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Dynamics of litter carbon turnover and microbial abundance in a rye detritusphere

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Abstract

Factors determining C turnover and microbial succession at the small scale are crucial for understanding C cycling in soils. We performed a microcosm experiment to study how soil moisture affects temporal patterns of C turnover in the detritusphere. Four treatments were applied to small soil cores with two different water contents (matric potential of −0.0063 and −0.0316 MPa) and with or without addition of ^{13}C labelled rye residues ($\delta^{13}C = 299‰$), which were placed on top. Microcosms were sampled after 3, 7, 14, 28, 56 and 84 days and soil cores were separated into layers with increasing distance to the litter. Gradients in soil organic carbon, dissolved organic carbon, extracellular enzyme activity and microbial biomass were detected over a distance of 3 mm from the litter layer. At the end of the incubation, 35.6% of litter C remained on the surface of soils at −0.0063 MPa, whereas 41.7% remained on soils at −0.0316 MPa. Most of the lost litter C was mineralised to CO_2, with 47.9% and 43.4% at −0.0063 and −0.0316 MPa, respectively. In both treatments about 6% were detected as newly formed soil organic carbon. During the initial phase of litter decomposition, bacteria dominated the mineralisation of easily available litter substrates. After 14 days fungi depolymerised more complex litter compounds, thereby producing new soluble substrates, which diffused into the soil. This pattern of differential substrate usage was paralleled by a lag phase of 3 days and a subsequent increase in enzyme activities. Increased soil water content accelerated the transport of soluble substrates, which influenced the temporal patterns of microbial growth and activity. Our results underline the importance of considering the interaction of soil microorganisms and physical processes at the small scale for the understanding of C cycling in soils.
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Keywords: Small scale; Decomposition; Litter; Soil–litter interface; Microbial succession; *r* strategists; *K* strategists; Temporal pattern; Water content; Soil enzymes; MUF

1. Introduction

Plant biomass is the major source of soil organic carbon (SOC), with an annual net primary production in terrestrial ecosystems worldwide of about 60 Pg C yr^{-1} (IPCC, 2001). This important substrate for soil microorganisms is heterogeneously distributed in the soil matrix. For example, van Noordwijk et al. (1993) estimated that only 5% of the soil was in contact with freshly introduced organic matter in an agricultural soil. The mineralisation of plant compounds by a succession of microorganisms as well as leaching of soluble compounds into the soil are controlled by biotic and abiotic factors (Coûteaux et al., 1995). These vary at different scales from millimetres to metres or even larger (Ettema and Wardle, 2002). Therefore, the interaction of plant litter distribution and varying soil properties at the small scale is very important for understanding the soil carbon cycle. The microhabitat in which this interaction takes place is the detritusphere; this layer includes the litter and the soil influenced by the litter. In the detritusphere, plant residues offer new sites for microorganisms, whereas soluble substrates are transported into the adjacent soil (Gaillard et al., 1999; Kandeler et al., 1999). The consequence is enhanced microbial activity and carbon turnover next to the litter layer. Gaillard et al. (1999) found increased dehydrogenase activity and transport of

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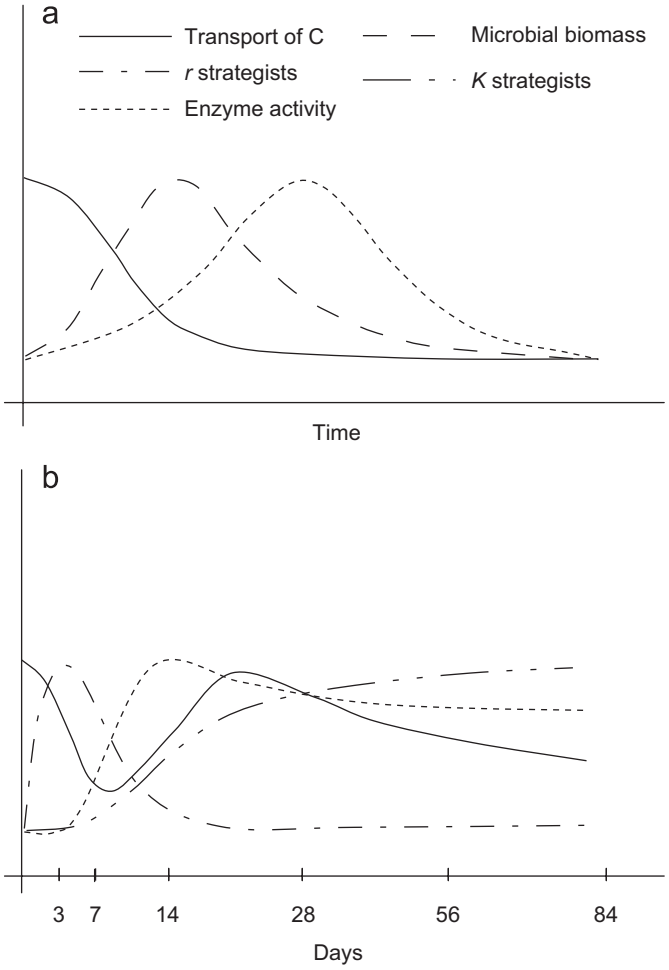

Fig. 1. (a) Schematic illustration of the temporal pattern of C transport, microbial biomass and enzyme activity as hypothesised before the experiment. (b) A concept for the interaction between C transport, *r* and *K* strategists and extracellular enzyme activity in the detritusphere based on the results of the present study.

litter-derived C within a distance of 3–4 mm from the litter layer. In a similar study, Kandeler et al. (1999) reported increased protease, xylanase and invertase activity over a distance of 1.1–1.3 mm. The importance of the soil layer in the detritusphere for litter mineralisation was shown by Gaillard et al. (2003): depending on the litter quality, 23–33% of the mineralisation occurred after litter C was transported into the soil.

However, the influence of many factors such as soil texture or soil water content on the C turnover in the detritusphere remain unclear. The influence of soil moisture on litter decomposition has been shown by Virzo de Santo et al. (1993) and Schimel et al. (1999). The transport of soluble C is affected by the soil water content, which is important for C turnover at the small scale. For example, the diffusion rate in a loamy soil was reduced by 50% at a matric potential of −0.1 MPa compared to saturation (Griffin, 1981). This might influence the transport and turnover of litter C in the detritusphere and therefore the response of the soil microbial community to litter addition. Measuring the phospholipid fatty acids (PLFA) after adding ryegrass, McMahon et al. (2005) observed a succession of bacteria and fungi over 80 days at field capacity. The effect of soil water content on the microbial succession during litter decomposition, however, has apparently never been studied at a small scale.

We recently found evidence for a changed temporal pattern of C transport and microbial activity under differing soil moisture regimes (Poll et al., 2006). After 2 weeks, an elevated water content reduced microbial biomass but increased enzyme activity. This was explained by a faster litter C transport in the wetter soil, allowing microbial biomass to peak early. At the end of the experiment, the microbial biomass was already decaying in this soil, thereby releasing extracellular enzymes.

The present study identifies temporal patterns of litter C turnover in the detritusphere. We expect transport of soluble litter C to peak early in the incubation, followed by peaks in microbial biomass and extracellular enzyme activity (Fig. 1a). A second objective was to analyse the modification of these temporal patterns by soil moisture regime. To test these hypotheses, we performed a microcosm experiment that simulates the soil–litter interface at two different water contents over 84 days. Highly ^{13}C labelled rye litter was used to trace litter C turnover at six sampling dates. Activity of extracellular enzymes was analysed to detect gradients and temporal patterns of microbial activity; ergosterol content and microbial biomass carbon were measured to test the response of fungi and total microbial biomass to litter addition.

2. Materials and methods

2.1. Soil and plant residues

Soil was sampled from the long-term field experiment in Rotthalmünster (Germany, 48°21′N, 13°12′E) near the Danube River in September 2002. Samples were taken from the clay-loamy topsoil of a Stagnic Luvisol (WRB) (pH ($CaCl_2$) 5.5, total C content 12.6 g kg^{-1}, total N content 1.6 g kg^{-1}). Wheat has been cultivated at the site in monoculture for the last 36 years with NPK fertilisation (171 kg N ha^{-1}). The $\delta^{13}C$ value of the SOC was −25.5‰, which indicates that the SOC was derived from C_3 plants. After sampling, the soil was sieved (<2 mm) and stored at −20 °C to minimise disturbance by soil faunal activity during the experiments. For the incubation, labelled rye residues with a $\delta^{13}C$ value of 299‰ (at% $^{13}C = 1.43$) and a C/N ratio of 40 were chosen. Information on the labelling procedure is given in Butenschoen et al. (2007). Rye residues were stored air-dried until the start of the experiment.

2.2. Experimental design

The experiment consisted of four treatments with two different matric potentials and without or with litter

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