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Short communication

Transport of free-living nematodes by runoff water in a Sudano-Sahelian area

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Abstract

The impact of runoff on transport of nematodes was studied using simulated rainfall at Thysse Kaymor, in the Sudano-Sahelian area of Senegal. Three 30 min, 60–75 mm rainfalls were applied every 2 days on three different plots. One plot was previously uncultivated (fallow) and the other two had been planted with groundnut and millet during the previous rainy season. A previous paper by Cadet et al. (2002) reported the results of studies on soil erosion, plant-feeding nematode composition and total free-living nematode density in runoff water, while this paper focuses on the structure of the free-living nematode fauna. The relative abundances of the different taxa of free-living nematodes in runoff water were very different from those found in the 0–10 cm top soil layer. *Rhabdolaimus*, Aphelenchina, Tylenchidae, free-living *Ditylenchus*, Rhabditidae and certain Cephalobidae were more numerous in the runoff water than in soil as estimated from the amount of eroded soil. *Rhabdolaimus* was the most abundant nematode in runoff waters from the groundnut and millet plots where it represented more than 50% of the nematode fauna. In the fallow plot, the most abundant nematode in runoff water was *Ditylenchus*. The over-representation of some taxa in runoff water was linked to their greater motility and to their greater abundance in the superficial layer of soil.

Keywords: Free-living nematodes; Runoff; Fallow; Tropical

1. Introduction

With the exception of earthworms and insects, the component species of the soil fauna do not travel far within the soil. In the case of nematodes, this distance does not exceed a few dozen centimetres a day and is usually much less (Nicholas, 1975). In addition to transport through their own activities, nematodes can be carried not only by other organisms (earthworms, insects, birds) but also by wind and water (Faulkner and Bolander, 1970; Baujard and Martiny, 1994; Cadet and Albergel, 1999).

To study the transport of nematodes with runoff water, an experiment was conducted, using simulated rainfall on a naturally infested area in the Sudano-Sahelian region of Senegal. The results of this experiment for plant-feeding nematode species and free-living nematode (taken as a whole) were analysed in Cadet et al. (2002), while this paper focuses on the structure of the free-living nematode communities in

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runoff water. Cadet et al. (2002) showed that most of the plant parasitic species were less numerous in the runoff water than estimated from the amount of eroded soil, whereas on the contrary, the free-living nematodes were more numerous. In fact, free-living nematodes represented between 40 and 70% of the total nematode density in the soil collected from the 0–10 cm horizon, but they represented between 98 and 99.5% of the total nematode density in the runoff water.

Since microphagous nematodes can contribute in a important way to the mineralisation of available nutrients for plants in poor soils (Ingham et al., 1985; Hassink et al., 1993), it is important to identify which free-living nematode taxa can be spread by natural agencies in the fields. This study aims to identify the free-living nematodes for which transport by runoff water constitutes an important mode of dissemination and to establish the reasons for differences between taxa.

2. Materials and methods

The experimental design is described fully in Cadet et al. (2002). Three plots, 5 m × 10 m, oriented down hill were isolated from the surrounding area by a shallow vertical metal sheet border. The three treatments were:

(1) Groundnut: plot cropped with groundnut and harvested at the end of October of the previous year;
(2) Fallow: uncultivated plot which represented a bare fallow; and
(3) Millet: plot cropped with millet and harvested at the end of October of the previous year.

The experiment was carried out in April 1998 before the first rains occurred. Three erosive rains were applied at 2-day intervals using a rainfall simulator. The intensity of the rainfalls varied between 60 and 75 mm h^{-1} and each rainfall event lasted 30 min. Runoff water leaving each plot was channelled into a single outlet point and the discharge was collected in a series of buckets. Methods of measuring soil loss and processing nematode samples from the outlets of the three plots are described in Cadet et al. (2002). The numbers of bulk water samples analysed to determine the free-living nematofaunal composition were 9, 11 and 7 for groundnut, 9, 7 and 6 for fallow and 5, 7 and 5 for millet, respectively following rains 1, 2 and 3. Soil samples for nematofaunal analysis were taken from the 0–10 cm top soil layer of each plot before the first rain event (Cadet et al., 2002). Three years after the rainfall simulations during the dry season (April 2001), four additional soil samples were taken from each of the 0–2, 2–4 and 4–6 cm soil layers in the millet field (which had been cultivated with a millet–groundnut rotation since the rain simulations) to analyse the nematode distribution in relation to soil depth.

After counting, nematodes were fixed in formol–propionic acid (4:1), transferred to glycerine and mounted on glass slides. From each bulked sample, an average of 170 free-living nematodes were identified utilising a magnification of 400×. The nematodes were assigned to taxonomic groups, usually to family level (Villenave et al., 2001). For the Cephalobidae identification was to genus level. Nematode taxa were assigned to trophic groups following Yeates et al. (1993).

Because water samples from the three plots were not independent but comprised a time series, the structure of the nematofauna was analysed by principal component analysis (ADE4, after Thioulouse et al., 1997). As differences among plots were much greater than among rains, changes in nematofauna in runoff water between rains are not presented. The difference between the actual density of nematodes observed in the runoff and the expected density based on analyses of soil nematode density and quantity of soil particles in the runoff was analysed by the Mann–Whitney non-parametric test.

3. Results

The average density of free-living nematodes in the 0–10 cm top soil layer was greater in the fallow plot (33,360 ind dm^3 soil) than in the other two plots and their density was greater in the millet plot (10,160 ind dm^3 soil) than in the groundnut plot (5480 ind dm^3 soil) (Cadet et al., 2002). Nematode community structure differed less between the two cultivated plots than between fallow and cultivated plots (Table 1(A)). The nematofauna of the fallow plot was dominated by Tylencholaimoidea, Dorylaimoidea,

Table 1
Relative abundance (%) of nematodes in soil and runoff water (A) and total numbers of nematodes collected in the runoff water compared with the expected numbers based on the quantities of eroded soil present in the water (B)

	(A) Relative abundance									(B) Total numbers			
	Soil						Runoff water			Observed in the runoff	Estimated from soil	Ratio	P[a]
	G[b]		F[c]		M[d]		G[b]	F[c]	M[d]				
	M	S.E.	M	S.E.	M	S.E.	M	M	M				
Root-hair feeders													
Tylenchidae	18.9	2.7	8.4	0.3	11.6	4.4	4.8	16.7	3.1	7019	1217	5.8	<0.05
Fungal feeders													
Aphelenchina	18.4	11.3	4.6	0.1	19.7	18.3	23.7	13.6	13.0	24778	1618	15.3	<0.10
Ditylenchus	5.7	0.3	6.3	0.9	1.2	0.2	2.6	26.3	1.7	5950	390	15.3	<0.05
Tylencholaimoidea	9.8	4.4	20.4	2.1	9.4	6.4	0.3	6.1	0.2	1384	1180	1.2	ns
Belondiridae	5.6	5.6	13.7	10.6	10.4	2.4	0.1	2.2	0.1	847	524	847	ns
Bacterial feeders													
Rhabditidae	0	0	0	0	0.5	0.5	0.2	5.7	3.3	3409	30	113.6	<0.05
Monhysteridae	0.5	0.5	0.9	0.9	0	0	0.1	0.2	0.1	155	28	5.6	ns
Rhabdolaimidae	0	0	1.2	1.2	2.4	0.4	51.4	10.2	71.9	76418	161	475.4	<0.05
Prismatolaimidae	0	0	0.9	0.9	0.5	0.5	0.1	0.2	0.1	72	46	1.6	ns
Alaimidae	0	0	0.4	0.4	0	0	0	0.1	0.1	44	20	2.2	ns
Plectidae	0.5	0.5	3.4	0.2	0	0	0.2	0.9	0.4	292	125	2.3	ns
Pseudacrobeles	7.9	2.9	11.8	0.9	2.9	0.1	12.4	6.1	1.1	9101	687	13.2	<0.10
Macrolaimellus	0	0	0	0	0	0	0	0.1	0.1	53	0	–	–
Chiloplacus	8.4	2.4	3.6	3.6	6.5	3.5	3.0	3.6	1.4	3024	559	5.4	<0.05
Zeldia	0.5	0.5	0.4	0.4	0.7	0.7	0	0.1	0	26	52	0.5	ns
Cervidellus	0	0	0	0	0	0	0	0.3	0	50	0	–	–
Acrobeles	0	0	2.4	1.5	1.4	1.4	0	0.2	0	56	149	0.4	ns
Cephalobus[e]	3.4	0.7	4.9	2.2	17.8	0.8	0.6	3.0	0.4	894	1042	0.9	ns
Stegellata	0	0	0	0	0	0	0	0.1	0	25	0	–	–
Other bacterial feeders	0	0	0.4	0.4	0	0	0.1	0.4	0.2	191	20	9.4	<0.05
Omnivorous													
Dorylaimoidea	19.0	8.2	15.0	3.3	14.9	7.9	0.2	3.8	2.8	2354	1492	1.6	ns
Predators													
Ironidae	0	0	0	0	0	0	0	0	0.1	45	0	–	ns
Discolaimus	1.4	1.4	1.3	0.5	0	0	0	0	0	0	56	0	–
Discolaimoides	0	0	0	0	0	0	0	0	0.1	25	0	–	–
Others	2.0	2	3.5	1.9	4.4	1.4	1.0	3.8	2.1	1707	305	5.6	<0.05

M: mean of data following three rain events; S.E.: standard error.
[a] *P* is the probability that estimated number is different from observed number (Mann–Whitney test).
[b] G: Groundnut.
[c] F: Fallow.
[d] M: Millet.
[e] *Cephalobus* referred to *Cephalobus* + *Acrobeloides* which were grouped because of difficulty of identification in routine analyses.

Belondiridae, *Pseudacrobeles* and Tylenchidae. In the millet and groundnut plots, Aphelenchina, Dorylaimoidea, Tylenchidae, Tylencholaimoidea and *Cephalobus* or *Chiloplacus* and *Pseudacrobeles* (respectively for the millet and groundnut) were the dominant nematodes.

The nematofauna of the runoff water from the fallow plot was clearly distinguished from that of the

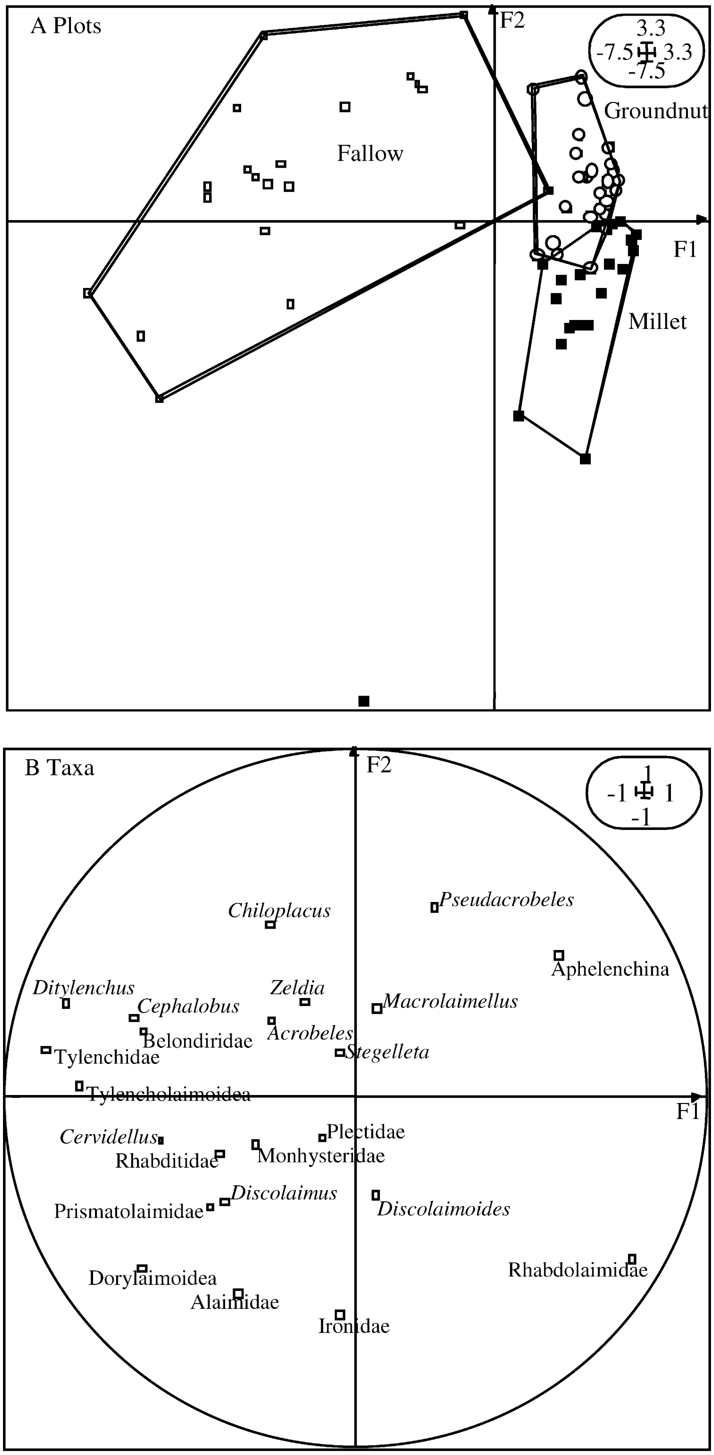

Fig. 1. Principal components analysis of the free-living nematodes (based on relative abundance values) in the runoff water. (A) Coordinates of the water samples from the different plots (based on data following three rain events): groundnut (○), millet (□) and fallow (■) on the first factorial plane F1 × F2. (B) Correlation circle for the different taxa.

other two plots (Fig. 1A), with samples from the fallow plot being located on the negative side of axis 1, while the samples from the millet and the groundnut plots are on the positive side of this axis. Taxa which discriminate between the fallow plot and the cultivated plots are Rhabdolaimidae on the positive side of the axis and *Ditylenchus*, Tylenchidae and Belondiridae on the negative side (Fig. 1B). The dominant nematode in the runoff water from the millet and groundnut plots was the bacterivorous nematode *Rhabdolaimus* sp. which represented, in the millet and groundnut plots, more than 50% of the total numbers of nematodes in the runoff waters (Table 1(A)). On the other hand, *Ditylenchus* and Tylenchidae were the dominant taxa in the runoff water of the fallow plot (25.4 and 16.1%, respectively). The majority of the samples from the groundnut plot are located on the positive side of axis 2, while the samples from the millet plot are situated on the negative side. The three taxa that discriminate between these plots are Aphelenchina and *Pseudacrobeles* (positive side of axis 2) and *Rhabdolaimus* (negative side of axis 2). The five taxa most represented in the runoff water from the three plots were: Rhabdolaimidae, Aphelenchina, *Ditylenchus*, Tylenchidae and *Pseudacrobeles*. The main difference between nematofaunal structure in the soil and in the runoff water was the proportion of Rhabdolaimidae (less than 3% in the soil and up to 71% in runoff water).

Table 1(B) indicates that six taxa that were dominant in the runoff water, namely Tylenchidae, Aphelenchina, *Ditylenchus*, Rhabdolaimidae, Rhabditidae, and *Pseudacrobeles*, were over-represented in the runoff water when compared to the numbers estimated to be present in the 0–10 cm top soil layer (difference significant at $P < 0.10$ for Aphelenchina and *Pseudacrobeles*, at $P < 0.05$ for the others). Rhabdolaimidae and Rhabditidae were the two taxa for which the ratio of runoff to soil was greatest, 475 and 114, respectively. *Chiloplacus* (Cephalobidae) also had more individuals in the runoff water than would be expected from those present in the soil. While these taxa were over-represented, there was no great difference between expected densities and measured densities for seven other taxa: Tylencholaimoidea, Belondiridae, Plectidae, Prismatolaimidae, Alaimidae, *Cephalobus* and Dorylaimoidea. Taxa which were under-represented in the runoff waters compared with their density in the soil were: *Zeldia*, *Acrobeles*, *Discolaimus*.

In complementary samples (April 2001), *Rhabdolaimus*, *Pseudacrobeles* and Aphelenchina were found to have significantly (Student–Newman–Keuls test, $P < 0.05$) higher relative abundance in the 0–2 cm (13.3, 28.1 and 7.0%, respectively) than in the 2–4 cm (1.6, 3.5 and 2.3%, respectively) and 4–6 cm layers (0.0, 0.4 and 4.5%, respectively). 89.3% of the total population of *Rhabdolaimus* was found in the 0–2 cm layer and 10.7% in the 2–4 cm layer. A very similar vertical distribution pattern was found for *Pseudacrobeles* (87.8, 10.9 and 1.3% in the 0–2, 2–4 and 4–6 cm layers, respectively). By contrast, Tylenchidae, *Ditylenchus*, Tylencholaimoidea or Belondiridae had significantly higher relative abundances in the 4–6 cm stratum than in the 0–2 cm layer but were abundant in all the three layers. The others taxa had relatively even depth distributions. Rhabditidae were not detected in these soil samples.

4. Discussion

The number of nematodes transported in runoff water was dependent on the plot history (Cadet et al., 2002): the total numbers of nematodes in the runoff water from the fallow plot, where the soil had not been worked for 20 months, were 4.8 and 5.6 times lower, respectively, than those carried away from the millet and groundnut plots. As the nematode density was highest in the fallow soil, the rate of capture (defined as the number of individuals collected in the runoff water per 100 nematodes in 1 dm^3 soil during the rain event) was even more different among the plots: 1.1 for the fallow plot, 21.0 and 17.6 for groundnut and millet, respectively (Cadet et al., 2002).

The structure of the soil free-living nematofauna in the three plots was comparable to that found in other millet fields in the same area (Villenave et al., 2001). However, the composition of the nematofauna of the runoff water was very different to that of the 0–10 cm top soil layer. Some taxa were over-represented in runoff water (mainly *Rhabdolaimus*, Rhabditidae, Aphelenchina, *Ditylenchus* and Tylenchidae), while others were under-represented (plant-feeding nematodes (Cadet et al., 2002) and some Cephalobidae). One possible reason for these differences may be the accessibility (or lack of accessibility) of the nematodes in the soil to the runoff water. Runoff water does not penetrate deeply into the soil, but is restricted to a mixing zone less than 2 cm deep (Zhang et al., 1997). Moreover, some nematode species prefer substrates that are rich in organic matter and these nematodes have their greatest densities in the litter or in the top centimetres of the soil. This is particularly true for bacterial-feeding and omnivorous nematodes, while plant-feeding nematodes generally prefer deeper layers (Ruess, 1995). We found that *Rhabdolaimus*, *Pseudacrobeles* and Aphelenchina were over-represented in the very superficial soil layer (0–2 cm). Thus, the partitioning of nematodes according to soil depth may partly explain the observed selective transport. Another reason that may explain the great abundance of some nematodes in the discharge is their motility: the shape of the nematodes might be an important characteristic. With the exception of Aphelenchina, all the nematodes that were over-represented in the runoff water have pointed or thin tails that would favour their movement in suspension. Furthermore, although present in soil, *Rhabdolaimus* is mainly an aquatic nematode, extremely abundant in fresh water (Traunspurger, 1995).

The taxa that were over-represented in the runoff water, except *Rhabdolaimus* (c–p 3), are all classified 1 or 2 on the colonisers–persiters scale of Bongers (1990). They are thus considered (with the exception of Tylenchidae which can feed on plant roots), as 'opportunists' and potential invaders of new lands. In an other experiment in the same area, Villenave et al. (2001) found that, after cultivating a fallow, the nematode whose density increased most was *Rhabdolaimus*, which increased 10-fold during the first two years of cultivation following clearing. This colonisation of the recently cultivated area was probably due to its high capacity to be transported in runoff water.

5. Conclusions

All taxa present in the soil were found in the discharge even if their abundance was relatively low. Nematodes were carried selectively in the runoff water probably because of two separate mechanisms. Rainfall affects the first few millimetres of soil and, therefore, the nematodes contained therein. Transport is also influenced by the shape of the nematode, with those that are thin with pointed tails seeming to be more easily transported than others. It is likely that the rapid development of some nematode populations following changes of land use (e.g. fallow to cultivation, annual crops to tree plantations, etc.) is made possible by the nematode input from rain runoff.

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