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Consequence of litter removal on pedogenesis: A case study in Bachs and Irchel (Switzerland)

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ABSTRACT

In forests, soils contain at least twice as much carbon than plants that mostly grow in the upper layers. Litter at the interface between soils and the atmosphere regulates a variety of biogeochemical cycles, which are important for both plants and soils and have possible implications for other environmental components. We have compared leachates collected during an incubation experiment on: a) two deciduous leaves; b) organic and mineral horizons; c) treated with litter removal (and untreated) plots, to assess the changes in the chemical composition of the litter layers and leachates during weathering and their influence on the underlying horizons. Two different types of broadleaves – beech and oak – become indistinguishable when they experience weathering. As a litter horizon is altered, it becomes more stable and loses fewer elements, both in gaseous and liquid forms. The annual removal of litter represents a net loss of biomass from the system. Nevertheless, the effect on soil in the medium term is not significant. Leaves and litter horizons were incubated in micro-lysimeters, leached, and characterised by different analytical approaches, from elementary analyses (dissolved organic carbon, CO_2 production, nitrogen forms, UV absorptivity) to solid state NMR spectroscopy. The results reveal that the removal of the litter does not degrade the underlying soils, in direct contrast to what was thought to be the case previously. Moreover, it extends previous knowledge that litter removal promotes an increase in fulvic acid activity in underlying horizons. The results demonstrate how this human disturbance, if not combined with other degradation factors, could promote podzolisation. In a wider outlook, if managed properly (for example, by burying litter removed after its use in animal husbandry), even the repeated removal of forest biomass contribute not negatively to the genesis of these soils.

1. Introduction

In soil genesis, the alteration products of one individual horizon become reagents within the next horizon; this phenomenon is particularly evident in the case of podzolisation (Ugolini et al., 1988). Podzolisation consists of two main chemical components: i) mobile organic acids, which are the key proton donors that drive the soil processes in the O, E and Bhs horizons, and govern both soil pH and leaching; ii) these acids dissolve minerals and form metal–organic complexes that are nested at the Bhs/Bs interface (Ugolini et al., 1977). One or more plant litter horizons exist above these mineral horizons under natural conditions, at the interface between the forest plant biomass and soil, and represent one of the potential key compartments that serves as a C sink (Bellassen and Luyssaert, 2014; Janzen, 2004; Luyssaert et al., 2010). Fresh plant litter generally consists of distinguishable vegetal remains, leaves, needles, roots, bark, twig and wood pieces, either fragmented or whole. This organic material rapidly or slowly degrades, depending on the local climatic and biological conditions (Catoni et al., 2016). This thin, delicate layer of organic material can be easily affected by humans. For instance, forest litter raking as a replacement for straw in husbandry is an old non-timber practice in forest management that has been widespread in Europe since the seventeenth century (Bürgi et al., 2006; Bürgi and Gimmi, 2007; Gimmi et al., 2008). At its peak in 1853, an estimated 50 Tg dry litter per year was raked at the European level (McGrath et al., 2015). Local historic forest litter-raking results in a long-term reduction in C pools in soils, which is relevant for C accounting on broader scales (Gimmi et al., 2013). After long-term raking, it has been calculated that mixed and deciduous forests show soil carbon depletion by up to 20% of the potential total soil carbon sink without gathering litter (Gimmi et al., 2013). Several studies have speculated that the influence of gathering forest litter might also play a key role in soil nutrient biogeochemical cycles (Glatzel, 1991); Glatzel (1990), Dzwonko and Gawronski (2002), and Vild et al. (2015) suggested that a progressive depletion of soil nutrients as a consequence of litter removal occurs.

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Several ecosystem models enable the impact of anthropogenic activities on ecosystems to be scaled up (e.g., Kaplan et al., 2012), although the timeframe within which soil carbon pools can reach equilibrium and/or fully recover remains unclear, as well as the effects on soil biogeochemical cycles. It is also unclear whether local soil biogeochemical cycles in individual specific circumstances can be realistically extrapolated, for instance, litter-raking.

Human intervention in soil processes has a considerably greater effect than natural perturbations and thus, exceeds the resiliency of soil to recover to its original condition (Amundson et al., 2015). Questions include how a soil evolves, whether human intervention alters one soil horizon and whether the soil formation process becomes slower sensu Simonson (1959) or Runge (1973). The aim of this study was to compare the properties of two broadleaf litters, to understand whether soil organic matter (SOM) develops and to develop a framework by which SOM chemistry is altered as it passes through various litter horizons towards mineral soil. Here, we present results from two beech forests; one mixed (beech and oak) and a pure (beech) forest grown under very similar environmental conditions. The aim was to understand how species influence the soil upon which they develop, and to evaluate the effect of the periodic removal of the forest litter. We postulate that litters of different composition, due to the diverse vegetation cover but built over similar soils have similar properties, and that litter removal, if not combined with other degradation factors, does not influence soil chemical quality.

2. Materials and methods

2.1. Study sites

Litter material was collected from two mature forests in Switzerland. The first stand is at Irchel (47°32′19″N, 08°36′12″E; elevation 640 m a.s.l.) and is 70 years old and dominated by *Fagus sylvatica* (L.). The second forest is located in the vicinity of Bachs (47°32′02″N, 08°26′45″E; elevation 589 m a.s.l.). The stand is dominated by *F. sylvatica* (L.) with *Quercus petraea* (Matt.) and some *Pinus sylvestris* (L.) present as a companion species. The potential natural vegetation is *Luzulo silvaticae–Fagetum typicum* (Zimmermann et al., 2006) in both locations.

The climate in both stands is characterised by mild winters and moderately warm summers. Mean January and July air temperatures are 0.3 and 18.6 °C, respectively. The number of days with ground frost is 75 per year and the temperature exceeds 30 °C on average for 4 days per year. The mean annual precipitation is 1110 mm, of which two-thirds falls during the growing season, from May to October (Ahrends et al., 2008; Meteo Swiss, 2015; Moser et al., 2010). The parent material is high-lying, consolidated plateau gravel and conglomerates in Irchel, and moraine in Bachs (Zimmermann et al., 2006). The soils beneath both stands are OL-OF-A-E/B-Bt-BC + soils, Haplic Luvisols (Epidystric) (IUSS WG WRB, 2015) with a dysmoder organic layer with a Humus Index of 7, which is a numerical expression of the humus form along a gradient of increasing litter thickness (Brêthes et al., 1995; Ponge and Chevalier, 2006).

Forest soil organic horizons are normally named on the basis of visual observations made directly in the field, thus, this is often subjective (Ponge, 1999). Therefore, to obtain a more objective basis for their classification, the two stands (Bachs and Irchel) were compared after a morphological description according to Zanella et al. (2011). A minimum thickness of horizons for description, diagnosis and sampling purposes has been established at 3 mm; thinner horizons are considered to be discontinuous. The amount of organic carbon in dry samples of all litter horizons without living roots was not less than 20% by mass (ISO 10694:1995 method for carbon elementary analysis). The organic layers were sampled according to their morphology. At the Irchel stand, the sequence of horizons was OLn-OLnv-OLv1-OLv2-OF-meA while at the Bachs stand was OLn-OLv-OFsz-meA (details in Supplementary information).

We investigated the influence of litter removal in four 100 m^2-treated plots at each location, where raking occurs yearly in April as a part of a planned experiment and we sampled a few days before the annual removal. After raking, within one year a continuous litter layer is reformed. Control plots of a similar size were established next to these 100 m^2-treated plots. We collected leaves from littertraps without soil contact, and from individual litter horizons. After carefully sampling the whole 1 m^2 of the removed 100 m^2-layers at both sites, the uppermost few centimetres of the A-horizon were sampled in both control and treated plots (five years of annual litter removal). Litter samples were taken at both sites: *Fagus* only at Irchel, mixed *Fagus* and *Quercus* at Bachs. The leaves, including bud scales, minuscule branches, seeds and other distinguishable material, collected from littertraps were then sorted manually in the laboratory. The rationale of this experiment was to compare a mixed beech litter and a pure beech litter; the collection of leaves via littertraps and their comparison aimed to determine which properties are species-specific. The collection of individual samples of litter and their comparison aimed to determine which properties were correlated with depth (i.e., decomposition).

2.2. Incubation experiment

The 250 mL-micro-lysimeters (Stericup, Millipore), which allowed the simultaneous measurement of soil respiration and leaching (Hagedorn and Machwitz, 2007) were incubated at 20 °C in the dark for 12 weeks (twelve leaching cycles, 4 replicates). After nine weeks of incubation some of the measured parameters fell below the detection limit or became constant. Air dried not fragmented litter material (4.5 ± 0.8 g) was placed into the filter units that contained an acid-washed glass wool pre-filter (3 g) on top of 0.45 μm Durapore® membrane filters. Then, 1.5 g glass wool was placed on top of the soils to allow a homogeneous distribution of the leaching solution. As we kept constant volume in all micro-lysimeters, the corresponding weights for the organic layers and A-horizons were in the range of 2.8–15.2 g, and 3.2–19.8 g, respectively.

All the analyses on leachates and emitted gas, including dissolved organic carbon (DOC), nitrogen forms, cation leaching, UV absorptivity, pH, electrical conductivity (EC) and CO_2-production were measured every 7 days while solid-state ^{13}C CP-MAS spectra on the solid phases were obtained at the beginning (time 0) and after 12 weeks. At each leaching cycle, 200 mL of a standard nutrient solution (2.5 μM H_3BO_3, 400 μM $CaCl_2$, 100 μM K_2HPO_4, 50 μM K_2SO_4, 0.2 μM $MnSO_4$, 5 μM $CuSO_4$, 50 μM $MgSO_4$ und 0.2 μM $ZnCl_2$) was applied to the litter with a peristaltic pump for 2 h. The micro-lysimeters were evacuated with a low suction of 50 hPa using a vacuum-controlled pump (EcoTech). To avoid an uneven wetting of the litter material, we did not apply suction during the application. Aliquots of the leachates were stored at 2 °C. Soil respiration was measured the following day by placing the filter units in 1.7-L PE containers, flushing them with CO_2-free air and measuring the increase in CO_2 with time. The concentrations of CO_2 were determined by passing the air of the containers through an infrared gas analyser (LI 6252, LI-COR) in a closed cycle for 1 min. The production of CO_2 was calculated by interpolating linearly between two measurements and integrating over the respective period. As rewetting might stimulate CO_2 production, this might lead to an overestimation of the total C-mineralisation. However, the overall mass balance of the 12-week experiment showed a close correlation between weighed mass loss and the total C losses from the litter as DOC by the weekly leaching and via respiration. The mean difference between the two independent estimates either based on C fluxes or on weight loss ranged between −12 to +8% for the different types of samples. These values, similar to those obtained by Hagedorn and Machwitz (2007) in the same laboratory, have been validated for the current study.