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Limitless decomposition in leaf litter of Common beech: Patterns, nutrients' and heavy metal's dynamics

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ABSTRACT

Long-term studies of Common beech litter decomposition are scarce and the relationship of its limit values to nutrients/heavy metals dynamics has not been sufficiently studied. The present study is a rare case in which beech litter decomposes almost entirely and enables analyses of the impacts of nutrients and heavy metals on litter decomposition. The aim of the present paper is to (i) determine a decomposition pattern of leaf litter and estimate the limit values and to (ii) determine the dynamics of the main nutrients and heavy metals (concentration and net amounts, based on ash-free litter) in an unpolluted stand of Common beech.

Common beech (*Fagus sylvatica* L.) leaf litter was incubated in polyester litterbags (1.5 mm mesh size) and 41 samplings were made over a period of 6.5 years until a mass loss of 88.9% was achieved. Carbon (C) plus 12 more nutrients and heavy metals were analyzed.

Mass losses of both whole litter and of C were used in order to estimate the limit values as well as to determine significant differences between the two approaches. An asymptotic function gave significant limit values that were close to 100% ($p < 0.0001$). These results were also supported by a single exponential function ($p < 0.0001$). The initial increase in concentrations of nutrients was followed by a decrease of N, P, K, Ca, Na and Mn. A similar pattern was observed for some of the heavy metals (Cu, Cd and Fe) while Zn concentrations decreased continuously. A net release (e.g. a decrease in the net amounts) was observed for all nutrients and heavy metals except for Cd. The litter fraction did not leave any stable residues (i.e. limit values were close to 100%), which was at least partly due to the low initial N and very high Mn concentration (20 times higher than in other studies).

Introduction

Litter decomposition is a central process in the internal cycling and storage of mineral nutrients and heavy metals in forest ecosystems. In most litter decomposition studies the most common plant nutrients are normally studied for their dynamics and storage. However, both plant litter and the upper soil layers contain different heavy metals, which normally have been studied as pollutants in polluted areas but considerably less in unpolluted environments.

Forest plant litter is decomposed mainly through microbial activity, which also means that nutrients dynamics are determined by the activity of microorganisms. The quantitative contribution of soil animals to decomposition (essentially comminution) is lower and varies from almost minimal in temperate and boreal ecosystems to high in tropical forests (Persson et al., 1980; González and Seastedt, 2001; Huhta, 2007). Thus, the most important environmental factors in regulating the decomposition rate of litter tend to be those that regulate the activity of microorganisms able to degrade woody tissue, for example white-rot fungi. Such factors include soil temperature and moisture, as well as the availability of nutrients and the nature of the energy source.

In a given environment and thus, a given climate, the litter's chemical composition strongly regulates mass-loss rates and nutrient dynamics, although the regulating factors may change with the litter's level of decomposition (e.g. Berg and McClaugherty, 2008). The dynamics of nutrients may have different roles in litter decomposition rates and patterns as well as indirectly in nutrient release and uptake.

A decomposition model with an early and a late stage (Berg and Staaf, 1980; Berg and Matzner, 1997) can be useful at least for some litters. Certain nutrients, such as nitrogen (N) and phosphorus

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(P), have been proposed as rate-enhancing factors in early decomposition stages (Aber and Melillo, 1982), whereas N has been suggested as a suppressing component in late stages, in which lignin is degraded in addition to polysaccharides (e.g. Berg and Matzner, 1997). In late decomposition stages manganese (Mn) has been related positively to litter mass loss, thus a heavy metal can be a rate-enhancing compound. This may be due to the fact that manganese is required for the synthesis of manganese peroxidase (MnP) a widely spread lignin-degrading enzyme (e.g. review by Hatakka, 2001).

High concentrations of heavy metals have been shown to hamper litter decomposition (Berg et al., 1991). The toxic effect of increased concentrations of heavy metals on soil respiration has been proven in several studies (Laskowski et al., 1993; Laskowski et al., 1995b; Niklinska et al., 1998; Scheid et al., 2009). The amplitude of the inhibitory effect varies considerably and depends on the characteristics of soil and forest floor as well as the decomposition stage – later stages are more susceptible to the inhibitory effects (Komulainen and Mikola, 1995; Berg et al., 1991). We cannot exclude that high heavy metal concentrations may influence the limit value of decomposition (Berg and Ekbohm, 1991) and thus, the size of slowly decomposing fractions.

During litter decomposition, concentrations of several nutrients and heavy metals increase in proportion to accumulated mass litter loss. Thus, although they may occur in low concentrations in newly shed foliar litter from unpolluted ecosystems, heavy metal concentrations may increase up to levels at which they may have a suppressing effect on the decomposition rate of the litter (e.g. Berg and McClaugherty, 2008).

Common beech (*Fagus sylvatica* L.) is a very common tree species in temperate and Mediterranean Europe; however, very little has been published in terms of the heavy metal impact on the decomposition patterns of its litter and nutrients. A recent study (Jakob et al., 2009) compares the patterns for the net release of N, P, K, Ca, and Mg from four leaf litters. The pattern of Common beech appears to deviate from those of Lime (*Tilia* spp.), Ash (*Fraxinus excelsior*), and Common maple (*Acer platanoides*). Studies on initial composition of nutrients in Common beech and their variation have been published by Staaf (1982), and Berg and Gerstberger (2004). Anderson (1973) found a limit value of 64.6% in a temperate forest and studies on Common beech litter in South Italy determined limit values ranging from 48 to 67% (Berg et al., 1996). The litter used in the latter study was rich in N and poor in Mn, two nutrients that influence the limit value (Berg and McClaugherty, 2008).

The aim of the present paper is to: (i) determine a decomposition pattern of leaf litter and estimate the limit values, and to (ii) determine the dynamics of the main nutrients and heavy metals (concentration and net amounts, based on ash-free litter) in an unpolluted stand of Common beech. We conducted a litter-bag decomposition experiment as well as an investigation of intact forest floor. The litter bag experiment lasted for approximately 6.5 years and gave insight into the changes of net amounts and concentrations of 13 nutrients and heavy metals in decomposing leaf litter. The impact of the concentration of heavy metals on decomposition rate and residual mass is also discussed. The study was conducted within the framework of the project "Complex ecosystem investigation in stationary conditions in the beech ecosystem *Calamintho grandiflorae – Fagetum*".

Study site

The study was conducted in Mavrovo National Park in western Macedonia. The research station and forest stand are situated in a well-developed, about 70–80 year-old Common beech forest on Bistra Mt., village Leunovo district, near Mavrovo Lake at 41°42′ N and 20°48′ E and at an altitude of 1400 m.

The climate is mountain-continental with a Mediterranean influence (Filipovski et al., 1996). The mean annual temperature (MAT) is 7.1 °C and the mean annual precipitation (MAP) is 1103 mm (Lazarevski, 1993).

Common beech is the dominant tree species at the investigation site with a density of 1200 trees ha^{-1} and a mean diameter at breast height (DBH) of about 16 cm. The understory is represented mainly by Common beech and Macedonian fir (*Abies borisii-regis*). The herb layer at the investigation site has low biomass with less than 6 kg ha^{-1} (Melovski et al., 2004a). Aboveground annual litter fall biomass is 4.98 t ha^{-1} of which 3.44 t ha^{-1} is foliar litter, 1.28 t ha^{-1} branches, and 0.25 t ha^{-1} acorns (Šušlevska et al., 2001; S. Hristovski, unpublished data).

The plant community developed on a dystric cambisol soil type (Ol-A$0_{f/h}$-A-B-(B)C-C). The forest floor is on average 6 cm thick with the upper mineral soil very rich in humic compounds with more than 10% organic matter and a pH of 5.8 (Table 1). The total content of humus as well as total concentrations of N, P, potassium (K), and Mn are clearly decreasing with depth, whereas those of iron (Fe) and sodium (Na) tend to increase with depth (Table 1). A more detailed description of the forest floor characteristics is given by Melovski et al. (2004b). The average litter layer organic mass is 20.6 t ha^{-1} that may be subdivided a follows: unaltered leaves – 1.23 t ha^{-1}, fragmented leaves – 4.47 t ha^{-1}, amorphous matter – 10.84 t ha^{-1}, branches – 3.37 t ha^{-1}, and acorns – 0.67 t ha^{-1} (Melovski et al., 2004b).

Materials and methods

Litter collection, storing, weighing, field incubations and sampling of litter-bags

Decomposition of leaf litter of Common beech was measured using 1.5 mm mesh nylon bags, 20 cm × 20 cm (Bocock et al., 1960) allowing for access of most decomposers with the exception of larger earthworms. In November 1997 newly shed leaves of Common beech were collected just after the main leaf fall. Litter material, air dried at room temperature was used. Exact moisture content was determined on separate samples that were dried at 105 °C. Amounts equivalent to 10 g absolutely dry leaves were placed into separate bags. In total, 123 bags were placed in three closely located plots, 5 by 5 meters (about 15 m apart) within a fenced area of 1 ha. The bags were laid on top of the litter layer and with time covered by new litter fall. Incubation took place on November 15, 1997 after which time one bag was collected from each of the tree plots every month. After April 2000 one bag of each of the three plots was collected every 3rd month.

Determination of mass loss

After sampling, plant remains, roots and soil particles were removed from the litter-bags after which the loss of dry mass was determined by drying the samples to constant mass at 105 °C. We made two determinations of litter mass loss, (i) one using whole litter mass including ash and (ii) another using the loss of organic matter, determined as carbon (C). For the latter see section "Calculations" below. Mean values of mass loss ($n = 3$) were calculated for each sampling.

Collection of soil samples

Soil samples were collected in the fenced area from three 1 m × 1 m soil pits excavated to a depth of 120 cm. Two samples were taken from each of the five soil horizons from each pit. All samples (30 in total) were air dried and stored in paper bags. Samples were milled and sieved (2 mm mesh size) and then analyzed