Microbial-feeding nematodes and protozoa in soil: Their effects on microbial activity and nitrogen mineralization in decomposition hotspots and the rhizosphere

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Received 8 February 1994. Accepted in revised form 28 May 1994

Key words: decomposition, nematodes, nitrogen mineralization, organic matter, protozoa, rhizosphere

Abstract

Food web studies from a range of ecosystems have demonstrated that the fauna contributes about 30% of total net nitrogen mineralization. This results mainly from the activities of microbial-feeding microfauna (nematodes and protozoa). Microbial and microfaunal activity is concentrated at spatially discrete and heterogeneously distributed organic substrates, including the rhizosphere. The dynamics of microfauna and their effect on nutrient cycling and microbial processes at these sites is reviewed. The potential manipulation of microfauna, either as an experimental tool to further understand soil microbial ecology or as a practical means of managing nutrient flows in agroecosystems, is discussed.

Introduction

Microbial-feeding microfauna (nematodes and protozoa) are part of the natural assemblage of microorganisms involved in decomposition and nutrient release in soils. Food web studies have shown the quantitative importance of microfauna in ecosystem budgets of nitrogen mineralization. Smaller-scale studies have demonstrated their importance at concentrations of organic matter, including the rhizosphere, (so called “active sites” or “hotspots”) in soil and the contribution that these active sites can have in overall nutrient flows and plant nutrition. These studies will be reviewed and used to discuss the possibilities for manipulating and managing microfaunal populations to control soil nutrient flows.

Food web studies

It is only relatively recently that below-ground food webs have been studied in sufficient detail, to allow the importance of soil fauna in N mineralization to be quantified. Approximately 30% of total net nitrogen mineralization (TNNM) is due to the direct effects of soil fauna. This figure has been measured in several studies from contrasting ecosystems (Table 1). In a North American grassland bacterial-feeding nematodes accounted for most of the N excreted by fauna (Hunt et al., 1987; Elliott et al., 1988), but at other grassland and arable sites protozoa have contributed most to N mineralization (Andren et al., 1988; Beare et al., 1992; De Ruiter et al., 1993; Rosswall and Paustian, 1984). In fungal-dominated food webs in coniferous forests the soil animals mainly responsible for mineralization were collembola (Verhoef and Brusgaard, 1990). The faunal contribution to TNNM in deciduous forests has not, to the best of my knowledge, been determined, but studies in the Black Forest (Germany) indicate that fauna contributed 25% to total litter decomposition (Beck, 1989). The fauna at this site was dominated by earthworms and although protozoa, the dominant microbivore, only constituted 10% of the faunal biomass they accounted for 66% of the faunal production (Schaefe, 1989).

Fauna became increasingly important mineralizers as systems became poorer in N, as reflected in the increasing percentage of TNNM due to fauna under
Table 1. The percentage of total net nitrogen mineralization attributed to the total fauna, and the contribution due to nematodes and protozoa, in contrasting ecosystems

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Fauna</th>
<th>Nematodes</th>
<th>Protozoa</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coniferous</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>Verhoef and Brussaard, 1990</td>
</tr>
<tr>
<td>forest</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>Persson, 1983</td>
</tr>
<tr>
<td>Grassland</td>
<td>37</td>
<td>22</td>
<td>12</td>
<td>Hunt et al., 1987</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Elliott et al., 1988</td>
</tr>
<tr>
<td>Arable</td>
<td>25</td>
<td>4</td>
<td>17</td>
<td>Roswall and Paustian, 1984</td>
</tr>
<tr>
<td>Polder</td>
<td>35</td>
<td>5</td>
<td>20</td>
<td>De Ruiter et al., 1993</td>
</tr>
</tbody>
</table>

Crops of decreasing N-status (Fig. 1). This is due to enhanced microbial immobilization as the N content of the substrate decreases, and fauna may well be the sole mineralizers of N after a pulse of low-N substrate (Hunt et al., 1987). The values quoted for the contribution of fauna to TNNM are likely to be conservative. These estimates only calculate the direct effect of fauna, the excretion of excess N, and not any stimulatory or indirect effects. De Ruiter et al. (1993) have modelled the possible indirect effects of fauna by deleting particular faunal groups from their food web model, and calculating the subsequent effects on N mineralization. They showed that amoebae could potentially account for up to 40% and bacterial-feeding nematodes up to 10% of TNNM. These calculations were very sensitive to parameter values of the C:N ratio of the substrate and microorganism, the biomass and the natural death rates of the fauna. Verhoef and Brussaard (1990) also showed that the contribution of soil fauna to TNNM could vary between 10–49%, depending on the parameter value of assimilation efficiency chosen. The measurement of such parameter values for field based organisms is an obviously important area for improving the accuracy of food web studies.

Nutrients from decomposing organic matter tend to pass along either a fungal- or a bacterial-based food chain, although the nature of the primary decomposer does not seem to affect the size of the faunal contribution, as shown in Table 1. There is not such a direct link between fungi and fungal-feeders as between bacteria and their consumers. In a semi-arid grassland, for example, almost all bacterial production could be accounted for by protozoan consumption but predation of fungi did not appear to be a major factor controlling fungal populations (Ingham et al., 1986). Fungal turnover could be due to the evacuation of cytoplasm-filled hyphae, death or feeding damage rather than consumption (Hunt et al., 1987).

These studies demonstrate that fauna have an important role in N mineralization in the field and that, except in the fungal-dominated coniferous forest soils, the most important microfaunal groups are bacterial-feeding protozoa (mainly amoebae) and nematodes.

Fig. 1. The percentage of total net nitrogen mineralization due to fauna under crops of differing nitrogen status (after Roswall and Paustian, 1984).

Effects of microfauna on nutrient availability

The role of nematodes and protozoa on microbiological processes and nutrient flow can be summarized as:

- Regulation and modification of the size and composition of the microbial community.
- Acceleration of the turnover of microbial biomass/soil organic matter/nutrients.
- The direct excretion of nutrients.
- The inoculation of new substrates by the phoretic transport or excretion of viable microorganisms.

(Anderson, 1987; Bamforth, 1985; Freckman, 1988; Freckman and Baldwin, 1988; Foissner, 1987; Griffiths, 1994; Ingham et al., 1985a; Visser, 1985; Lousier and Bamforth, 1988; Stout and