Soil Biology & Biochemistry 65 (2013) 264–273

Contents lists available at SciVerse ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

The effects of earthworm species on soil behaviour depend on land use

M. Hedde [a,*], F. Bureau [b], P. Delporte [b], L. Cécillon [c], T. Decaëns [b]

[a] INRA, UR 251 PESSAC, RD 10, F-78026 Versailles, France
[b] Normandie Université, UR, ECODIV-EA 1293, Fédération de Recherche SCALE-FED 4116, F-76821 Mont Saint Aignan Cedex, France
[c] Irstea, UR EMGR Ecosystèmes montagnards, 2 rue de la Papeterie-BP 76, F-38402 Saint-Martin-d'Hères, France

ARTICLE INFO

Article history:
Received 20 December 2012
Received in revised form
31 May 2013
Accepted 7 June 2013
Available online 25 June 2013

Keywords:
Earthworm ecology
Soil ecosystem engineers
Soil aggregates
Soil organic carbon
Soil structural stability
Near infrared spectroscopy
Carbon mineralisation

ABSTRACT

This work is concerned with the effect of five earthworm species on short-term soil dynamics through carbon (C) mineralisation and large soil aggregate characteristics (production, stability, organic matter content and composition) in laboratory experiments. We hypothesised that the influence of earthworms on soil behaviour depends on individual species and land use history. Substrates were a sequence of three similar luvisols that had been subjected to different land use histories and represented increasing C contents from 10 mg kg^{-1} (cropped soil), to 20 mg kg^{-1} (5-year-old pasture soil) and 33 mg kg^{-1} (permanent pasture soil). We found that relative C mineralisation was slower in pasture than in cropped soils, which can be explained by differences in the physical protection of soil organic matter (SOM). Land use history influenced (i) the amount of large macro-aggregate production through earthworm behaviour (casting activity), and (ii) the size distribution of water stable soil fractions within the large macro-aggregate produced. No effect of earthworm species on SOM composition was observed with near infrared spectrometry indicating that the chemistry of large macro-aggregates was mainly driven by land use type. Earthworm species had more pronounced effects on physical (large aggregate production and stability) than on biological (C mineralisation promotion) or biochemical (SOM composition) features. This paper shows that, although earthworm effects on soil processes are now obvious, a number of factors may interact in such complex systems so that we should hesitate to make generalisations.

1. Introduction

Widespread concerns arise about how to manage C fluxes in the context of global warming and the increased CO_2 concentration in the atmosphere (Smith et al., 2005). The protection of soil C has increasingly been investigated. Vegetation and soil management are essential to promote C sequestration in soils (Lal, 2004). Most available studies show that C stocks fall dramatically when land use changes to annual cropping and slowly increase when it returns from annual cropping to perennial vegetation, such as forest, savannah or pasture. Among the mechanisms of soil organic matter protection, Six et al. (2002) highlighted the importance of the formation and maintenance of stable micro-aggregates within macro-aggregates.

The loamy soils of north-western France provide an interesting model to illustrate these land use effects on soil functions and properties. In this area, as in many other areas worldwide, annual crops are characterised by low organic matter returns and deep conventional ploughing. Such practices usually result in soil organic matter (SOM) loss and in an alteration of physical properties such as a decrease in aggregate stability (Le Bissonnais, 1996). A method of restoration that is increasingly considered is to include a pasture phase within arable crop rotations. Such changes in crop rotation may also alter the soil fauna (Decaëns et al., 2011) and the soil processes they contribute to. Among the countless forms of life that inhabit the soil environment, earthworms are considered as key ecosystem engineers that influence soil behaviour on various temporal and spatial scales (Lavelle and Spain, 2001). The relationship between earthworm activity, soil structure and SOM dynamics has long been recognised (Lavelle and Martin, 1992). Earthworms enhance the incorporation of plant residues into soil aggregates (Bossuyt et al., 2004; Ketterings et al., 1997), create soil porosity and stable aggregates through their burrowing and casting activities, affect OM localisation in the soil profile (Ketterings et al.,

---

[*] Corresponding author. Tel.: +33 (0)1 30 83 32 70; fax: +33 (0)1 30 83 32 59.
E-mail addresses: mickael.hedde@versailles.inra.fr, mhedde@versailles.inra.fr (M. Hedde).

0038-0717/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.soilbio.2013.06.005

1997) and indirectly influence soil aggregation by their control of microorganism activities in the drilosphere (Brown, 1995). However, the magnitude of earthworm effects on SOM dynamics may differ significantly between species (Bossuyt et al., 2006).

In the present work, we aimed to estimate the effects of five earthworm species on soil structure and SOM dynamics in soils with different characteristics resulting from contrasting land use history. We hypothesised (i) that the functional role of earthworm species differs, and (ii) that this functional role depends on land use. We quantified and compared the role of five earthworm species on (i) the production and stability of macro-aggregates and (ii) C protection/mineralisation and biochemical composition of SOM. The experiments were carried out under laboratory conditions, using the soil of three adjacent plots developed on loamy luvisols under different land use.

2. Material and methods

2.1. Field background

Soils and earthworms were sampled at the Lycée Général Technologique Agricole et Agroalimentaire of Yvetot (Normandy, France) (Decaëns et al., 2011). This site is located on a loamy plateau, approximately 200 km west of Paris (49°36′N, 0°44′E). The climate is temperate oceanic, with a mean annual temperature of 10 °C (with a low seasonal variation) and a mean annual precipitation of 800 mm.

In order to test earthworm effects on soil behaviour from different land use systems, the soil of three adjacent agricultural plots was sampled. All soils were decarbonated loamy Luvisols (IUSS Working Group WRB, 2006) equivalent to LUVISOLS (AFES, 2009). On average they consisted of 15% clay, 66% silt and 19% sand. Three different plots were sampled for this study: an annual crop (CS), a 5-year-old temporary pasture (TP) and a permanent pasture (PP). Soil pH_{water} was 6.4 in CS and 5.8 and TP and PP. Soil organic C content increased regularly from 10 to 20 and 33 g kg^{-1} in CS, TP and PP soils.

CS has a history of long-term (at least since 1970) cropping (wheat–maize rotation plus flax or beet) with intensive ploughing and fertilisation. TP rotation consisted of a crop (2 yrs wheat–maize) followed by grassland (4–8 yrs) rotation. Before pasture establishment, the soil was tilled (30 cm deep) and 50 Mg ha^{-1} of cattle manure was surface applied. At pasture establishment, mixed seeds of *Lolium* sp. L., *Trifolium repens* L., *Festuca elatior* L., *Phleum pratense* L. were sown at a rate of 21 kg ha^{-1}. Thereafter, plant assemblages were not managed. Afterwards, an annual fertilisation of 180 kg of N ha^{-1} was applied. PP had a long-term history of pasture (at least since 1970), and represented the oldest local plot with permanent cover and no tillage. Both pastures were grazed for dairy milk production from mid-March to mid-September with a stocking rate of 2–5 livestock units per ha according to the season.

In each stand, about 10 kg of soil (0–10 cm depth) was sampled in May 2006. After collection, soils were air-dried, sieved at 2 mm and homogenised. The five earthworm species used for the experiment were *Aporrectodea caliginosa* (Savigny 1826), *Aporrectodea rosea* (Savigny 1826), *Aporrectodea icterica* Savigny 1826, *Aporrectodea longa* Ude 1885 and *Allolobophora chlorotica* (Savigny 1826). These species were the most abundant of the nine occurring in the study area (Decaëns et al., 2011). The ecological category and the body mass of each of them are given in Table 1. Sexually mature (clitellated) individuals were sampled by hand sorting in May 2006, and maintained in experimental conditions (see below 2.2) for one month to acclimatise and to prevent the input of non-experimental ingested material.

Table 1
Characteristics of the species placed in microcosms.

Earthworm species	Ecomorphological category (Bouché, 1972)	Mean individual weight (mg) (mean ± se)
Allolobophora chlorotica	Endogeic	191 ± 20
Aporrectodea caliginosa	Endogeic	432 ± 53
Aporrectodea icterica	Endogeic	798 ± 26
Aporrectodea rosea	Endogeic	189 ± 15
Aporrectodea longa	Anecic	1083 ± 75

2.2. Experimental design

Hermetically sealed 1000 mL glass jars (17 cm height, 10 cm diameter) were used as microcosms. A total of 57 microcosms were set up, including 3 ‘atmospheric-controls’ without soil and without earthworms (see below), 9 animal-free controls (3 soils × 3 replicates), and 45 containing both earthworms and soils (3 soils × 5 species × 3 replicates). In microcosms other than atmospheric-controls, we added 150 g of dry soil that was rewetted to field capacity with deionised water at the onset of the experiment. One earthworm per species was added to each microcosm. For a given species, special attention was paid to minimise initial body mass differences between replicates by selecting individuals of similar fresh body mass (Table 1). Microcosms were then stored for three weeks in a climate chamber (10 ± 1 °C and a 10 h light:14 h dark photoperiod). Soil mass and the experimental duration were similar to those used by Bossuyt et al. (2004), who assumed that such conditions lead to maximum aggregation after 20 days. In our case, preliminary studies have shown that such conditions allow a high survival rate and that individual biomass loss, when it occurred, did not exceed 20%.

2.3. Modification of soil structure

2.3.1. Size distribution of soil aggregates

At the end of the experiment, earthworms were gently extracted from microcosms. The soil was then air-dried to constant weight and dry-sieved to isolate and weigh four soil aggregate fractions. Following the aggregate classes defined by Bossuyt et al. (2006), we separated large macro-aggregates (>2 mm), small macro-aggregates (200–2000 μm), micro-aggregates (50–200 μm) and the clay- and silt-size particle fraction (<50 μm) (Fig. 1).

2.3.2. Structural stability of large macro-aggregates

Determination of the degree of aggregate stability was made using the standard method described in ISO/CD 10930 based on Lebissonnais and Singer (1993). We used the more disruptive test of this method, which is the fast-wetting treatment. Five grams (dry weight) of large macro-aggregates were placed in deionised water for 10 min before being shaken in 90% ethanol five times on a 50 μm-mesh sieve. The material remaining on the sieve was dried at 40 °C to constant weight (about 48 h). Size distribution after disruption was obtained by sieving the dried material over 6 sieves of 2000, 1000, 500, 200, 100 and 50 μm mesh sizes. We calculated the mean weight diameter (MWD), which is the sum of the mass percentage of each size fraction multiplied by the mean size of the fraction (Kemper and Chepil, 1965). The granulometric fractions obtained by disintegration were grouped into four classes of water-stable aggregates (WSA) within large macro-aggregates: large macro-WSA (>2000 μm), small macro-WSA (200–2000 μm), micro-WSA (50–200 μm) and a silt- and clay-size particle fraction (<50 μm) (Fig. 1). Finally, for each class, we calculated the