IMPACT OF TILLAGE AND RESIDUES FROM ROTATION CROPS ON THE NEMATODE COMMUNITY IN SOIL AND SURFACE MULCH DURING THE FOLLOWING SUGARCANE CROP

By

GR STIRLING[1], NV HALPIN[2], MJ BELL[3], PW MOODY[4]

[1]*Biological Crop Protection Pty. Ltd., 3601 Moggill Road, Moggill,Qld*
[2]*Queensland Department of Primary Industries and Fisheries, Bundaberg, Qld*
[3]*Queensland Department of Primary Industries and Fisheries, Kingaroy, Qld*
[4]*Queensland Department of Environment and Resource Management, Indooroopilly, Qld*
graham.stirling@biolcrop.com.au

KEYWORDS: Crop Rotation, Green Cane Trash Blanket (GCTB), Minimum Tillage, *Pratylenchus*, *Meloidogyne*, *Xiphinema*, Free-living Nematodes, N Mineralisation, Suppressive Soils.

Abstract

THE IMPACT of three cropping histories (sugarcane, maize and soybean) and two tillage practices (conventional tillage and direct drill) on plant-parasitic and free-living nematodes in the following sugarcane crop was examined in a field trial at Bundaberg. Soybean reduced populations of lesion nematode (*Pratylenchus zeae*) and root-knot nematode (*Meloidogyne javanica*) in comparison to previous crops of sugarcane or maize but increased populations of spiral nematode (*Helicotylenchus dihystera*) and maintained populations of dagger nematode (*Xiphinema elongatum*). However the effect of soybean on *P. zeae* and *M. javanica* was no longer apparent 15 weeks after planting sugarcane, while later in the season, populations of these nematodes following soybean were as high as or higher than maize or sugarcane. Populations of *P. zeae* were initially reduced by cultivation but due to strong resurgence tended to be higher in conventionally tilled than direct drill plots at the end of the plant crop. Even greater tillage effects were observed with *M. javanica* and *X. elongatum*, as nematode populations were significantly higher in conventionally tilled than direct drill plots late in the season. Populations of free-living nematodes in the upper 10 cm of soil were initially highest following soybean, but after 15, 35 and 59 weeks were lower than after sugarcane and contained fewer omnivorous and predatory nematodes. Conventional tillage increased populations of free-living nematodes in soil in comparison to direct drill and was also detrimental to omnivorous and predatory nematodes. These results suggest that crop rotation and tillage not only affect plant-parasitic nematodes directly, but also have indirect effects by impacting on natural enemies that regulate nematode populations. More than 2 million nematodes/m^2 were often present in crop residues on the surface of direct drill plots. Bacterial-feeding nematodes were predominant in residues early in the decomposition process but fungal-feeding nematodes predominated after 15 weeks. This indicates that fungi become an increasingly important component of the detritus food web as decomposition proceeds, and that that the rate of nutrient cycling decreases with time. Correlations between total numbers of free-living nematodes and mineral N concentrations in crop residues and surface soil suggested that the free-living nematode community may provide an indication of the rate of mineralisation of N from organic matter.

Introduction

Research by the Sugar Yield Decline Joint Venture has shown that introducing a legume rotation crop into the sugarcane farming system reduces the need for fertiliser nitrogen, provides some control of root pathogens and improves sugarcane growth and yield (Garside *et al.,* 1999; 2002; Garside and Bell, 2001; 2007; Stirling *et al.,* 2001; 2002).

Minimising tillage, controlling wheel traffic and retaining crop residues are also beneficial as they enhance levels of soil organic matter, reduce the impact of compaction, improve soil structure, reduce losses from erosion and lessen fuel and labour costs (Braunack and Ainslie, 2001; Braunack and McGarry, 2006).

However, despite the fact that residue retention, minimum tillage, leguminous rotation crops and controlled traffic using GPS guidance are now being adopted in the Australian sugar industry (Garside *et al.,* 2005), data on the effects of integrating these practices into the sugarcane farming system are relatively limited.

This paper reports the effects of crop rotation, tillage practice and residue retention on nematode communities at a field site near Bundaberg. Plant-parasitic nematodes were monitored because previous research has shown that they reach high population densities in Queensland sugarcane fields (Blair *et al.,* 1999 a; b); they reduce the yield of sugarcane (Blair and Stirling, 2007) and their population densities are affected by the host status of a rotation crop (Stirling *et al.,* 2001; 2002). The free-living nematode community was of interest because of its potential to indicate a soil's biological status (Wilson and Kakoili-Duarte, 2009), and because managing soils in a manner that is conducive to bacterial and fungal feeding nematodes is likely to be beneficial to soil fertility (Ingham *et al.,* 1985). The main objectives were to examine interactions between crop rotation and tillage on plant-parasitic nematodes; to monitor the population dynamics of free-living nematodes in situations where crop residues were either left on the soil surface or incorporated into the soil with tillage implements; and to determine whether that status of the free-living nematode community was a useful indicator of N mineralisation rates in decomposing crop residues.

Methods

The experiment was a factorial consisting of 3 crop histories × 2 tillage practices × 4 replicates and was set out in a randomised block design. Details of the experiment are given by Bell *et al.* (2010), but briefly, maize and soybean crops were harvested for grain on 13 April and 8 May 2006, respectively, plots were then replanted with the same crop and these crops were mulched with a flail mower on 6 July 2006.

The third crop history treatment was continuous sugarcane, and it was harvested on 7 July 2006. Half the plots were then tilled (24 July 2006) and in late September 2006 sugarcane (Q151) was planted into tilled or non-tilled plots to establish the tillage treatments [conventional tillage (CT) or direct drill (DD)]. Due to poor emergence in the direct drilled continuous sugarcane treatment, these plots were replanted in late November 2006 and all other treatments were mown to slow their development while plants established in the former treatment. Although plots were split for nitrogen (0 and 150 kg N/ha), samples discussed in this paper were taken from plots that received no nitrogen (unless otherwise indicated).

Soil and crop residue samples were collected prior to establishing tillage treatments, at the time sugarcane was planted and periodically during the plant crop. Soil samples consisted of composite samples of 10 cores from each plot collected at a depth of 0–10 cm. Crop residues on the soil surface were removed from three randomly-selected areas (1.8 × 0.5 m) within each plot and weighed. Ammonium N was determined in air dry soil or crop residues by a modified Berthelot indophenol reaction, and nitrate + nitrite-N by the Griess-Ilsovay reaction, with nitrite levels assumed to be negligible (Method 7C2; Rayment and Higginson, 1992).

Nematodes were extracted from 200 mL of soil (approximately 205 g dry weight) and from 20–30 g dry weight equivalent of crop residues at their field moisture content, by placing soil or residue on a standard extraction tray (Whitehead and Hemming 1965). After 2 days, nematodes were recovered by sieving twice over a 38 µm sieve. The Nematode Channel Ratio (Yeates 2003) was calculated as NCR = B/(B+F), where B and F were the number of bacterial-feeding and fungal-feeding nematodes, respectively. Since fine-tailed Tylenchidae with small stylets (e.g. *Tylenchus*) were commonly found in crop residues as they were decomposing, they were considered fungal-feeders rather than plant associates.

Two indices that are descriptors of soil food web condition [the Enrichment Index (EI) and Structure Index (SI)] were calculated using methods detailed by Ferris *et al*. (2001). EI indicates the degree to which bacterial-feeding opportunists have multiplied in response to the microbial flushes that follow disturbance or resource inputs, while SI is calculated from the abundance of omnivores and predators and indicates the stability of the food web.

Statistical analyses

Data were analysed by analysis of variance using Genstat™. In situations where samples were collected several times from the same plots, time was used as a repeated measure.

Relationships between numbers of free-living nematodes/g residue or 200 mL soil and concentrations of mineral N in crop residues and soil were examined using data from soybean, maize and sugarcane plots (DD plots only) at the first four sampling times (–8, 2, 15 and 35 weeks after planting sugarcane). Free-living nematode populations were correlated with soil mineral N concentrations at the time nematode samples were collected, and also with N concentrations at the following sampling time.

Results

Plant-parasitic nematodes

The first samples were collected in July 2006, just before tillage treatments were imposed. Nine plant-parasitic nematodes were recovered from these samples; the six species listed in Table 1 together with three nematodes that occurred in relatively low numbers, namely stunt nematode (*Tylenchorhynchus annulatus*, stubby root nematode (*Paratrichodorus minor*) and ring nematode (*Criconemella* sp.). Soybean markedly reduced populations of *P. zeae* and increased populations of *Helicotylenchus dihystera* whereas except for *Xiphinema elongatus*, sugarcane and maize sustained similar numbers of plant-parasitic nematodes (Table 1).

Table 1—Impact of the previous crop on the most common plant-parasitic nematodes (numbers/200 mL soil)[A] in a field trial at Bundaberg immediately before tillage treatments were imposed and two months prior to planting sugarcane.

Common name	Scientific name	Sugarcane	Maize	Soybean
Lesion nematode	*Pratylenchus zeae*	616a	724a	55b
Root-knot nematode	*Meloidogyne javanica*	17a	31a	1a
Reniform nematode	*Rotylenchulus parvus*	536a	250a	88a
Spiral nematode	*Helicotylenchus dihystera*	46b	38b	379a
Spiral nematode	*Rotylenchus brevicaudatus*	95a	109a	89a
Dagger nematode	*Xiphinema elongatum*	122a	14b	104a

[A] Nematode counts are back-transformed means of transformed data [$\log_{10}$ (no. nematodes + 1). Within each row, numbers followed by the same letter are not significantly different (P = 0.05)

Analysis of population dynamics data for *P. zeae* in the plant crop of sugarcane showed a significant interaction between crop history, tillage practice and time. Two and 7 weeks after planting, populations of *P. zeae* were highest following maize and sugarcane but were significantly lower in conventionally tilled than direct drilled plots (Figure 1).

Nematode populations then increased markedly and later in the season tended to be higher (but not significantly higher) following conventional tillage. *P. zeae* populations following soybean were very low 2 and 7 weeks after planting, but from 15 weeks until plant crop harvest they were similar to maize and sugarcane, regardless of the tillage treatment.

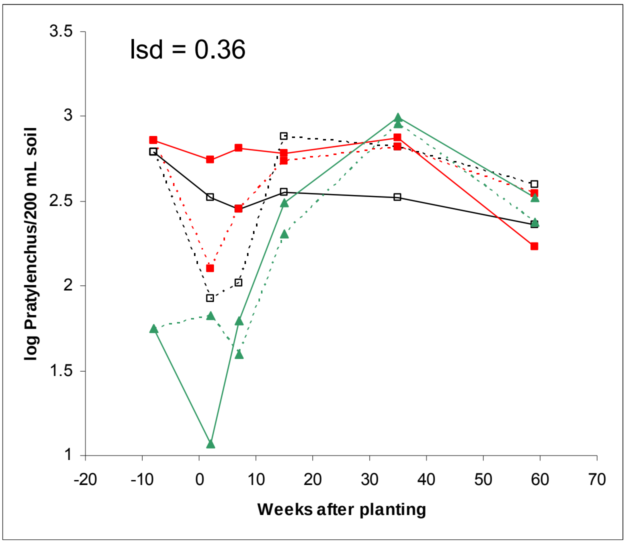

Fig. 1—Effect of previous crop history [sugarcane (□), maize (■) and soybean (▲)] and tillage practice 8 weeks prior to planting [conventional till (---), direct drill (—)] on populations of lesion nematode (*Pratylenchus zeae*) in the upper 10 cm of soil in a plant crop of sugarcane.

Analyses of results for *M. javanica* showed significant interactions for crop history × time and tillage practice × time. Initial populations of *M. javanica* were lower following soybean than the other histories, but 35 and 59 weeks after planting, populations were highest following soybean, significantly lower following sugarcane and intermediate following maize (Figure 2). The tillage effect was manifested as lower nematode populations early in the season and higher populations late in the season following conventional tillage, with differences between the two tillage practices being significant at 7 weeks and 59 weeks (Figure 3).

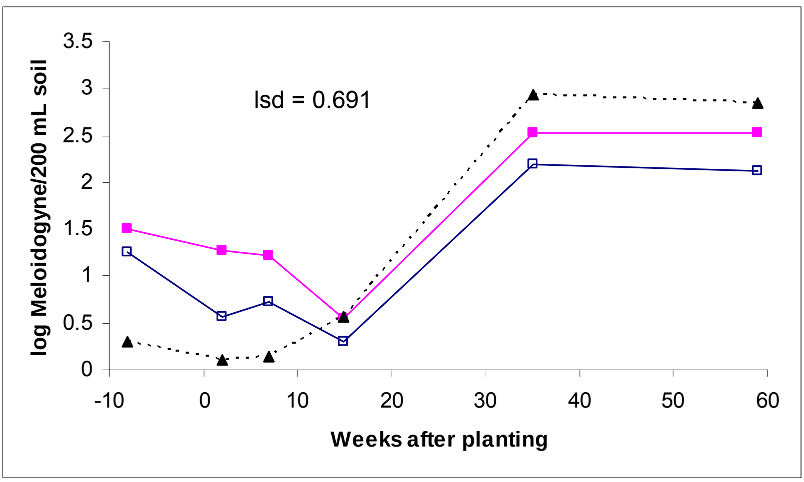

Fig. 2—Effect of previous crop history [sugarcane (□), maize (■) and soybean (▲)] on populations of root-knot nematode (*Meloidogyne javanica*) in the upper 10 cm of soil a plant crop of sugarcane.

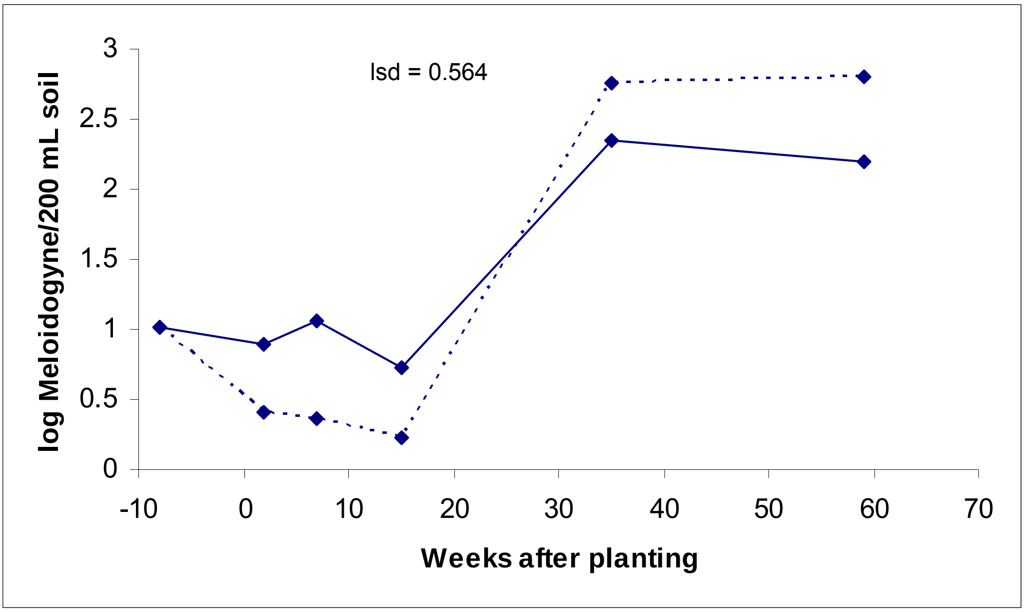

Fig. 3—Effect of tillage 8 weeks prior to planting [conventional till (---), direct drill (–)] on populations of root-knot nematode (*Meloidogyne javanica*) in the upper 10 cm of soil in a plant crop of sugarcane.

All plots (including those that had received 150 kg N/ha during the plant crop) were sampled soon after plant crop harvest. Analyses of data obtained from these samples showed that populations of *P. zeae* were significantly higher following soybean than after either maize or sugarcane, and that N application did not affect populations of this nematode (data not presented).

For *M. javanica*, there was a significant crop history × N interaction. In the sugarcane history, N-fertilised plots had higher root-knot nematode populations than nil plots, whereas the opposite was true in the soybean history (data not presented).

Reniform nematode was the only other plant-parasitic nematode to reach relatively high population densities after sugarcane was planted, with populations at 15 and 35 weeks often reaching 300–600 nematodes/200 mL soil.

However, reniform nematode population densities were not significantly affected by crop history, tillage practice or time.

Dagger nematode populations were lower than most of the other plant-parasitic nematodes, but analyses of data for this nematode showed a significant effect of crop history, and a significant tillage × time interaction.

Numbers were lowest after maize, intermediate after sugarcane and highest after soybean, while at 35 weeks there were significantly more nematodes following conventional tillage than direct drill. Populations of *X. elongatum* in some plots were as high as 270 nematodes/200 mL soil and roots in these plots showed symptoms that were probably caused by this nematode (necrosis of root tips together with stunting and excessive branching of fine roots).

Free-living nematodes in soil

In July 2006, prior to the imposition of tillage treatments, the free-living nematode population in soil was much higher following soybean than either maize or sugarcane, as 3.82, 1.56 and 1.36 million nematodes/m^2, respectively, were present to a depth of 10 cm (Figure 4). The nematode population then declined in plots cropped previously with soybean whereas it increased initially and then declined following maize and sugarcane. The end result was that there were significantly more free-living nematodes following sugarcane than soybean during the period 15–59 weeks after planting (Figure 4). Tillage also had an impact on free-living nematodes in soil, with numbers consistently higher following conventional tillage than direct drill. This difference was significant at 2, 7, 15 and 35 weeks (Figure 5).

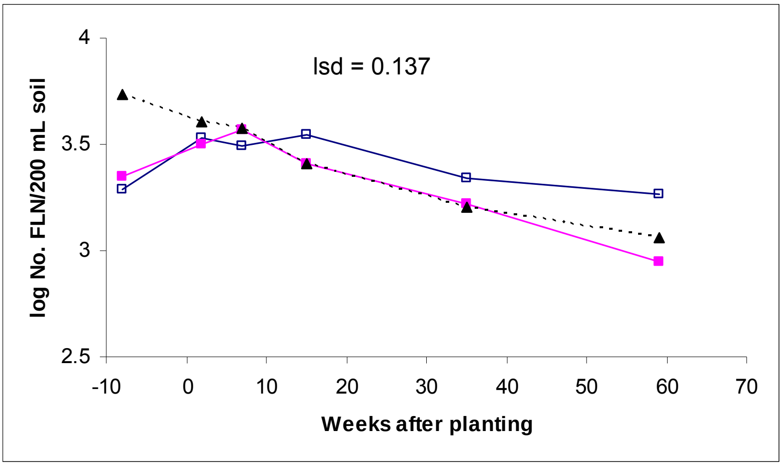

Fig. 4—Effect of previous crop history [sugarcane (□), maize (■) and soybean (▲)] on numbers of free-living nematodes in the upper 10 cm of soil in a plant crop of sugarcane.

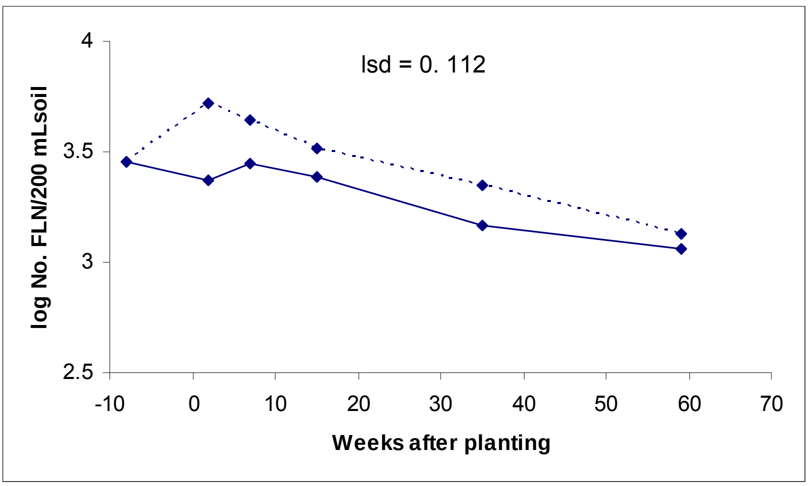

Fig. 5—Effect of tillage practice 8 weeks prior to planting [(conventional till (---), direct drill (–)] on numbers of free-living nematodes in the upper 10 cm of soil in a plant crop of sugarcane.

In addition to changes in total numbers of free-living nematodes as the season progressed, there were also changes in the composition of the nematode community. In both the soybean history and the conventional tillage treatment, bacterial-feeding enrichment opportunists were predominant early and then declined, as evidenced by the significant crop history × tillage practice × time interaction for EI (Figure 6).

Tillage had a bigger impact on the nematode community than the previous crop, and this was reflected in the NCR (the proportion of bacterial-feeding to fungal-feeding nematodes), which was significantly higher following conventional tillage than direct drill. There was also a significant tillage × time interaction, with the difference between tillage treatments mainly due to the much higher NCR in conventionally tilled plots 15 weeks after planting (Figure 7).

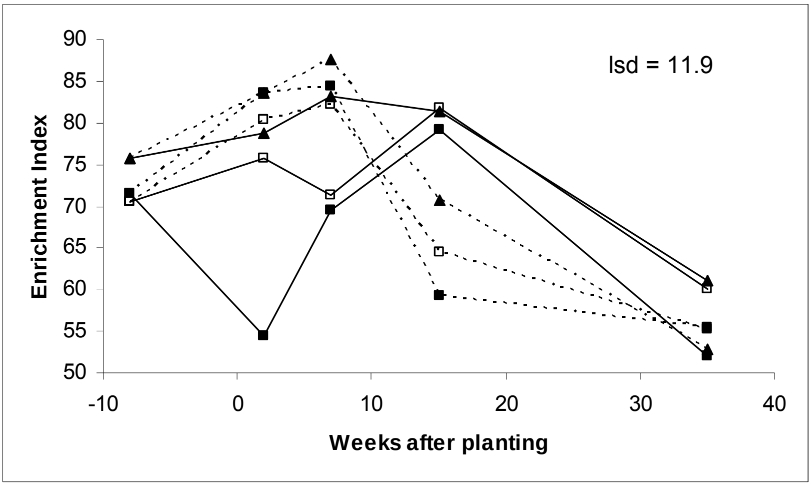

Fig. 6—Effect of previous crop history [sugarcane (□), maize (■) and soybean (▲)] and tillage practice 8 weeks prior to planting [conventional till (---), direct drill (—)] on the Enrichment Index in the upper 10 cm of soil in a plant crop of sugarcane.

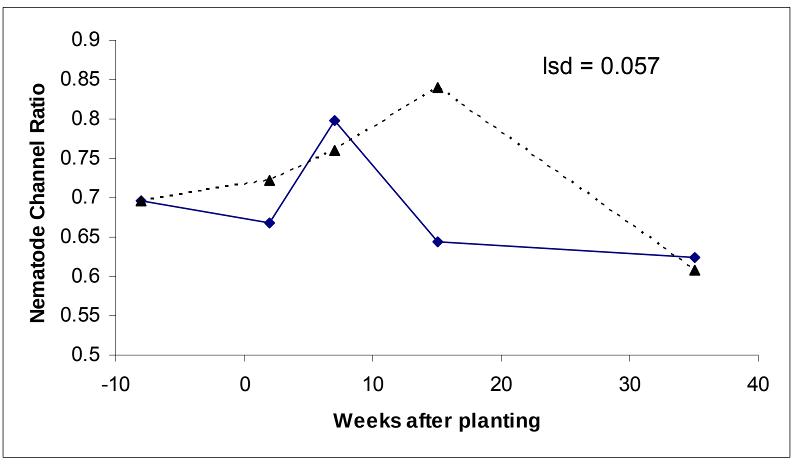

Fig. 7—Effect of tillage practice 8 weeks prior to planting [conventional till (---), direct drill (—)] on the Nematode Channel Ratio in the upper 10 cm of soil in a plant crop of sugarcane.

There were also significant crop and tillage effects (but no interactions) on the structure of the nematode community (i.e. the prevalence of omnivorous and predatory nematodes), with the SI lower following soybean than either sugarcane or soybean, and higher in direct drill than conventional till (Table 2).

Table 2—Effect of previous crop and tillage practice on the structure of the nematode community in the upper 10 cm of soil during a plant crop of sugarcane.

	Structure Index			Structure Index
Sugarcane	76.9		Conventional till	72.7
Maize	77.1		Direct drill	77.8
Soybean	71.6			
			LSD (P = 0.05)	1.98
LSD (P = 0.05)	2.42			

Free-living nematodes in crop residues

Although less soybean residue was mulched on the soil surface than either maize or sugarcane, numbers of free-living nematodes/m^2 in July 2006 were significantly higher following soybean (Figure 8), largely because the nematode population density in soybean residue (1168 nematodes/g dry weight of residue) was much greater than in maize or sugarcane residue (391 and 115 nematodes/g, respectively). However, this situation changed as the season progressed, with more nematodes/m^2 at the end of the season following maize and sugarcane than following soybean (Figure 8).

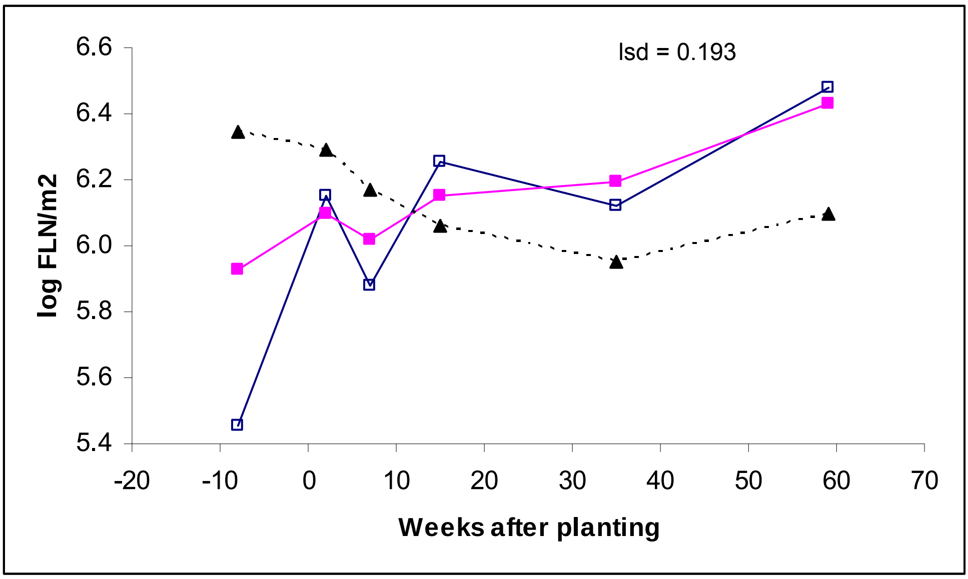

Fig. 8—Numbers of free-living nematodes recovered from surface residues from previous crops of sugarcane (□), maize (■) and soybean (▲) as they decomposed during a plant crop of sugarcane.

The main bacterial-feeding nematodes in surface residues were two groups of enrichment opportunists, the Rhabditidae and *Panangrolaimus*, with *Panangrolaimus* generally predominant. *Aphelenchoides* was the most common fungal feeder, but Tylenchidae were also relatively common, usually comprising 10–30% of the fungal-feeding nematode community. Since the proportion of bacterial and fungal feeders changed with time and there were relatively few omnivores and predators, the NCR proved to be a good indicator of the biological status of residues as they decomposed.

This index for soybean residue was higher than for sugarcane or maize at the first sampling date (24 July 2006), but over the whole sampling period there was no effect of residue source and no residue source × time interaction. However, there was a significant temporal effect, with the NCR declining regardless of the residue source (Figure 9). By the time the sugarcane plant crop was due to be harvested, the NCR was about 0.2, indicating that about 80% of the nematodes in surface residues were fungal-feeders.

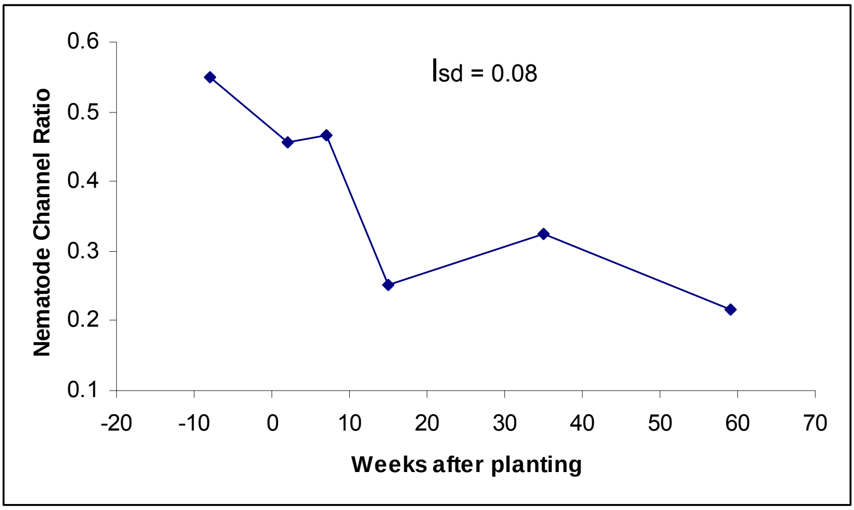

Fig. 9—Temporal changes in the Nematode Channel Ratio in surface residues from previous crops as they decomposed during a plant crop of sugarcane.

Mineral N in crop residues and soil

At the time monitoring commenced, the amount of sugarcane, maize and soybean biomass mulched on the soil surface was equivalent to 14.7, 12.0 and 8.4 t dry weight/ha, respectively. These residues then decomposed, and only 15–20% remained at the end of the sugarcane plant crop (Figure 10). Measurements taken in DD plots during the first 10 months of the decomposition period showed that in both crop residues and soil, there was much more mineral N following soybean than either maize or sugarcane (Figures 11 and 12). However, mineral N concentrations showed similar temporal trends in all treatments, reaching a maximum 15 weeks after planting and then declining. In crop residues, 50–80% of the mineral N was NH_4-N, whereas in soil, about 50% was NH_4-N at the first and last sampling times and only

10–20% at other times. Correlation analyses indicated a relationship between numbers of free-living nematodes in crop residues and mineral N (r = 0.45 and 0.70 for N concentrations measured at the same and the next sampling time, respectively). A similar trend was observed in soil (r = 0.57 for mineral N concentrations measured at the same time and r = 0. 72 for measurements at the following sampling time).

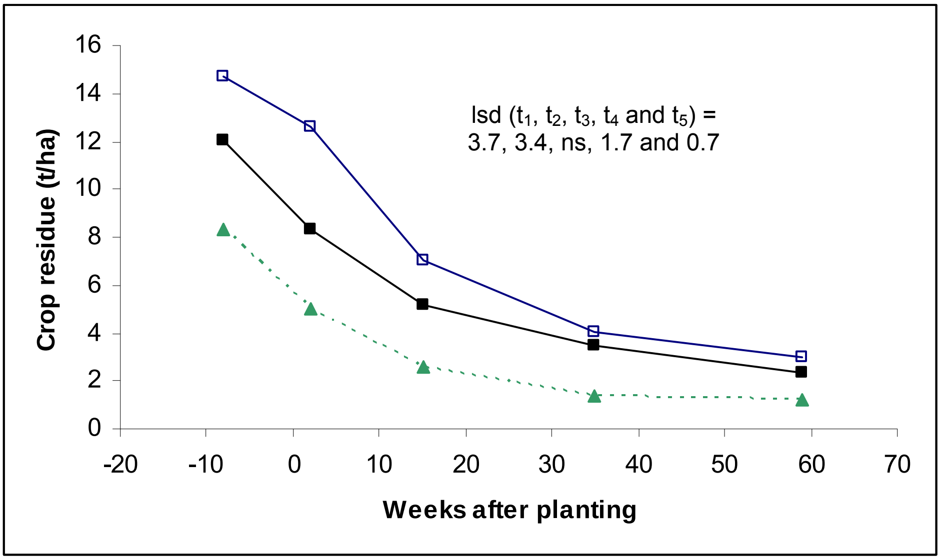

Fig. 10—Decomposition of surface residues from previous crops of sugarcane (□), maize (■) and soybean (▲) during a plant crop of sugarcane.

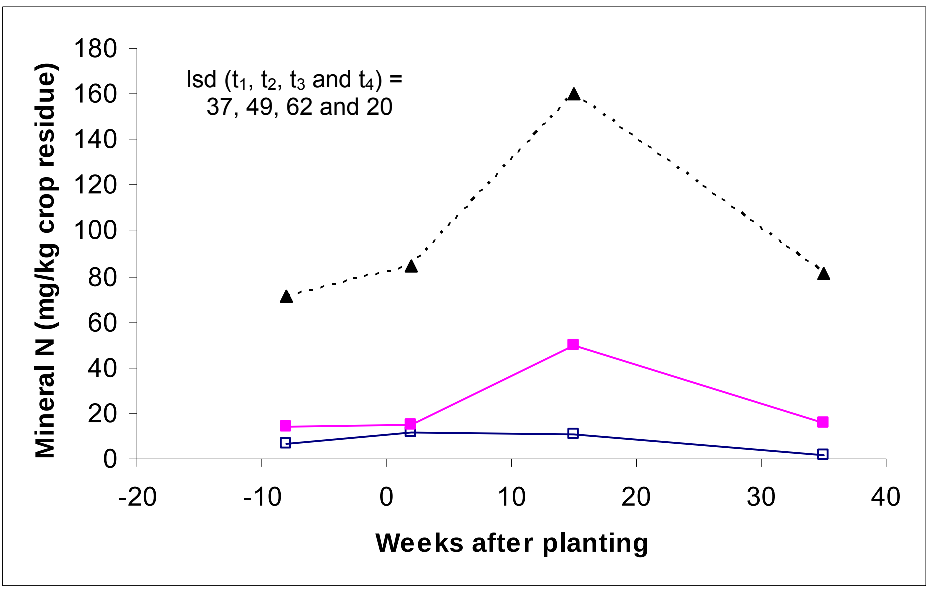

Fig. 11—Mineral N in surface residues from previous crops of sugarcane (□), maize (■) and soybean (▲) during a plant crop of sugarcane.

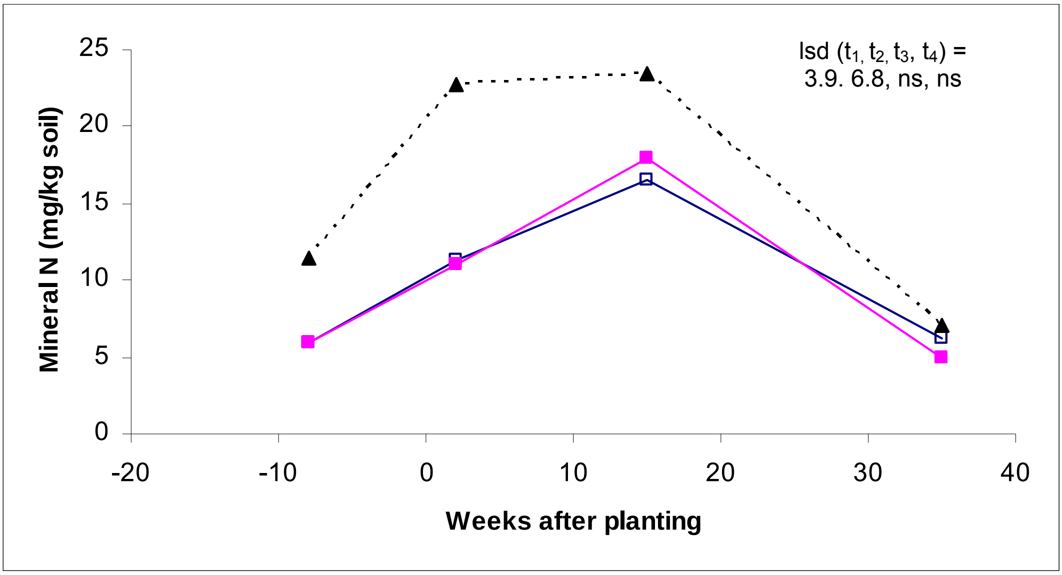

Fig. 12—Mineral N in the surface soil (0–10 cm) during a plant crop of sugarcane following previous crops of sugarcane (□), maize (■) and soybean (▲).

Comparisons of mineral N in the 0–10 cm zone of tilled and direct drill plots showed that concentrations were significantly higher in DD than CT at the time sugarcane was planted (8.4 v 6.0 mg N/kg soil) and also at 3 months (5.8 v 4.8 mg N/kg soil). However, the reverse applied at 6 months (7.3 v 10.5 mg N/kg soil) and also at final harvest of the plant crop (5.1 v 9.7 mg N/kg soil). Interactions between tillage and cropping history were never significant.

Discussion

This study showed that a soybean rotation crop reduced populations of several of the plant-parasitic nematodes found in sugarcane soils, confirming results from numerous field trials over many years (Stirling *et al*., 2001; 2002; 2006; 2007). However, soybean had little effect on populations of *R. parvus*, perhaps because reniform nematodes can survive well in the absence of a host (Apt, 1976). Populations of spiral nematode (*H. dihystera*) increased on soybean but this species is not an important pathogen of sugarcane (Spaull and Cadet, 1990). The relatively high populations of *X. elongatum* following soybean were of some concern because this species damages root tips and causes stunting and excessive branching of the sugarcane root system (Spaull and Cadet, 1990). Since similar symptoms were observed in this trial, dagger nematode may become a relatively more important component of the pathogenic nematode community when soybean is used as a rotation crop in light-textured soils.

Populations of plant-parasitic nematodes were generally reduced for about 3 months after a tillage event, probably because nematodes were either damaged by the tillage equipment or killed by heat or desiccation after being brought to the soil surface during a tillage operation. Populations of some nematodes (particularly *M.*

javanica and *X. elongatum*) then resurged strongly in tilled plots and remained much higher than in non-tilled plots for most of the sugarcane growing season. The reasons for this difference in the rate of resurgence are not known, but there may have been more root biomass in the higher yielding conventionally-tilled plots (Bell *et al*., 2010). It is also possible that tillage was not only detrimental to plant parasites but also to the suppressive forces that regulate nematode populations. The main natural enemies of nematodes (fungi, predatory nematodes and microarthropods) are all vulnerable to tillage (Wardle, 1995) and because predators generally have relatively long life cycles, it takes time for them to re-establish following a tillage event. SI reflects the proportion of omnivorous and predatory nematodes in the nematode community and the fact that this index was reduced by tillage provides evidence that natural enemies were affected by tillage in this experiment.

Although a soybean rotation crop reduced populations of *P. zeae* and *M. javanica*, this reduction was only temporary. From about 15 weeks after planting sugarcane, populations following soybean were as high as or higher than after maize or sugarcane. This would have been expected if the soybean rotation crop had improved root biomass or root health, but in this trial, sugarcane yields did not increase following soybean (Bell *et al.,* 2010). It is therefore likely that soybean reduced the soil's biological suppressiveness to plant-parasitic nematodes.

Soybean residue decomposes rapidly due to its relatively low C/N ratio and so it is possible that there was insufficient biomass to sustain high populations of free-living nematode through a full year of the following sugarcane crop. This in turn would have had indirect effects on the natural enemies of plant-parasitic nematodes, as they utilise free-living nematodes as a food source. Alternatively, the N in soil after the soybean crop may have had a direct effect on natural enemies. Omnivorous and predatory nematodes are relatively sensitive to N (Tenuta and Ferris, 2004), while some predatory fungi are thought to switch from a predatory to saprophytic mode of nutrition when the N concentration increases (Barron, 1992). Regardless of the reason, SI and suppressiveness are related (Sanchez-Moreno and Ferris, 2007) and so the reduction in SI following soybean suggests that it reduces the soil's suppressiveness to plant-parasitic nematodes.

Our observations of the free-living nematode community clearly showed that soybean had a major impact on the soil biological community and that those impacts were apparent within two months of the rotation crop being harvested. By mid July 2006, there were more than 6 million nematodes/m^2 in plots that had grown soybean and about one-third of these nematodes were in residues on the soil surface. Although the nematodes in soil were predominantly bacterial feeders (as indicated by the high EI), there was a relatively balanced community of fungal and bacterial feeders in crop residues (as indicated by a NCR of about 0.5). Thus considerable decomposition of residues (and presumably N mineralisation) occurred within 2 months of soybean harvest, with bacterial feeders giving way to fungal feeders as labile compounds (utilised by bacteria) were depleted and more recalcitrant materials (favoured by fungi) became relatively more important microbial food sources. Residue samples taken 15 weeks after sugarcane was planted indicated that this trend had continued, as the nematode population in soil had declined by more than 50% and the nematode community in crop residues was now strongly fungal-dominant.

The dynamics of free-living nematode populations were similar following sugarcane and maize, but differed from soybean in that nematode populations peaked later (after the following sugarcane crop was planted) and then declined. Since there was more residue biomass on the soil surface following maize and sugarcane than soybean, biological activity was sustained for much longer following the former crops, resulting in higher nematode populations at the end of the first sugarcane growing season.

Tillage also had major effects on the free-living nematode community, with numbers consistently higher in tilled soil for at least 12 months, presumably because tillage facilitates decomposition by mixing surface residues into the soil. An increased decomposition rate in tilled soil is probably the reason that the proportion of enrichment opportunistic bacterial feeding nematodes relative to fungal-feeders declined more quickly in tilled than direct drill plots.

Nutrients in crop residues are transferred from organic matter to microorganisms during the decomposition process but are not mineralised until those microbes die or are consumed by predators (e.g. protozoa and nematodes). Excess nutrients are then excreted in mineral form by the predators and can be used by plants.

Free-living nematodes are therefore an integral part of nutrient cycling processes in soil and their population dynamics should provide an indication of changes in the rate of mineralisation of nutrients such as N.

This was confirmed by our data, as the high early peak in bacterial-feeding nematode populations in soybean plots (both in crop residues and soil) was associated with high concentrations of mineral N during the period around and soon after sugarcane was planted. The fact that populations of free-living nematodes were most closely correlated with mineral N concentrations 10–20 weeks later is further evidence that nematodes contribute to nutrient cycling processes and may provide an indication of N mineralisation rates.

Interpretation of relationships between populations of free-living nematodes and N mineralisation are complicated by the fact that the mineral N concentrations presented in this paper represent the total remaining after any losses from leaching and/or denitrification.

Data in an accompanying paper (Bell *et al*., 2010), for example, indicated that some leaching of N did occur at this site. Another difficulty with interpretation is that decomposing residues from different rotation crops not only differed in quality but also in biomass.

Nevertheless, our data suggest that N mineralisation slowed markedly from about 15 weeks after planting, which was about the same time as a decline in the NCR in surface residues indicated a switch from bacterial to fungal decomposition channels within the soil food web. Fungivorous nematodes do not mineralise N as readily as bacterivores (Ferris *et al*., 1998; Chen and Ferris, 1999; 2000; Okada and Ferris, 2001) and so mineralisation rates began to slow as fungal-feeding nematodes began to predominate within the nematode community.

With regard to the effect of tillage on N mineralisation, our data suggest that soil mineral N concentrations in DD plots remained relatively stable in the 0–10 cm zone throughout the season. In contrast, concentrations in CT plots were lower initially and increased later in the season. However, these data reflect the amount of N mineralised minus the N immobilised, denitrified and/or leached into deeper layers, and so these temporal effects may not be due to differences in mineralisation rates. A close relationship between mineral N concentrations and populations of free-living nematodes in the upper layers of soil is therefore unlikely. However, the fact that there were more free-living nematodes in tilled than non-tilled plots at all sampling times suggests that tillage may have increased N mineralisation rates for at least 12 months.

Acknowledgements

This work was funded by the Sugar Research and Development Corporation as project BS286- Improved Sugarcane Farming Systems.

REFERENCES

Apt WJ (1976) Survival of reniform nematodes in desiccated soils. *Journal of Nematology* **8**, 28.

Barron GL (1992) Lignolytic and cellulolytic fungi as predators and parasites. In ‘The fungal community, its organisation and role in the ecosystem’ (Eds GC Carroll, DT Wicklow). (Marcel-Decker, New York).

Bell MJ, Garside AL, Halpin N, Salter B, Park G (2010) Interactions between rotation breaks, tillage and N management on sugarcane grown at Bundaberg and Ingham. *Proceedings of the Australian Society of Sugarcane Technologists* **32**, (These Proceedings).

Blair BL, Stirling GR (2007) The role of plant-parasitic nematodes in reducing yield of sugarcane in fine-textured soils in Queensland, Australia. *Australian Journal of Experimental Agriculture* **47**, 620–634.

Blair BL, Stirling GR, Whittle PJL (1999a) Distribution of pest nematodes on sugarcane in south Queensland and relationship to soil texture, cultivar, crop age and region. *Australian Journal of Experimental Agriculture* **39**, 43–49.

Blair BL, Stirling GL, Pattemore JA, Whittle PJL (1999b) Occurrence of pest nematodes in Burdekin and central Queensland sugarcane fields. *Proceedings of the Australian Society of Sugarcane Technologists* **21**, 227–233.

Braunack M, Ainslie H (2001) Trash blankets and soil physical properties: Mackay experience. *Proceedings of the Australian Society of Sugarcane Technologists* **23**, 154–160.

Braunack MV, McGarry D. (2006) Traffic control and tillage strategies for harvesting and planting of sugarcane (*Saccharum officinarum)* in Australia. *Soil and Tillage Research* **89,** 86–102.

Chen J, Ferris H (1999) The effects of nematode grazing on nitrogen mineralisation during fungal decomposition of organic matter. *Soil Biology and Biochemistry* **31**, 1265–1279.

Chen J, Ferris H (2000) Growth and nitrogen mineralisation of selected fungi and fungal-feeding nematodes on sand amended with organic matter. *Plant and Soil* **218**, 91–101.

Ferris H, Bongers T, de Goede RGM (2001) A framework for soil food web diagnostics: extension of the nematode faunal analysis concept. *Applied Soil Ecology* **18**, 13–29.

Ferris H, Venette RC, van der Muelen HR, Lau SS (1998) Nitrogen mineralisation by bacterial-feeding nematodes: verification and measurement. *Plant and Soil* **203**, 159–171

Garside AL, Bell MJ (2001) Fallow legumes in the Australian sugar industry: A review of recent research findings and implications for the sugarcane cropping system. *Proceedings of the Australian Society of Sugarcane Technologists* **23**, 230–235.

Garside AL, Bell MJ (2007) The value of legume breaks to the sugarcane cropping system—cumulative yields for the next cycle, potential cash returns from the legume, and duration of the break effect. *Proceedings of the Australian Society of Sugarcane Technologists* **29**, 299–308.

Garside AL. Bell MJ, Cunningham G, Berthelsen J, Halpin N (1999) Fumigation and rotation effects on the growth and yield of sugarcane. *Proceedings of the Australian Society of Sugarcane Technologists* **21**, 69–78

Garside AL, Bell MJ, Robotham BG, Magarey RC, Stirling GR (2005) Managing yield decline in sugarcane cropping systems. *International Sugar Journal* **107**, Issue 1273, 16–26.

Garside AL, Berthelsen JE, Pankhurst CE, Blair BL, Magarey RC, D'Amato CD, Bull JI (2002) Effects of breaks from sugarcane monoculture and biocides on the growth and yield of a subsequent sugarcane crop. *Proceedings of the Australian Society of Sugarcane Technologists* **24**, 82–91.

Ingham RE, Trofymow JA, Ingham ER, Coleman DC (1985) Interactions of bacteria, fungi, and their nematode grazers: effects on nutrient cycling and plant growth. *Ecological Monographs* **55**, 119–140.

Okada H, Ferris H (2001) Effect of temperature on growth and nitrogen mineralisation and fungal-feeding nematodes. *Plant and Soil* **234**, 253–262

Sanchez-Moreno S, Ferris H (2007) Suppressive service of the soil food web: Effects of environmental management. *Agriculture, Ecosystems and Environment* **119**, 75–87.

Rayment GE, Higginson FR (1992) Australian laboratory handbook of soil and water methods. Inkata Press, Melbourne.

Spaull VW, Cadet P (1990) Nematode parasites of sugarcane. In 'Plant Parasitic Nematodes in Subtropical and Tropical Agriculture'. (Eds M Luc, RA Sikora, J Bridge) pp. 461–491. (CAB International: Wallingford, UK).

Stirling GR, Moody P, Stirling AM (2007) The potential of nematodes as an indicator of the biological status of sugarcane soils. *Proceedings of the Australian Society of Sugarcane Technologists* **29**, 339–351.

Stirling GR, Blair BL, Wilson E, Stirling AM (2002) Crop rotation for managing nematode pests and improving soil health in sugarcane cropping systems. *Proceedings of the Australian Society of Sugarcane Technologists* **24**, 129-134.

Stirling GR, Blair BL, Pattemore JA, Garside AL, Bell MJ (2001) Changes in nematode populations on sugarcane following fallow, fumigation and crop rotation, and implications for the role of nematodes in yield decline. *Australasian Plant Pathology* **30**, 232–235.

Stirling GR, Berthelsen JE, Garside AL, James AT (2006) The reaction of soybean and other legume crops to root-knot nematodes (*Meloidogyne* spp.), and implications for growing these crops in rotation with sugarcane. *Australasian Plant Pathology* **35**, 707–714.

Tenuta M, Ferris H (2004) Sensitivity of nematode life-history groups to ions and osmotic tensions of nitrogenous solutions. *Journal of Nematology* **36**.85–94

Wardle DA (1995) Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. *Advances in Ecological Research* **26**, 105–183.

Whitehead AG, Hemming JR (1965). A comparison of some quantitative methods of extracting small vermiform nematodes from soil. *Annals of Applied Biology* **55**, 25–38.

Wilson MJ, Kakouli-Duarte T (Eds) (2009) ‘Nematodes as environmental indicators’. (CAB International: Wallingford, UK).

Yeates GW (2003) Nematodes as soil indicators: functional and biodiversity aspects. *Biology and Fertility of Soils* **37**, 199–210