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Effects of endogeic earthworms on the soil organic matter dynamics and the soil structure in urban and alluvial soil materials

Joël Amossé [a,b,*], Pascal Turberg [c], Roxane Kohler-Milleret [a], Jean-Michel Gobat [a], Renée-Claire Le Bayon [a]

[a] *Laboratory of Soil and Vegetation, University of Neuchâtel, Rue Emile Argand 11, CH-2000 Neuchâtel, Switzerland*
[b] *Laboratory of Soil Biology, University of Neuchâtel, Rue Emile Argand 11, CH-2000 Neuchâtel, Switzerland*
[c] *Laboratory of Ecological Systems (ECOS), School of Architecture, Civil and Environmental Engineering, Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 2, CH-1015 Lausanne, Switzerland*

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ABSTRACT

Earthworms are considered as key actors of soil processes at different spatial and temporal scales and provide essential ecosystem services linked to climate regulation or primary production. However, little is known about their basic functional roles (e.g. organic matter decomposition, soil structuring processes) in perturbed systems such as urban or alluvial soils. Alluvial soils are characterized by regular physical perturbation through flooding and associated erosion/sedimentation processes which are rather similar to perturbations (e.g. temporal instability, spatial heterogeneity) affecting urban soils. Due to their close soil characteristics, we hypothesized that in both cases, soil functioning is similar with respect to soil fauna activity. Under controlled conditions, our objective was to investigate the effects of two endogeic earthworm species, *Allolobophora chlorotica* (pink morph) and *Aporrectodea rosea* (the two most abundant species found in the studied urban site), on soil organic matter (SOM) dynamics and soil structure (network of earthworm burrows) comparing an urban and an alluvial soil. We investigated the growth of individuals (weight gain and reproduction success) and assessed their effects on SOM decomposition (cumulative C–CO_2 emission, nitrogen and phosphorus mineralization) and soil structure (macroporosity, total length and connectivity of segments) after one and three months of incubation. Our results showed higher growth of *A. rosea* in the alluvial soil compared to the urban soil. However, the total length of burrows, carbon and nitrogen mineralization were often higher in the urban soil especially when the two species were combined. This trend can be mainly explained by lower organic matter content found in the urban soil which may influence positively the burrowing activity and negatively the growth of earthworms. Endogeic earthworms appear a key feature of the soil functioning in the urban context through their roles on organic matter transformation, the formation and maintenance of the soil structure.

1. Introduction

Soil invertebrates such as earthworms are considered as key actors of soil processes at different spatial and temporal scales and provide essential ecosystem services (MEA, 2005; Blouin et al., 2013). As soil engineers (Jones et al., 1994; Lavelle et al., 2006), earthworms contribute significantly to the formation and the maintenance of the soil structure which positively influence physicochemical properties of soils (Jouquet et al., 2006; Lavelle et al., 2006; Blouin et al., 2013). In urban soils from temperate regions, endogeic earthworms (Bouché, 1977) are highly diverse (Schlaghamerský and Pižl, 2009; Glasstetter, 2012). Moreover, they are probably the most resistant earthworms recorded in disturbed soils (Lavelle and Spain, 2001; Jouquet et al., 2010). Despite the general recognition of the importance of earthworms in ecosystems, their potential has not been explored much in urban soils. It is for example unclear if the effects of endogeic earthworms, whose roles in soil organic matter (SOM) transformation and soil structuration are well documented in natural and agricultural soils (Edwards and Bohlen, 1996; Lavelle and Spain, 2001; Edwards, 2004; Bernard et al., 2011; Capowiez et al., 2012), are similar in urban soils. Few studies reported the burrowing activity of earthworms under controlled conditions in different urban soils (Nahmani et al., 2005; Milleret et al., 2009; Pey et al., 2013) but no comparison exists between alluvial and urban soil materials.

In the urban context, the major constraints are the mixing of materials from several origins (e.g. bricks, glass, compost) as well as the compaction of soils (McKinney, 2002; Hazelton and Murphy, 2011). This can affect the soil structure, water infiltration and air circulation and limits living conditions for plants (e.g. root penetration) and for soil organisms (e.g. habitat reduction) (McKinney, 2008; Roithmeier and Pieper, 2009). Comparison of urban soils with natural ones is useful in order to assess if soil fauna has similar effects on soil processes in the urban context as in natural setting. Alluvial soils seem to be a good reference for urban soils

* Corresponding author at: Laboratory of Soil and Vegetation, University of Neuchâtel, Rue Emile Argand 11, CH-2000 Neuchâtel, Switzerland.
E-mail address: pascal.turberg@epfl.ch (P. Turberg).

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in that they are both young soil systems which are constituted of materials that have been manipulated, disturbed or transported at different spatial and temporal scales (Amossé et al., 2014). In this context, the aim of this study was to compare the effects of two endogeic earthworm species, *Allolobophora chlorotica* (pink morph, Savigny, 1826) and *Aporrectodea rosea* (Savigny, 1825), on the SOM dynamics and the soil structure in urban and alluvial soil materials. We hypothesized that the growth and the effects of earthworms in urban soils are similar to alluvial soils due to their close characteristics. Under laboratory conditions (microcosms), we studied (1) the soil organic matter dynamics through C–CO_2, N–NH_4^+, N–NO_3^- and available phosphorus measurements; (2) the characteristics of earthworm burrows (macroporosity, total length of burrows and number of nodes) using the X-ray computed tomography imaging method; and (3) assess the growth of earthworms (weight gain and reproduction rate) in urban and alluvial soil materials.

2. Material and methods

2.1. Soil properties and earthworm sampling

The physicochemical properties of the alluvial and the urban soil are shown in Table 1.

The alluvial soil material was sampled from a Fluvic Cambisol (Calcaric Siltic) (IUSS Working Group, 2007)/FLUVIOSOL TYPIQUE carbonaté, pierrique et polyphasé (Baize and Girard, 2009) in the natural floodplain of the Allondon river (Switzerland, canton of Geneva, 46°12′10″ N, 5°59′57″ E). The urban soil material was collected from a Terric Anthrosol (Siltic) (IUSS Working Group, 2007)/ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé à matériau terreux et à artefacts (Baize and Girard, 2009) in a stone quarry restored in 1995 (Switzerland, canton of Neuchâtel, 47°0′20″N, 6°54′46″E). The alluvial and urban soil profiles were both constituted on a sequence of three soil horizons, respectively Aca/JpcaMca/IIDcaMca and LtpAzca/IILtpAzcaSzca/IIIDca (Baize and Girard, 2009) as described by Amossé et al. (2014).

The alluvial and urban soil materials were collected from the first soil horizon (organomineral soil), air-dried and then sieved at 2 mm in order to remove stones. After a previous identification of earthworm species in the two sites, *A. chlorotica* (pink morph) and *A. rosea* — the dominant species in terms of abundance — were collected in the urban site with the digging method (Glasstetter, 2012). Adults were kept and transferred to the laboratory one week before the experiment for their acclimation to new environmental conditions.

2.2. Experimental design

Microcosms were filled up with 942 cm^3 of urban (U) and alluvial (A) soil materials (PVC pipe, 12 cm in height × 10 cm in internal diameter; Binet et al., 2006), that is equivalent to 1150 g (1.22 $g \cdot cm^{-3}$) of urban and 950 g (1.01 $g \cdot cm^{-3}$) of alluvial soil materials, respectively. Before the experiment, soils were moistened with tap water until the water hold capacity, respectively 0.29 and 0.33 $g \cdot g^{-1}$ for urban and alluvial soil materials. Microcosms with and without earthworm were set-up (5 replicates) in order to assess the effects of earthworms on soils. Three adults of *A. chlorotica* (C, pink form) (mean weight 0.22 g ind^{-1} ± 0.08 g ind^{-1}) or *A. rosea* (R) (0.20 g ind^{-1} ± 0.04 g ind^{-1}) were relieved of their gut contents before the inoculation. A combination of two adults of each species (RC) was also tested in order to assess species interactions in urban and alluvial soil materials. Microcosms were closed air tight and incubated in an acclimatized chamber at 15 °C with a day/night cycle of 14 h light and 10 h dark per day. The study was carried out over one and three months of incubation in order to assess the growth of earthworms and the effects of each species over time. Soil respiration was monitored twice a week on the first month and once a week during the last two months of incubation when respiration measurements were more stable. At the end of each incubation period, microcosms were analyzed by X-ray CT imaging method (Capowiez et al., 1998; Nahmani et al., 2005) as described in Section 2.4. A metal core (5 cm in height × 2.5 cm in internal diameter) was thereafter introduced into the upper 5 soil centimeters of each microcosm in order to measure the soil bulk density. Finally, earthworms were hand-collected, counted and weighted and a mix of the upper 5 soil centimeters was air-dried and sieved before chemical analyses.

Table 1
Initial physicochemical properties of alluvial and urban soil materials.

	Alluvial soil	Urban soil
Texture (USDA, 1975 in Gobat et al., 2013)	Loamy-clayed	Loamy
Clay (%)	33.0	20.7
Silt (%)	30.3	34.7
Sand (%)	36.7	44.6
pH_{H2O}	7.7	8.1
C_{org} (%)	4.0	2.2
N_{tot} (%)	0.28	0.17
N–NO_3^- ($mg \cdot kg^{-1}$)	0.52	0.00
N–NH_4^+ ($mg \cdot kg^{-1}$)	19.67	10.30
C_{org}/N_{tot}	14.3	12.9
P_{tot} ($mg \cdot kg^{-1}$)	525.9	629.4
$P_{available}$ ($mg \cdot kg^{-1}$)	12.2	33.2
$CaCO_3$ (%)	22.7	19.6
CEC ($cmolc \cdot kg^{-1}$)	21.6	13.3
Water holding capacity ($g \cdot g^{-1}$)	0.33	0.29

2.3. Soil respiration and chemical analyses

Respiration was assessed through the measurement of C–CO_2 in microcosms after an incubation period of 24 h. For this purpose, a beaker with 30 ml of NaOH (0.5 M) was laid in each microcosm to trap CO_2 from the soil. The sodium hydroxide coming from the beaker was then mixed with barium chloride in excess (20%) and titration (877 Titrino plus, Methrom) was made with hydrochloric acid (0.5 M) until the stoichiometric point (pH 8.6) to measure soil respiration (Binet et al., 2006). The amount of ammoniac N–NH_4^+ and nitrates N–NO_3^- were respectively measured after extraction with H_2SO_4 (0.5 M) and KCl (0.5 M) by spectroscopy at 636 nm and 410 nm, respectively (Scheiner, 2005). Organic carbon C_{org} and total nitrogen N_{tot} were measured according to the CHN method after acid fumigation of soils in order to remove carbonates prior to analyses (Harris et al., 2001). Available forms of phosphorus ($P_{available}$) were quantified according to the Olsen method and total phosphorus (P_{tot}) was measured following mineralisation and spectroscopy at 720 nm (Carter and Gregorich, 2007).

2.4. Earthworm burrow network

Non-destructive X-ray computed tomography (X-ray CT), was used to analyze the burrow system (volume, total length of burrow segments, number of nodes, number and mean length of burrow segments). Microcosms were scanned with a LightSpeed VCT (GE Healthcare) scanner, which contains a 64-channel detector having an axial pitch of 0.625 mm. The X-rays emitted with a maximum energy of 120 keV (average energy spectrum of 70 keV) with a 640 mA tube current and focalized on 1.2 mm spot size. Particular attention was paid to the voxel size in order to undertake quantitative image analysis. One image slice was reconstructed with 512 × 512 pixels of size 0.215 × 0.215 mm. Although the detector resolution in the axial direction was 0.625 mm, the distance between slices was 0.312 mm due to an overlay of the scanned slices. Hence, the voxel size was 0.215 × 0.215 × 0.312 mm. To avoid artifacts of microcosm border, the image analysis was limited in each microcosm to a standardized cylindrical volume of 10.2 cm in height × 9.75 cm in diameter centered on the vertical axis of the microcosm.