European Journal of Soil Biology 79 (2017) 14–20

Contents lists available at ScienceDirect

European Journal of Soil Biology

journal homepage: http://www.elsevier.com/locate/ejsobi

Effects of land use on soil microbial biomass, activity and community structure at different soil depths in the Danube floodplain

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ARTICLE INFO

Article history:
Received 28 October 2016
Received in revised form
13 January 2017
Accepted 3 February 2017
Available online 14 February 2017

Handling Editor: Yakov Kuzyakov.

Keywords:
Soil microbial biomass
Microbial activity
PLFA
Soil ecosystem functioning
Land use
Soil depth

ABSTRACT

Human activities such as land use and -management may strongly affect the soil's ability to provide ecosystem services, in which microbes are playing a key role. Because sampling is usually restricted to the topsoil, little is known about effects of land use on ecosystem functioning down the soil profile. The present study assessed the effects of different land use types (arable, forest, grassland) on soil microbial biomass, activity and community structure at different soil depths (A, AC, C horizons), under the same climatic and pedological conditions, in the Danube Floodplain in Austria.

Microbial biomass was 4–5 times lower in the arable field than in forest and grassland in the upper horizons. Additionally, both microbial biomass and activity decreased 3–4 fold with soil depth in forest and grassland. However, up to 30% of total microbial biomass was found in the C horizon in the arable field. We found a differentiation of microbial community structure between land use types and with soil depth: i.e. strong differences in the topsoil between land uses, whereas community structure in the C horizon was similar.

This study confirms that land use exerts strong effects on soil microbes in the topsoil and that microbial biomass and activity decrease with soil depth. However, considerable microbial biomass and activity are found below 30 cm depth which is usually not included in samplings. In the deeper soil horizon effects of land use disappear, with microbial community structure and functioning becoming similar in similar pedological conditions.

1. Introduction

Sustainable land management is essential for continuation of life on Earth as we are used to, and can only be obtained if we understand the interplay between soil physical, chemical and biological processes. These processes govern a wide array of ecosystem services such as the provision of food, feed and fibre, carbon sequestration, hydrological regulation and contaminant attenuation [1]. Human activities, such as land use and –management, have strong effects on soil ecosystem functioning, hence studying the soil processes under different land uses is necessary in order to protect and regenerate the soil's ability to deliver ecosystem services.

Soil microorganisms can make up more than 95% of the total soil biomass [2], and play important roles in soil ecosystem functioning, given their role in soil formation processes, dynamics of SOM, and cycling of nutrients [3–5]. Soil biochemical processes mediated by soil microbes are sensitive to land use, e.g. through differences in litter composition and rooting depth and –turnover rates [6,7].

Effects of land use on soil microbial biomass and community

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http://dx.doi.org/10.1016/j.ejsobi.2017.02.001
1164-5563/

structure have been found especially in the rooted topsoil, where differences in litter composition and root turnover rates are most evident. Several studies have shown that microbial biomass decreases with soil depth [8,9], which is likely linked to decreased resource (SOM) availability in the deeper soil horizons [10]. Besides a decrease in microbial biomass with soil depth, also the structure of the microbial community, in terms of group abundances analysed using phospholipid fatty acids (PLFA), may differ between different soil horizons [11,12]. This raises the question of how such differences in soil microbial community structure in the deeper soil layers may be affected by land use type, and how these difference affect provision of ecosystem services such as C sequestration.

The Marchfeld area in the Danube floodplain in Austria provides an excellent opportunity to study land use effects on the soil microbial community at different soil depths in a single soil type. The basin consists of arable fields, forests and grasslands, on young developing Chernozems in homogeneous river sediments, deposited approximately 400–600 years ago. Hence, all soils have been formed from the same parent material and have a similar soil age and pH. Yet, the different land use types differ in type of litter input, rooting depth, rhizosphere effects and land management practices. Our objectives were to assess the effects of three land use types (arable, grassland and forest) on soil microbial biomass, activity and community composition at different soil depths. We hypothesised that (1) land use type affects soil microbial biomass, activity and community structure, via its effects on substrate quantity and quality in the soil, (2) land use effects will be most pronounced in the upper soil horizon, and (3) differences between land uses will decline with soil depth. To test these hypotheses, soil from each of the three land use types (arable, grassland and forest), from three soil horizons (A, AC and C), was analysed in terms of its microbiological and soil physicochemical properties. We used different methods for estimating microbial biomass and activity to evaluate whether the results of these methods were comparable and could possibly be harmonized in the scope of future monitoring schemes.

2. Methods

2.1. Site description

The Marchfeld study area is located in the Danube floodplain downstream of Vienna (Austria). During Alpine glaciations the Danube continuously incised into the uplifting Tertiary basin and accumulated melt-water terraces. The floodplain is morphologically subdivided into two units: the recent floodplain *sensu stricto* and a slightly higher area covered by older fluvial deposits. The soils are classified as former Fluvisols, in development towards Chernozems. Mean annual temperature in the sampling area is approximately 9 °C and mean annual precipitation is about 550 mm with dry summers [13]. Samples were taken from three land use types in the floodplain *sensu stricto*, where soil forms on the alluvial sediments deposited over the last 600 years [13]. Land use history can be followed using historical maps starting in the early 18th century: a grassland (N 48°08′38.9, E 16°52′35.4), converted from forest to grassland between 1809 and 1859; an arable field under intensive agricultural production (N 48°08′27.9, E 16°41′53.2), converted in the first half of the 20th century from grassland (that already existed before 1781); and a mixed forest (N 48°08′40.0, E 16°41′37.3), which evolved semi-naturally (Fraxino-Ulmetum). The cropland is under intensive agricultural use and received mineral fertiliser according to the Austrian fertilisation recommendations [14], depending on the cultivated crop (winter wheat at time of sampling, 1997–2011: winter barley (46% of total crops), rape seed (20%), potato, sugar beet, wheat, maize, and triticale (each 6.8%)). All sites are protected against floods of the Danube river by a dike constructed between 1882 and 1905.

2.2. Sampling

In May 2011, for each land use type three plots were selected where all measurements were carried out; the plots were separated by approximately 30–40 m. At each plot, composite soil samples (ca. 1 kg, from 10 to 15 cores) were taken using a 8 cm diameter corer. Samples were taken from three soil horizons, identified in the field: A (0–10 cm), AC (30–40 cm in grassland and cropland, 50–60 cm in forest), and C (55–65 cm in grassland and cropland, 70–80 cm in forest). For homogenisation, soil samples were gently broken by hand and sieved through a 5 mm sieve in the field. Soil samples were transported in plastic boxes, and kept at 4 °C in the dark for the microbiological analyses, and air-dried in the laboratory prior to physicochemical analyses. Samples for the analysis of the microbial community structure (PLFA) were sieved through 2 mm sieve and kept at −18 °C until analysis. Prior to use, the soil samples were defrosted for 12 h at 4 °C. Microbiological and physicochemical analyses were done in duplicate in the lab, and means of the data provided as sample values.

2.3. Soil physicochemical measurements

Soil bulk density was measured using metal cylinders, from which the contents were weighed after drying. Particle density was measured volumetrically using pycnometers [15]. Soil porosity was estimated as 1- (bulk density/particle density). Soil pH was measured electrochemically (Microprocessor pH Meter pH196 WTW, Weilheim, Germany) in H_2O at a soil:solution ratio of 1:2.5 [15]. Content of carbonates (mineral carbon) was measured gas volumetrically [15]. Total carbon (TC) and nitrogen (TN) contents were measured using dry combustion [16], total organic carbon (TOC) was calculated as the difference between total and carbonate carbon. Hot-water-extractable carbon (HWC) was measured as the carbon present in solution after 16 h at 80 °C, potentially mineralisable nitrogen (PMN) was measured as the increase in NH_4 during 1 week of anoxic incubation in slurry at 40 °C, and carbon and nitrogen mineralisation rates were determined using gas chromatography during a 6 week incubation at 20 °C, as described in Van Leeuwen et al. [17]. Dissolved organic carbon (DOC) was determined by UV adsorption at 254 nm [18].

2.4. Soil microbial biomass and activity

Bacterial and fungal biomass were measured by direct counts using image analysis and epifluorescence microscopy [19], as described in Van Leeuwen et al. [17]. Also the ratio of fungal to bacterial biomass was calculated based on direct counts. Additionally, microbial biomass was determined by the chloroform fumigation-extraction method [20] and quantified based on PLFA extractions (as the sum of bacterial, fungal and unclassified PLFA's).

Bacterial activity was estimated by measuring [^{14}C]leucine incorporation [21]. Additionally, microbial activity was measured using dimethyl sulphoxide (DMSO) reduction to dimethyl sulphide (DMS) following Alef and Kleiner [22]. We added 275 μl of DMSO solution (6.6% w/v) to 1.5 g of fresh soil and incubated at 30 °C for 3 h. After incubation, 100 ml of the gas phase was removed and injected into a gas chromatograph (Hewlett-Packard 5890 GC; HP5 methyl silicon column (5 m × 0.2 mm, Agilent)), with flame ionization detector and Helium (He) as the carrier gas.