known.

Turf grass

This is included as an example where nematode management seems to be failing, despite a very high value "crop", considerable testing for nematodes, and willingness to use most management techniques almost irrespective of cost. There are some limitations on the techniques which can be used, for example to keep stadia in use, but there is also a large range of management techniques available: everything from the choice of substrate or soil, the watering regimes, fertilization, coring and aerating, to the use of soil amendments can be managed with a high degree of precision. Despite all these advantages, nematode management does not seem to provide the outcome desired in many cases. The initial successes with untargeted chemical strategies have not been sustainable.

The lack of sustainably successful nematode management has perhaps been associated with many factors. One factor is the absence of a clear picture of the nematodes causing damage. Even which genus or genera in combination should be of most concern is not yet clear. A second factor is the lack of knowledge of the biology of the nematodes in question and when they are of concern. The same threshold values are applied in a wide variety of situations. A third factor is the apparent complexity of the plant-parasitic nematodes causing problems. (However, this may be purely a result of the lack of knowledge of the first 2 factors.) A fourth factor is the overuse of the single strategy favoured, especially in the absence of any effective targeting, which has lead to decreased efficiency of that strategy. A fifth factor is the absence of alternatives: other strategies were not considered until recently. A sixth factor is that the increasing health and environmental concerns with increased pesticide use were not given priority when the trend outside was towards decreased pesticide use. A seventh factor is that the funding base of the industry is fragmented, which precludes comprehensive studies necessary for more long-term solutions.

Wheat

Nematode management in wheat has had mixed success in the Australasian region. There has been considerable success for Cereal Cyst Nematodes, but less success so far for Root Lesion Nematodes. The differences between the management of these nematodes in wheat, and between them and the nematodes in turf may be instructive.

With Cereal Cyst Nematode, the taxonomy of the nematodes causing damage is well understood in the region, even to the level of pathotype. The biology, population dynamics and interaction with their plant hosts are well known and relatively simple, with a single generation per year. There is only one pathotype of one species present in Australia. A combination of strategies is used, involving testing, resistance, crop rotation and hygiene, which are effectively targeted. Perhaps because of the knowledge of the biology of the nematode, alternative management strategies were developed, even after initial success with hygiene and crop rotation. The funding base of the industry was highly centralised and supportive of research on nematode management in this area for a considerable period of time, which allowed comprehensive studies necessary for more long-term solutions. All of these features are in contrast to the situation surrounding turf, whereas there are both similarities and differences with Root Lesion Nematodes in wheat.

Perhaps the only failure in the success of management for Cereal Cyst Nematodes in wheat has been the emergence of Root Lesion Nematodes as a major concern. By concentrating on just one species to the exclusion of other potential threats known to be present, the successful management developed for Cereal Cyst Nematodes has failed for Root Lesion Nematodes.

Many of the features of the management of Root Lesion Nematodes in wheat are intermediate between the situation for Cereal Cyst Nematodes and turf nematodes. The taxonomy is better known than for the multiple genera in turf, but less is known than for Cereal Cyst Nematodes. Several species are well characterised, but there is one species of doubtful identity and little work on population structure within species. Likewise, knowledge of the biology of the Root Lesion Nematodes is intermediate between Cereal Cyst Nematodes and turf nematodes. The same threshold values are applied in a variety of situations, the interactions between species and their interactive effects are poorly known, and the population dynamics are poorly known. The complexity of the nematode populations also appears intermediate between that for Cereal Cyst Nematodes in wheat and the multiple nematode genera in turf. Up to 3 species may be present and there are multiple generations per year. A single strategy is not used against Root Lesion Nematodes as in turf nematodes, but there is a heavy emphasis on plant resistance. This is perhaps related to the apparent taxonomic complexity making rotations more difficult to design. There is a danger of resistance-breaking races appearing.

The funding base for research on Root Lesion Nematodes in wheat is similar to that which supported the successful management of Cereal Cyst Nematodes. However, the situation seems more akin to the unsuccessful situation in turf nematodes, with a heavy emphasis on a single strategy, in this case plant resistance. (There are some similar concerns over genetic modifications as to those over pesticides.) There is some research into alternative approaches using crop rotation and tillage management, but this has received limited support. There are also very limited attempts to look at potential future management issues, such as Stunt Nematodes (*Tylenchorhynchus* spp.), which occur in very high populations in many wheat cropping areas.

The net result of the situation with Root Lesion Nematodes is one of only partially successful management, and continuing losses.

Cotton

Cotton is one of the most profitable crops in the region at the moment, and the area being planted is growing at a rapid rate. Nematode management does not currently play a large role in the crop. Many areas have been planted only recently in sites isolated from sources of potential nematode pests, so nematode problems may take a few years to develop. However, successful insect pest management has been associated with the general success of the crop, so the characteristics of insect management may provide a useful comparison with those presented for nematodes.

The characteristics of insect pest management in this crop are similar in many ways to those of Cereal Cyst Nematodes in wheat. The insects causing damage are well known taxonomically and biologically. Not only are the interactions of insects with the plant well characterised, but the interactions of pests with their predators and pathogens are also relatively well understood. There is one major insect pest (*Helicoverpa armigera)*, and a number of lesser pests, but the level of knowledge means that the complexity of the situation is not a major impediment to management. The crop is monitored, and the management applied depends on the results and local situation. Several different strategies of pest management are used: crop modification, application of chemicals, natural enemies and biological techniques. Integrating the different techniques is a priority, for example to prevent resistance-breaking races developing. Research is proceeding on increasing the range of options available and improving targeting of existing techniques. Health and environmental concerns with use of pesticides and genetically modified organisms are being given priority. Finally, there is a well-organised funding base supportive of comprehensive studies necessary for more long-term solutions.

The current situation has not always been the case. There have been spectacular failures of pest management in this crop in the past, resulting in complete collapse of the crop in several areas. These failures were often associated with the same characteristics as with turf nematodes, *viz* poor knowledge of pests, untargeted overuse of a single management strategy.

CONCLUSIONS

The greatest successes in management of nematodes, as well as other animals, seem associated with similar characteristics:

- a high level of detailed knowledge of the species associated with the crop, their biology and population dynamics;

- a high level of monitoring, with high grower awareness;

- a range of targeted management techniques being available and applied, depending on the situation.

The fewer the pests associated with a crop, and the simpler their genetic structure, the easier it is to achieve more successful management.

If a low and decreasing level of losses to nematode pests is an indicator of successful management, then nematode management is successful in some of the crops and agricultural systems considered in this paper. Cereal Cyst Nematode in wheat, Burrowing Nematode in banana, Potato Cyst Nematodes in potato and Citrus Nematode in citrus all have many of the characteristics listed above and nematodes have been managed reasonably successfully in all. Less successful has been management of Root Lesion Nematodes in wheat, Root Knot Nematodes in some horticultural crops, nematodes in sugar cane, pasture and turf. In these cases, taxonomic, biological or ecological knowledge is often inadequate, monitoring insufficient, and management options limited.

THE FUTURE

The future developments in nematode management in the Australasian region may be related to the characteristics of successful management missing in the particular cropping situation. In many crops and agronomic systems, the current gaps are similar. This section presents a synthesis of these gaps and trends in nematode management in the Australasian region.

Taxonomy

Identification of the species and pathotype of nematodes associated with particular crops in particular areas is undoubtedly a need. Too often there may be several species within a genus, or even several genera, which are not differentiated and this may be associated with less than optimal nematode management. This is perhaps a characteristic of the region not shared by other parts of the world. A large, diverse land area, very few nematode systematists, and a short history of agriculture have meant that the nematode fauna associated with plants is relatively poorly known.

Biology, ecology and population dynamics

The biology, ecology and population dynamics of the nematode species are also gaps in many of the situations considered. The relationships between nematode populations and physical conditions such as soils, temperature and rainfall are also largely unknown.

Damage thresholds, taking account of these factors are very poorly developed, rather a single value is often used, irrespective of conditions. The gaps in relating nematode management to physical conditions are possibly peculiar to the region. Certainly there are much better area-specific nematode management systems in place in, for instance, south-eastern USA and much of Europe. The large, diverse land area of the Australasian region exacerbates the importance of this gap.

Likewise, the interactions between nematodes and the host plants are poorly known in many situations in the region. Like the situation with soil conditions, this aspect seems much more adequately researched out of the region. The interactions between nematodes and other pathogens is also a large gap in current knowledge essential to nematode management which seems often omitted from nematode management in the region.

Management of the many nematodes in the soil which do not feed directly on plants is another large gap. The interactions of these nematodes with plant-parasitic nematodes, soil conditions and plant growth are very poorly known in the region, in contrast to many other regions. This seems to offer an area where management options may be vastly increased and improved, particularly with "novel biological" methods.

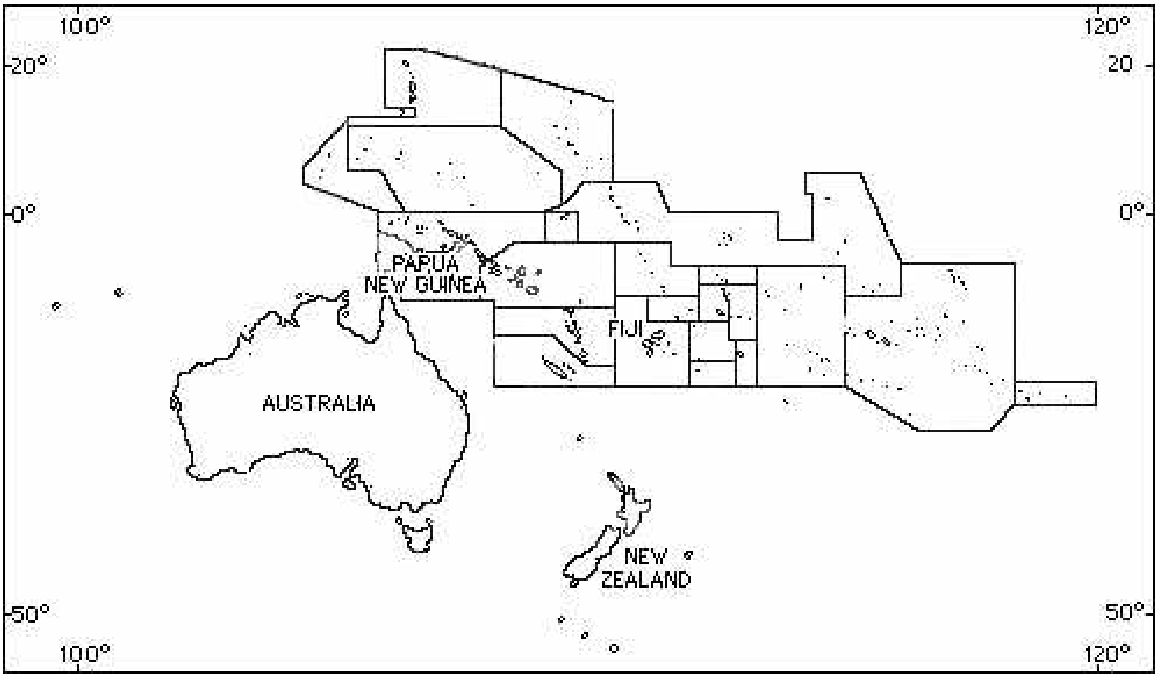
Management options

Successful nematode (and insect) management seems related to having a range of targeted management strategies to apply. In many crops, current management relies heavily on 1 type of management, be it chemical control, plant resistance or crop rotation. Where there are different approaches to nematode management, they are proceeding independently. For example, when "novel biological" agents are used, chemicals are completely absent and use of resistance is not considered. Likewise when resistance is the preferred management option, novel alternatives and chemicals are not considered. It seems that eventually these presently separate lines will have to converge towards a more integrated approach. The threats of resistance-breaking races, changes in soil microbial populations, enhanced biodegradation of chemicals, and increased regulatory or consumer demands to minimise chemical use will probably force this convergence. However, the development and subsequent deployment of new management options will depend on the advances in the other areas listed above.

Quarantine

In many cases, nematode management in the region is simplified considerably by the limited range of species or pathotypes which must be managed, so quarantine is extremely important in the successes in the nematode management in the region. In the case of Cereal Cyst Nematode, the presence of only 1 race or pathotype has allowed the range of integrated measures which have proven so successful. The introduction of additional races with different genetic or morphological characters, different distributions, different alternative hosts, different virulence or resistance-breaking genes, or other characteristics may see much more complex solutions required. Even in taxa where the information on taxa present, genetic structure and hosts, is not as good as that for Cereal Cyst Nematode, adding any additional variability through populations or species from overseas would make nematode management much more difficult and expensive.

FIGURE 1. MAP OF REGION COVERED BY THIS REVIEW



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