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Soil faunal communities from mofette fields: Effects of high geogenic carbon dioxide concentration

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Mofette fields, i.e. geogenic, cold CO_2-exhaling gas vents occurring naturally in regions of tectonic or volcanic disturbances provide an excellent opportunity to investigate long-term responses of the soil biota to increased CO_2 concentrations. The upper centimeters of mofette soils present a small-scale mosaic of different CO_2 and O_2 concentrations: From up to 100% CO_2 and 0% O_2 around local degassing vents to ambient soil atmosphere (<2% CO_2). The present field study investigated the influence of CO_2 on the community structure of Collembola as representatives of the air-filled fraction of the pore system and of Nematoda as inhabitants of soil water films.

Canonical correspondence analyses revealed strong correlations between soil faunal communities and environmental measures, above all CO_2 concentration, organic matter content and plant coverage. An increase in CO_2 concentration was followed by a steady decline in collembolan and nematode species richness and collembolan densities, but below a threshold of 62% CO_2 had no significant effect on overall nematode densities. Collembolans developed viable populations at up to 20% CO_2, where some mofettophilous species had their highest densities and frequencies, but other more general species also occurred (66% of overall collembolan densities). Nematodes, on the other hand, maintained individual-rich populations at up to 62% CO_2, but above 20% CO_2 nematode communities consisted almost entirely (97.6%) of three mofettophilous species: one feeding on bacteria, one on fungi and one on plant roots. Likely a combination of active and passive life phases together with temporal and micro-scale changes in environmental conditions allows survival of few mofettophilous species under CO_2 conditions too extreme for most other species. The finding that mofettophilous species maintained denser populations in high CO_2 patches, with species optima between 3% and 40% CO_2, indicates that they even profit from CO_2 degassing, presumably via changes in food supply or due to the lack of competitors.

1. Introduction

Soil animals inhabit a variety of surprisingly extreme, life-threatening environments, e.g. saline meadows (Schulz and Schnitter, 2012), deserts (Whitford et al., 1981), Antarctic soils (Russell et al., 2014), and salt marshes (Witteveen and Joosse, 1987). One of the most extreme environments where soil life can be found are post-volcanic mofette fields. Mofette fields are geogenic, cold CO_2-exhaling gas vents occurring naturally in regions of volcanic or tectonic disturbances (Weinlich et al., 2006, 2013; Pfanz, 2008; Pfanz et al., 2014). Here CO_2 originates from magma chambers in the earth's mantle and rises through clefts and cracks in the crust upwards to the soil surface and into the atmosphere. Organisms living in the pore system of mofette soils experience extremely unfavorable conditions: Besides the direct toxic effects of CO_2, these include O_2 deficiency and high soil acidity, the latter often irreversible (Heinicke et al., 2009; Weinlich et al., 2013). Spatially these adverse environmental conditions are rather small-scale patchworks of patches under highly divergent CO_2 regime. Around the degassing vents, which are distributed irregularly over the mofette site, the upper centimeters of the mofette soil-pore system maintain up to 100% CO_2 and zero oxygen. In only some tens of centimeters distance of such vents, the soil atmosphere may again be ambient (<2% CO_2).

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A variety of laboratory experiments have illustrated the short-term influence of CO_2 on single species under constant conditions (e.g., Zinkler and Platthaus, 1996; Rasman et al., 2012). Field studies investigating the long-term response of soil fauna to high CO_2 concentrations that lasted decades to thousands of years, however, are practically non-existent. Of the few published reports, Cotrufo et al. (1999) found severe negative effects on soil fauna at extreme CO_2 concentrations. And Yeates et al. (1999), comparing the nematode fauna in mofette fields to a reference site, found significant decreases in total abundance and diversity, but also an increase in the dominance of bacterial-feeders, for which they assumed CO_2 as well as pH and microbial C to be responsible.

In an earlier study on collembolans from mofette sites, Russell et al. (2011) were among the first who accurately measured CO_2 concentrations parallel to sampling with soil samples, from which collembolans were extracted, being taken directly adjacent (5–10 cm) to CO_2 and O_2 measurement points. In this earlier study, twelve collembolan species from soil samples taken in direct vicinity of actual degassing vents (100% CO_2) were identified. Five of these species were not found under ambient CO_2 at the site and were considered to be mofettophilous, one (*Folsomia mofettophila*) being new to science (Schulz and Potapov, 2010). In the present investigation, we developed a new method of field-measuring CO_2 concentrations within the faunal soil sample to even more accurately associate occurring soil fauna to the occurring CO_2 concentrations.

The present field study focuses on the one hand on Collembola as representatives of the air-filled fraction of the pore system, and on the other hand on nematodes as the dominant soil faunal group of the water-film fraction of soil pores. We hypothesized that air and aquatic soil fauna will be differentially affected by CO_2 excess, O_2 deficiency and soil acidity, and will accordingly have different strategies to cope with or avoid extremes. Our objectives were to 1) study the long-term influence of high CO_2 concentrations and associated soil-physicochemical alterations on community structure of nematodes and collembolans, and 2) identify threshold conditions, i.e. highest CO_2, lowest O_2 and pH values, under which soil biota actually maintain populations.

2. Material and methods

2.1. Study site

The investigation site is part of the Cheb Basin, a shallow neogene intracontinental basin that has formed at the intersection of the Eger Graben, the Cheb-Domažlice Graben and the Regensburg–Leipzig–Rostock fault zone. The CO_2 degassing area is a 7 km long and 0.5 km wide band along the Počatky–Plesná fault zone within the Eastern Cheb Basin, located between the villages Milhostov and Nebanice. The Počatky–Plesná fault zone forms an escarpment in Pliocene and Pleistocene sediments and probably was active since the late Pleistocene (Bankwitz et al., 2003). North of Milhostov, the Počatky–Plesná fault zone is still seismically active at a length of approximately ten kilometers, and frequently swarm earthquakes are measured, which in the Plesná valley are triggered by magma movements in a depth of ca. 65 km (Kämpf et al., 2013). The present study concentrated on two study sites within the Plesná valley, one 12 m × 18 m, the other 10 m × 13 m in size, which are situated close to each other and close to the village of Hartoušov (Hartoušov meadow: 12° 27′ E, 50° 07′ N, 423 m a.s.l.). In spring 2009 the diffuse degassing structures at Hartoušov emitted 1.559 t CO_2 per square meter and day, without reactive magma-derived components (H_2S and CO) and with only occasional traces of hydrogen (Kämpf et al., 2013).

2.2. Sampling

Sampling of soil cores took place in 2011 on April-5th (39 soil samples) and June-15th (30 soil samples). Sampling spots were chosen in close proximity (5–10 cm distance) to grid points of botanical surveys that investigated the two mofette areas since 2009 and collected data on the present and past plant society and CO_2 regime (Fig. 1). Grid points were situated at the corners of 1 m × 1 m plant survey plots, so that the present soil samples were at minimum 1 m apart from each other. From altogether 401 grid points, those (69) were chosen that included an as broad as possible range of different CO_2 concentrations. At both sampling

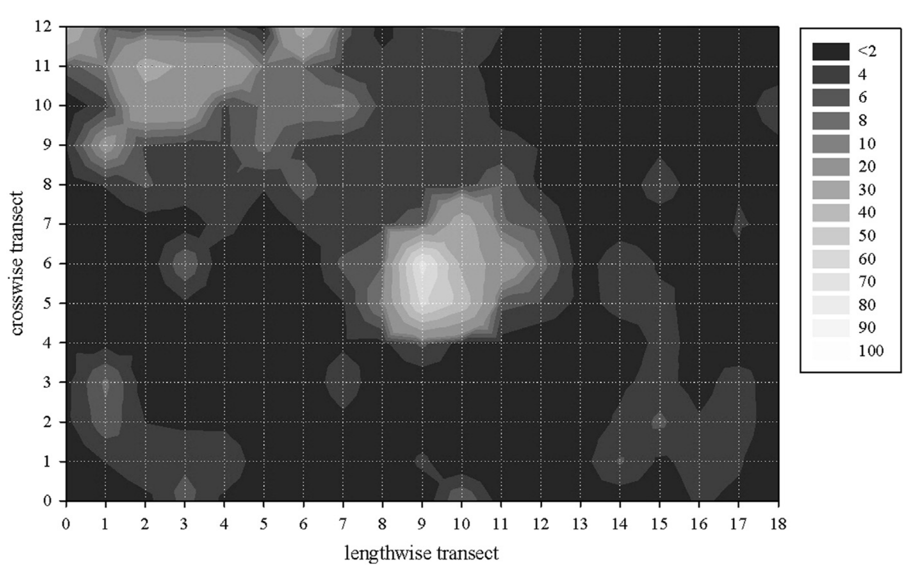

Fig. 1. Field measures of CO_2 concentration [%] taken from grid points of botanical surveys 2011.