

Some observations on the influence of agricultural practices on the nematode faunae of some South Australian soils

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Summary – Three different soils from three localities were examined in September–November for numbers and diversity of nematodes. Numbers varied from 157 to 4027/50 g dw. Numbers of nematodes in modified shrub land were consistently less than those in pasture or wheat growing regimes. In the agricultural regimes plant parasitic forms, notably *Pratylenchus*, predominated; plant associated nematodes such as *Cephalenchus* occurred to a lesser extent. The most widespread nematode was the bacterial feeding *Acrobeloides nanus* which occurred at all sites. Fungal feeding nematodes also occurred at all sites but were particularly prominent at one site where a clavate-tailed aphelenchoid was the most common nematode. Predacious nematodes were least abundant in the agricultural plots but were more abundant in modified shrub land. Proportions of nematodes in six feeding groups were determined and fungal feeder/bacterial feeder ratios and trophic diversity calculated. Various indices were used to compare the occurrence of nematodes in different sites.

Résumé – Observations concernant l'influence des pratiques agricoles sur la faune nématologique dans quelques sols du sud de l'Australie – La densité et la diversité des nématodes présents dans trois types de sols provenant de trois localités ont été observées pendant les mois de septembre à novembre. Les nombres varient de 157 à 4027 pour 50 g de sol (poids sec). Les nombres de nématodes dans les sols sous paysage de buissons modifié sont nettement plus faibles que dans les pâturages ou les terrains cultivés en blé. Dans les terres cultivées, ce sont les formes phytoparasites qui dominent, en particulier le genre *Pratylenchus*; des nématodes associés aux plantes, tel *Cephalenchus*, sont, dans une moindre mesure, également présents. Le nématode le plus répandu est l'espèce bactériophage *Acrobeloides nanus*, présente dans tous les sites examinés. Les nématodes fongivores sont également présents dans tous les prélèvements, et particulièrement abondants dans un site où un Aphelenchoïde à queue en massue constituait l'espèce la plus commune. Les nématodes prédateurs sont moins abondants dans les zones cultivées et plus abondants dans les sols sous paysage de buissons modifié. Les proportions des nématodes appartenant aux six groupes trophiques ont été déterminées et le rapport fongivores/bactériophages, ainsi que la diversité trophique, calculés. Différents indices ont été utilisés pour comparer les valeurs liées aux nématodes dans les différents sites.

Key-words : Nematodes, diversity, land use, soils, Australia.

Agricultural practices affect native soil biota through the introduction of new species of crop plants and organisms that are symbiotic (e.g. mutualistic or parasitic) with these plants, through cultivation and through application of agrochemicals. These collectively lead to changes in soil climate, structure and chemistry. Because nematodes are influenced by these man-made changes, assessment of the nematode faunae in soils under differing intensities of management may provide an index of the degree of disturbance and an indication of the longterm impact of various types of land use on soil properties and processes.

The nematode genera *Anguina*, *Ditylenchus*, *Heterodera*, *Meloidogyne* and *Pratylenchus* can significantly influence agricultural management in South Australia (Kimpinsky *et al.*, 1976; McKay *et al.*, 1976; Bird, 1978; Stanton *et al.*, 1979; Georg *et al.*, 1989); however, the native faunae are poorly known (Reay & Wallace, 1981; Nobbs, 1992).

Most soils in the semi-arid wheat belt of South Australia are derived from tertiary sediments which are strongly weathered and have low levels of organic carbon, plant-available phosphorus and nitrogen. The Mediterranean-type climate of South Australia has dominant winter rainfall and a high drought frequency. Cereal crops are typically grown for 1-2 years followed by a year of the grasses *Lolium*, *Hordeum*, *Bromus* and *Vulpia* and the legumes *Medicago* and *Trifolium* all of which are grazed by livestock. The dominant crop, wheat (*Triticum aestivum*), is sown in May-June and harvested in November-January.

Our work provides, from limited sampling, initial information on the abundance and diversity of the nematode fauna in the soil under native shrub land containing some introduced weeds and compares it with the nematode faunae of variously managed agricultural plots in the same localities.

ANALYSIS

Because of the variability of soil moisture and bulk density between soils and samples, the total counts/50 g moist soil have been converted to number/50 g dry soil and number/m² (in 0-10 or 0-15 cm soil depth). Analysis of variance was carried out on data for four indicative populations.

Nematode taxa were assigned to feeding groups and the proportion of the nematodes in each of the feeding groups determined. From this the fungal feeder/bacterial feeder ratio (F/B) and trophic diversity ($T = 1/\sum p_i^2$ where p_i is the proportion of individuals in the i th trophic group) were calculated (Freckman & Ettema, 1993).

Using the data for each taxon we calculated :

$$\begin{aligned} \text{richness} \quad SR &= (s-1)/\log_e N \\ \text{diversity} \quad H' &= \sum_{i=1}^s p_i \log_e p_i \\ \text{evenness} \quad J' &= H'/H' \text{ max} \\ \text{dominance} \quad \lambda &= \sum p_i^2 \\ \text{diversity} \quad H_2 &= -\log_e \lambda \end{aligned}$$

where

p_i is the proportion of individuals in the i th taxon

s is the number of taxa

N is the number of individuals identified

$H' \text{ max}$ is $\log_e s$

The Shannon-Weaver index (H') is commonly used to assess *diversity* but as it may be dominated by the abundant taxa or the overall number of taxa, both *evenness* and *richness* have been calculated (Pielou, 1975; Yeates, 1984). The Simpson Index (λ) has been used to assess *dominance* and its \log_e transformation offers an alternative measure of diversity (H_2) (Pielou, 1975).

The nematode Maturity Index (MI) proposed by Bongers (1990) for non-plant parasitic nematodes (i.e. for feeding groups 1-3, 5-6) is :

$$MI = \sum_{i=1}^n v_i \cdot p_i$$

where

v_i is the $c-p$ value of the i th taxon

p_i is the proportion of the i th taxon

$c-p$ values of 1-5 are given by Bongers (1990) to reflect the perceived r-k strategy gradient among nematodes.

The more restricted PPI (Plant Parasitic Index) (Bongers, 1990), which includes only plant pathogenic nematodes (feeding group 4) and $\sum MI = \sum_{i=1}^n v_i \cdot p_i$ (Yeates, in press) which includes all feeding groups, have also been calculated.

As the values of the derived indices and ratios may not be normally distributed it is not generally valid to apply routine statistical procedures to them.

Results

TOTAL NUMBERS OF NEMATODES

We estimated the total numbers of nematodes in the soils to range from 157 to 4027 per 50 g dry wt of soil or from 555 000 to 10 635 000 nematodes per m² of soil (Table 3). The Kapunda site was sampled three times at monthly intervals and no overall pattern was apparent although the numbers were greater in October than in September and November. Further, numbers under modified shrub land were always lower than numbers under pasture. Analysis of variance showed highly significant treatment, time and interaction effects (Table 4).

The data for Avon on a single sampling show a range almost as great as those for the three Kapunda samplings but it does appear that the number of nematodes under continuous farming is similar to that at the old trial site which was less than those under modified shrub land and conventional cultivation. The nematode numbers were greatest under pasture and direct drilled regimes (Table 3). At both Kapunda and Avon modified shrub land had relatively small populations of nematodes.

Overall differences between total numbers in the agricultural regimes at each location may reflect both seasonal and soil texture factors. The large population (4027/50 g dry soil) recovered from the Northfield trial (Table 3) where the soil had a higher clay content than the other soils (Table 1) may be related to soil texture through the impact of texture on microbial populations as described below.

Table 2. Assessment of efficiency of mister extractor based on extraction of 40 g (field moist) soil samples for 5 days.

Replicate	Water flow rate in tubes (ml/3 h)	Nematodes recovered from mister	Nematodes lost by overflow	Nematodes recovered by sieving after misting	Total nematodes /40 g soil	% recovered by mister
1	24	1331	10	108	1449	92
2	10	1185	10	241	1436	82.5
3	11	1197	10	127	1334	90
4	5	1148	10	101	1259	91

Table 3. Total nematode population estimates for each soil management regime and sampling date. Populations are expressed /50 g dry soil (\pm standard error), /50 g field moist soil and /m²; sampling depths are indicated.

Soil and treatment			/50 g dry soil	/50 g moist soil	/m ²
KAPUNDA (0-15 cm depth)					
September	Conventional cultivation	(CC)	406 \pm 86	312	1,437,000
	Direct drilled	(DD)	513 \pm 167	398	1,816,000
	Pasture	(Past)	228 \pm 57	165	807,100
	Modified shrubland	(Shrub)	157 \pm 48	129	555,000
October	Conventional cultivation	(CC)	2678 \pm 312	2464	9,457,000
	Direct drilled	(DD)	2998 \pm 612	2771	10,635,000
	Pasture	(Past)	1051 \pm 252	909	3,489,000
	Modified shrubland	(Shrub)	800 \pm 229	731	2,806,000
November	Conventional cultivation	(CC)	556 \pm 47	451	1,856,000
	Direct drilled	(DD)	188 \pm 48	150	629,000
	Pasture	(Past)	756 \pm 257	588	2,692,000
	Modified shrubland	(Shrub)	321 \pm 160	284	1,000,000
AVON (0-10 cm depth)					
October	Conventional cultivation	(CC)	1553 \pm 408	1360	3,115,000
	Direct drilled	(DD)	3125 \pm 474	2730	6,268,000
	Pasture	(Past)	2812 \pm 698	2489	5,641,000
	Modified shrubland	(Shrub)	1586 \pm 744	1496	3,181,000
	Continuous farming	(CF)	371 \pm 212	348	744,000
	Old trial site	(Trial)	614 \pm 166	565	1,232,000
NORTHFIELD (0-15 cm depth)					
November	Old trial site	(Trial)	4027 \pm 467	3001	8,794,000

Table 4. Results of analysis of variance of the abundance /50 g dry soil of four nematode populations each assessed on three dates at Kapunda under four management regimes with five replicates. F ratios with $p \leq 0001$ are denoted by ***.

Source of variation	Degrees of freedom	F. ratio			
		Total	<i>Pratylenchus</i>	<i>Acrobeloides</i>	Mononchidae
time	2	49.39***	16.30***	22.24***	1.00
treatment	3	8.00***	14.36***	10.47***	0.45
time \times treatment	6	7.08***	4.39***	7.96***	1.76
error	48				

NEMATODE TAXA AND FEEDING GROUPS

Some 50 taxa (Kapunda 39, Avon 47, Northfield 23) were noted during the identification process but many were represented by only a few immature specimens. The only nematodes we have identified to species are *Acrobeloides nanus* (all sites), *Pratylenchus thornei* (Kapunda) and *P. neglectus* (Avon). Taxa which made significant contributions to the faunae are listed separately but others have been given as aggregates (Tables 5 and

6). At Kapunda the four taxa which made the greatest contributions to the fauna were *Pratylenchus* (21-57% in agricultural areas), *Acrobeloides nanus* (4-28% in all samples), *Cephalenchus* (5-24% under conventional cultivation and pasture) and Tylenchidae (30-39% in modified shrub land). At Avon *Pratylenchus* (25 and 36% in CC and DD respectively), *Cervidellus* (23-31% in CC, DD and shrub land), Tylenchorhynchidae (4-10% under wheat and pasture) and *Acrobeloides nanus* (10-16% in continuous farming and old trial) were significant contributors. The single sampling at Northfield yielded high proportions of *Helicotylenchus* (10%), a clavate aphelenchoid (19%), Tylenchidae (19%) and Tylencholaimidae (22%). Analysis of variance showed highly significant treatment, time and interaction effects in *Pratylenchus* and *Acrobeloides nanus*, but no effects were significant in the uncommon Mononchidae (Table 4).

Plant pathogenic nematodes were dominant (mean 56%) at the agricultural Kapunda sites in September with bacterial feeding and plant associated taxa contributing 76% of the fauna in modified shrub land (Table 7). In October the proportion of plant pathogenic forms in the agricultural plots was lower (mean 35%) but in these plots plant associated taxa had increased

Table 6. Percentage composition of the nematode fauna under six management regimes (CC, conventional cultivation; DD, direct drilled; Past, pasture; Shrub, modified shrubland; CF, conventional farming; Trial, former trial site) at Avon and one at Northfield, South Australia. See Table 4 for further explanation.

Taxon	c-p value	Feeding group	Avon					Northfield	
			CC	DD	Past	Shrub	CF	Trial	
Tylenchidae	2	5	3.6	6.4	7.7	1.4	10.5	2.7	19.1
<i>Cephalenchus</i>	2	5	0.5	—	—	—	6.7	—	—
<i>Ditylenchus</i>	2	2	3.0	1.4	1.8	3.7	3.8	1.1	1.6
Tylenchorhynchidae	3	4	5.8	4.1	10.7	1.4	6.9	0.1	—
<i>Pratylenchus</i>	3	4	24.7	36.0	8.3	0.3	2.5	4.9	—
<i>Helicotylenchus</i>	3	4	—	—	—	—	—	—	9.9
<i>Paratylenchus</i>	2	4	18.7	5.6	27.8	1.1	1.2	16.5	2.2
Aphelenchoid clavate	2	2	—	—	—	0.4	—	—	18.9
Aphelenchina	2	2	4.2	3.4	4.5	7.9	7.4	4.9	6.6
Rhabditidae	1	1	—	0.5	0.3	4.4	0.2	1.1	—
<i>Panagrolaimus</i>	1	1	0.9	—	7.1	0.2	7.7	4.8	—
<i>Acrobeloides nanus</i>	2	1	4.6	1.7	7.9	3.6	16.7	10.2	6.0
<i>Cervidellus</i>	2	1	30.2	31.2	11.3	23.8	4.6	18.7	0.7
Cephalobidae	2	1	0.2	3.1	0.8	12.0	5.0	1.2	3.8
Plectidae	2	1	1.7	0.3	0.2	6.4	5.3	9.1	0.2
<i>Wilsonema</i>	2	1	—	0.9	—	11.9	2.3	6.4	—
<i>Prismatolaimus</i>	3	1	—	—	—	—	1.5	—	—
<i>Monhystera</i>	2	1	—	—	—	1.3	—	—	1.0
<i>Tripyla & Tobrilus</i>	3	3	—	—	—	—	1.1	0.3	—
Dorylaimidae	4	6	1.8	5.5	8.1	3.2	14.1	6.0	6.6
<i>Tylencholaimus</i>	4	2	—	—	0.5	—	—	5.0	10.6
Tylencholaimidae	4	2	—	—	1.7	—	—	3.4	11.7
Actinolaimidae	5	6	—	—	—	14.7	—	—	—
Aporcelaimidae	5	6	—	—	1.4	1.8	0.9	1.1	0.6
Nygolaimidae	5	3	—	—	—	0.3	—	2.2	0.3
Mononchidae	4	3	—	—	—	—	0.5	—	—
<i>Alaimus</i>	4	1	—	—	—	—	1.1	—	—

Table 7. Indices of the nematode faunae under four management regimes on three sampling occasions at Kapunda; the equation for each index and details of the regimes are given under methods.

	September				October				November			
	CC	DD	Past	Shrub	CC	DD	Past	Shrub	CC	DD	Past	Shrub
Taxa identified (s)	22	15	18	26	10	14	17	21	17	17	19	25
Specimens identified (N)	319	264	220	208	415	435	394	320	456	251	419	330
% bacterial feeding	26.6	27.2	7.8	34.4	20.3	35.8	5.8	23.4	17.4	29.3	15.5	25.9
fungal feeding	7.1	24.0	9.9	15.5	9.5	11.8	17.5	31.8	3.9	9.7	14.8	17.0
predacious	0.8	0.7	2.1	3.1	—	—	2.2	7.4	0.8	5.9	—	9.4
plant pathogenic	57.4	45.6	65.0	1.2	39.0	30.0	34.6	4.2	55.6	47.5	36.2	2.8
plant associated	6.0	1.7	11.6	41.7	31.0	22.3	32.8	31.3	20.0	4.7	32.8	40.8
omnivorous	2.0	0.8	3.4	4.3	0.2	0.2	7.1	1.7	2.3	2.9	0.7	4.1
F/B	0.27	0.88	1.27	0.45	0.47	0.33	3.02	1.36	0.22	0.33	0.95	0.66
T	2.44	2.94	2.21	3.13	3.35	3.55	3.75	3.83	3.15	3.05	3.51	3.65
SR	3.64	2.51	3.15	4.68	1.49	2.14	2.68	3.47	2.61	2.90	2.98	4.14
H'	1.59	1.65	1.67	2.44	1.25	2.01	2.11	2.13	1.70	1.92	2.14	2.29
J'	0.51	0.61	0.58	0.75	0.54	0.76	0.75	0.70	0.60	0.68	0.73	0.71
λ	0.33	0.28	0.36	0.16	0.23	0.17	0.17	0.18	0.31	0.26	0.18	0.15
H ₂	1.11	1.29	1.03	1.81	1.46	1.78	1.76	1.71	1.16	1.34	1.74	1.92
Σ MI	2.53	2.45	2.77	2.16	2.37	2.23	2.99	2.10	2.57	2.65	2.43	2.31
MI	1.90	1.99	2.35	2.15	1.67	1.91	2.58	2.10	2.04	2.39	2.11	2.30
PPI	3.00	3.00	3.00	2.67	3.00	2.98	3.00	2.12	3.00	3.00	3.00	2.57

	06		
Plant density (P)	18		
Organic residues (O)	27	29	
% Inorganic feeding	27.3		
Insect feeding	7.2		
predators			
plant pathogens	22.3	42.7	
plant associated	9.1	6.8	
antagonists	1.2	2.1	
	0.15	0.13	
	2.52	1.77	
	1.34	1.23	
	1.94	1.35	
	0.71	0.65	0.78
	1.2	0.84	0.15
	1.03	1.42	2.03
	2.34	2.56	2.36
	2.03	2.35	2.33
	2.33	2.33	

	06	07	Plant Total
	24	23	22
	206	313	20
	44.4	51.3	11.1
	11.3	14.7	49.4
	7.2	2.8	6.3
	22.3	31.3	13.7
	17.3	1.7	13.1
	11.3	7.1	7.2
	0.15	0.13	4.14
	2.52	1.76	0.13
	1.34	1.23	3.43
	1.94	1.35	2.79
	0.71	0.65	0.51
	1.2	0.84	2.10
	1.03	1.42	2.36
	2.34	2.56	2.71
	2.03	2.35	2.33
	2.33	2.33	2.33

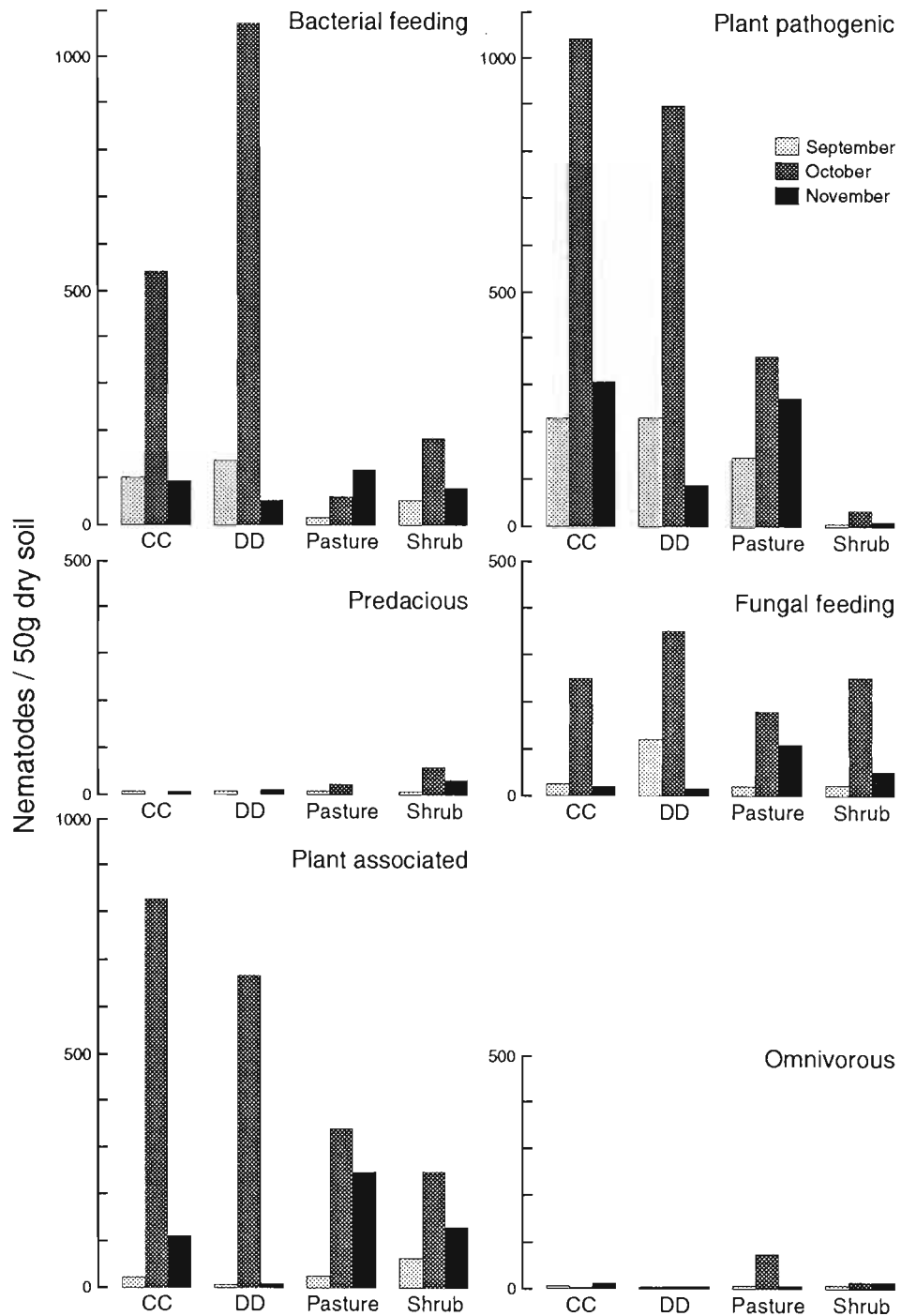


Fig. 1. Populations of nematode feeding groups at three sampling times under four management regimes at Kapunda, South Australia. (CC, conventional cultivation; DD, direct drilled; Past, pasture; Shrub, modified shrub land. Each value is the mean of 5 replicate samples).

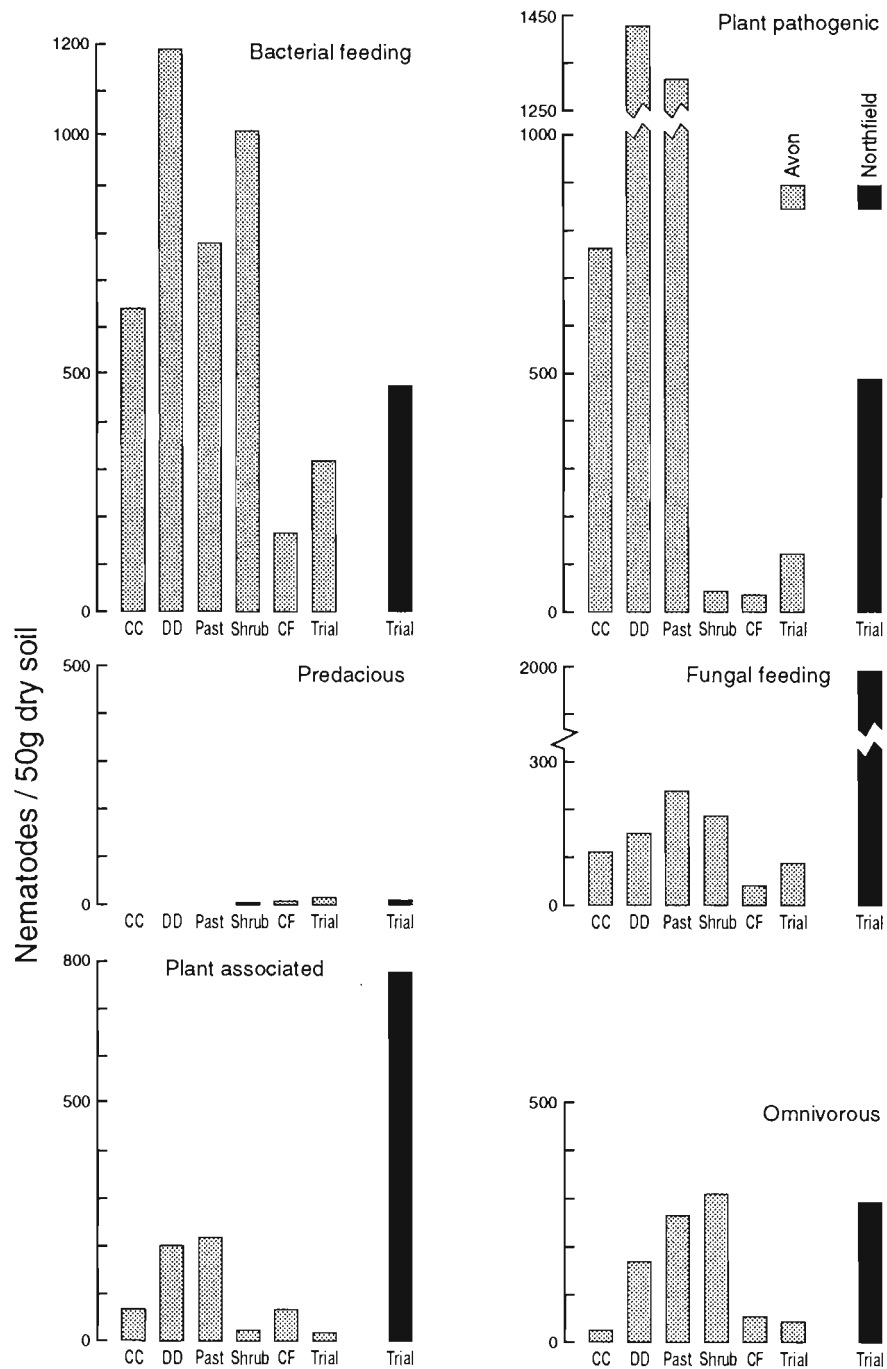


Fig. 2. Populations of nematode feeding groups under six management regimes at Avon and under one regime at Northfield, South Australia. [CC, conventional cultivation; DD, direct drilled; Past, pasture; Shrub, modified shrub land; CF, conventional farming; Trial, experimental trial site. Each value is the mean of 4 (Avon) or 5 (Northfield) replicate samples].

Table 9. Mean numbers (\pm standard errors) of nematodes by taxa extracted from washed roots recovered from 5 cm diameter 15 cm deep cores taken over wheat plants on three sampling occasions at Kapunda, South Australia; mean oven dry root weight is given; $n = 5$ in each case.

	September	October	November	Mean
<i>Pratylenchus</i>	1342 \pm 324	957 \pm 377	1017 \pm 223	1105
<i>Acrobeloides nanus</i>	108 \pm 24	284 \pm 107	100 \pm 23	164
Aphelenchina	78 \pm 28	120 \pm 33	122 \pm 42	107
Tylenchidae	71 \pm 14	76 \pm 26	38 \pm 3	62
Rhabditidae	115 \pm 54	19 \pm 11	29 \pm 9	54
<i>Cephalenchus</i>	186 \pm 129	1 \pm 1	21 \pm 18	69
<i>Panagrolaimus</i>	10 \pm 6	45 \pm 12	43 \pm 19	33
others	47 \pm 18	63 \pm 15	34 \pm 17	48
Total	1957 \pm 318	1565 \pm 503	1404 \pm 245	1642
root weight (g)	0.545 \pm 0.940	0.628 \pm 0.147	0.690 \pm 0.090	0.621

Discussion

The total estimates of nematode populations (Table 3) reflect overall management impacts on the endemic fauna. Data of Reay and Wallace (1981) and Nobbs (1992) for native vegetation and pastoral shrub land in South Australia indicate populations of 50–300 and 200–300/50 ml soil from September to November and, given management effects, our results are compatible with these. As shown by Nobbs (1992) there are great changes in abundance of nematodes over a full year and although at our wheat sites we might have expected to recover *Heterodera avenae*, which has been recorded from agricultural sites (including Avon) in South Australia (Rovira *et al.*, 1981), it has been shown that the soil inhabiting larval form of these nematodes is not found in the soil at the times that we sampled (Georg *et al.*, 1989).

The taxa we identified show differences between management regimes and soils (Tables 5, 6). Yeates (1984) showed that under pasture the soil was more important than season or year in determining the composition of the nematode fauna and results from the present work indicate that, as sand content increases, so do the number of taxa. In the Kapunda samples *Paratylenchus*, *Wilsonema*, *Nyngolaimidae* and *Alaimus* were

generally restricted to shrub land. The Avon soil yielded sizeable populations of *Paratylenchus* in all management regimes and *Cervidellus* was also abundant; in this soil *Wilsonema*, *Nyngolaimidae* and *Alaimus* each had a distribution different from that at Kapunda. The most significant difference between the nematode fauna in the heavy clay at Northfield and the other soils was the presence of *Helicotylenchus* and the clavate aphelenchoid in the former. Studies of nematodes in ecological successions (e.g. Wasilewska, 1979) and under various management regimes (e.g. Bergeson & Ferris, 1986; Yeates & Hughes, 1990; Freckman & Ettema, 1993) can show that such regimes have significant effects on the abundance of particular taxa. It is important to note that such effects are soil specific and, as our results indicate, different effects may be found in different soils. The presence or absence of a particular species is determined by many factors and thus cannot be used as a general indicator for the effects of any particular soil type.

Freckman and Ettema (1993) introduced the concept of trophic diversity to nematode ecology and found that few treatments had a significant effect on trophic diversity across management regimes in fine loamy soils in Michigan (U.S.A.). At Kapunda, trophic diversity was consistently highest in shrub land but in the more sandy soil at Avon areas under continuous farming had the highest trophic diversity (Tables 7, 8). The ratio of fungal feeding nematodes to bacterial feeding nematodes has been used as an index of relative availability of food resources and decomposition pathways (Wasilewska, 1979; Hendrix *et al.*, 1986). While differences in the ratio may be statistically significant (e.g. Freckman & Ettema, 1993; Yeates *et al.* 1993), the ratio is also very dependent on the proportion of "rhizosphere soil" in the samples (e.g. Hofman & s'Jacob, 1989). In the present work, although pastures consistently showed the highest ratio of the four agricultural regimes, there was considerable variation. The values for F/B under pasture were 0.31 at Avon and 1.27, 3.02 and 0.95 at Kapunda; in the heavy clay at Northfield, the ratio was 4.19 (Tables 7, 8). It appears that individual F/B ratios are too greatly influenced by soil type and season in these South Australian soils to be useful indicators of soil processes. That is not to say, however, that such ratios may not be useful discriminators under defined soil and climatic conditions.

Predacious nematodes, since they represent the top trophic level in the soil microfauna, have been suggested to be useful indicators of soil biological conditions (e.g. Arpin *et al.*, 1984; Wardle & Yeates, 1993) but their low abundance in agricultural or mineral soils may limit their usefulness, as has been found by Freckman and Ettema (1993). We have also found that these nematodes occur in very low numbers. At Kapunda they occurred in greatest numbers in shrub land (Table 7) whereas in the sandy loam at Avon they were recovered at low

frequency in three of the treatments (including conventional farming); they were also present at Northfield (Table 8). It is also worth noting that at Avon, tardigrades (known to be predators of soil microbiota, Hallas & Yeates, 1972) were present at an average of 15/50 g dry soil (*ca* 30 000/m²) and they probably utilize a similar resource to the predacious nematodes. As is the case with the F/B ratio, underlying soil factors may mean that predacious nematodes do not provide a generally applicable index of biodiversity.

Species richness is a basic measure of biological diversity. By applying the same calculation to similarly identified nematodes under grazed pastures Yeates (1984) found values of 2.60-4.69. Converting the results of Freckman and Ettema (1993) to SR (rather than the number of taxa identified) gives values of 5.47-6.61 for identification to species level. As was the case in the Freckman and Ettema (1993) data, our highest values were under the least disturbed regime (shrub land). The highest value was in sandy loam at Avon and values in this soil were consistently higher than in the silty loam. This agrees with the results of Yeates (1984) who showed SR to be greatest in the most coarse textured of the sites he sampled. Soil texture apparently plays a significant role in influencing nematode diversity.

The various indices of diversity, evenness and dominance all depend on assumptions about the relative contribution of each taxon to the particular fauna and until different assumptions are proposed and accepted (Wolda, 1981) most workers will continue to use those that we have chosen. Diversity (H') and species richness are correlated and, in our study, greatest under shrub land (except for the anomalous conventional farming). Evenness (J') and H' were lowest under conventional cultivation at Kapunda (i.e. the regime with the greatest degree of disturbance) but at Avon values for direct drilled were slightly lower (Tables 7, 8). Dominance, as measured by Simpson's λ , was highest under the regimes with greater disturbance and lowest under shrub land. H_2 diversity, computed from λ , showed the opposite, consistent effect.

Bongers (1990) proposed the maturity index as a "measure of environmental disturbance" but for our data from Kapunda, the pasture samples rather than those from modified shrub lands have the greatest MI values (2.35-2.58). While at Avon the shrub land MI (2.53) is greater than that for pasture, an even higher value (2.65) has been found for the trial site (= once fertilized pasture). Our MI are compatible with those of Bongers (1990) and are slightly greater than those of Freckman and Ettema (1993). Values for New Zealand pastures calculated from the data of Yeates (1984) are 2.11-3.54 (Yeates, in press) which are generally greater than Bongers' values. However, in a range of disturbed situations, MI was lowered (Yeates, in press) in keeping with the proposal of Bongers (1990). At Kapunda if all plant and soil nematodes are included in

the Σ MI as proposed by Yeates (in press) pasture has the highest Σ MI and MI values in September and October while direct drilled ranks third, but in November the ranking of these regimes is reversed (Table 7). At Avon when the four regimes used at Kapunda are considered shrubland has the highest Σ MI and MI values and conventional cultivation the lowest (Table 8); however, continuous farming and the old trial site do not show consistent relations to the other regimes. Certainly among the regimes common to Kapunda and Avon sites neither Σ MI nor MI values can, with a single sampling, consistently indicate the degree of disturbance.

The plant parasitic index (PPI) for agricultural sites at Kapunda is dominated by taxa with $c-p=3$ and the PPI has a value of approximately 3 (Table 7). Where other taxa are involved in shrub land, the PPI is lower. At Avon and Northfield there is a more heterogeneous range of plant parasites and the PPI is more variable but shows no general trend. While Freckman and Ettema (1993) found statistically significant changes in the PPI with different degrees of human intervention, as in the present work, there was no obvious trend.

Indices of biological populations can potentially condense complex population information and thus indicate relative levels of biodiversity, agronomic productivity, pollution/disturbance and ecosystem sustainability. Not only are these aspects themselves interrelated but also soil effects may be greater than management effects (Yeates, 1984) and sediment texture may have a greater effect on nematode diversity than heavy metal pollution (Tietjen, 1980). There may be significant direct or indirect interactions between populations of different classes of soil organisms (e.g. nematodes with enchytraeids, tardigrades, earthworms) (Yeates, 1968; Hallas & Yeates, 1972; Yeates, 1981; Ingham *et al.*, 1985). At a given site, seasonal, depth and management factors *inter alia* may significantly affect indices (e.g. Yeates, 1984; Yeates *et al.*, 1993). Investigating nematodes in a single soil in Michigan, Freckman and Ettema (1993) found disturbance could be reliably detected by multivariate analysis and MI, with added information coming from diversity indices and functional groups (= feeding groups). Our analysis of nematodes of some South Australian soils has found several indices confounded by textural effects but various measures of diversity (SR, H' , J' , λ) warrant further investigation. If we regard shrub land as the least disturbed regime, the nematode maturity index does not appear satisfactory.

The three soils which we studied were included in the series examined by Amato and Ladd (1992) who found a close correlation between native soil microbial biomass and soil clay content and the proportion of total soil pore space attributable to fines pores (less than 6 μ m diam.). We have found a significant positive correlation between the numbers of fungal feeding nematodes and the clay content of the soils. Differences in protection of microbes from nematode-grazing in soils of differing tex-

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