Science of the Total Environment 584–585 (2017) 614–621

Contents lists available at ScienceDirect

Science of the Total Environment

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

Urban and industrial land uses have a higher soil biological quality than expected from physicochemical quality

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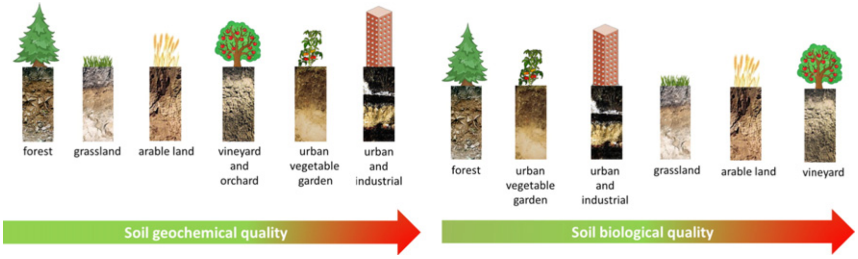
HIGHLIGHTS

- A database of 3096 replicates from 758 sites was established from 13 French databases.
- Agricultural land uses constrain microarthropod communities more than urban and forest land uses do.
- Soil and biological indicators provide complementary information on soil anthropisation.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 October 2016
Received in revised form 13 January 2017
Accepted 13 January 2017
Available online 25 January 2017

Editor: D. Barcelo

Keywords:
Collembola
Anthropisation
Agricultural soils
Garden soils
Industrial and urban soils
Forest soils

ABSTRACT

Despite their importance both in soil functioning and as soil indicators, the response of microarthropods to various land uses is still unclear. The aim of this study is to assess the effect of land use on microarthropod diversity and determine whether a soil's biological quality follows the same physicochemical quality-based gradient from forest, agriculture-grassland, agriculture-arable land, vineyards, urban vegetable gardens to urban, industrial, traffic, mining and military areas. A database compiling the characteristics of 758 communities has been established. We calculated Collembola community indices including: species richness, Pielou's evenness index, collembolan life forms, the abundance of Collembola and of Acari, the Acari/Collembola abundance ratio, and the Collembolan ecomorphological index. Results show that agricultural land use was the most harmful for soil microarthropod biodiversity, whilst urban and industrial land uses give the same level of soil biological quality as forests do. Furthermore, differences between the proportions of Acari and ecomorphological groups were observed between land uses. This study, defining soil microarthropod diversity baselines for current land uses, should therefore help in managing and preserving soil microarthropod biodiversity, especially by supporting the preservation of soil quality.

1. Introduction

Cropping, urbanisation and industrialisation deeply affect ecosystems, including biotopes such as soil (Cluzeau et al. 2012; Santorufo et

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http://dx.doi.org/10.1016/j.scitotenv.2017.01.086

al. 2014a). Anthropisation designates the effects of "human activity" (El Khalil et al. 2013). These human activities modify the ability of soil to provide crucial ecosystem services such as primary production, biodiversity, filtering of toxicants and nutrient dynamics. The ability of soil to fulfil functions and provide ecosystem services is defined as soil quality by Morel et al. (2014). The modifications of soil characteristics and biodiversity are dependent on a hierarchy of factors (e.g. climate, pedogenesis, human activities) with land use at the bottom. Land use involves differences in scale, intensity and duration of human impact on soils (Bullock and Gregory 1991; Morel et al. 2005).

To assess the soil quality, stakeholders mainly use soil physicochemical parameters that are well-defined indicators. A study based on topsoil chemical properties in France (Joimel et al. 2016) has demonstrated a gradient of soil anthropisation from forest, agriculture-grassland, agriculture-arable land, vineyards, urban vegetable gardens to soils of urban, industrial, traffic, mining and military areas (so abbreviated as SUITMA), with an increase in Cd, Cu, Pb and Zn contamination, and in pH and available P content.

On the other hand, soil organisms are more and more frequently considered as being soil quality indicators. Soil invertebrates and more specifically microarthropods, including Collembola and Acari, are often considered as relevant bioindicators of human activities including agriculture, contamination or urbanisation (e.g. Cortet et al. 1999; Santorufo et al. 2012; Zhu and Zhu 2015). Indeed, they take part in many soil functions including litter decomposition, the nitrogen and carbon cycles and creation of soil micro-aggregates (Cortet et al. 2003; Filser 2002). Moreover, microarthropods are abundant, relatively easy to sample, and they quickly respond to soil disturbances (McIntyre et al. 2001). At the European level, they have been selected as one of three main bio-indicators to be used in soil surveys (Bispo et al. 2009). Recently, several projects have been conducted on the French national scale, such as Bioindicateur (ADEME) (Pérès et al. 2011), RMQS Biodiv (Cluzeau et al. 2012) and RMQS Ecomic (Dequiedt et al., 2011), in order to assess the biological levels of soil biota under various land uses and soil managements. These studies were able to define the status of given soil's biological quality, focusing on forest, agriculture and permanent crops (e.g. Bohanec et al. 2007; Cluzeau et al. 2012; Pérès et al. 2011; Ponge et al. 2013).

Concerning microarthropods, and particularly Collembola, species richness has been proven to differ according to land use, usually with a decrease from forests to agricultural lands (e.g. Heiniger et al. 2014; Ponge et al. 2003), even though some studies have shown no relation between richness and land uses (Martins da Silva et al. 2015). Finally, to date, knowledge concerning the effect of land use on the diversity of microarthropods remains limited, especially in the cases of urban and industrial land uses.

Thanks to data collected over 20 years from 13 different research programs, we propose to assess soil biological quality by comparing microarthropod community indices (species richness, abundances, Pielou's evenness index, ecomorphological groups of Collembola, and functional groups of Acari) and the Collembolan ecomorphological index. The ecological structure (abundance of ecological groups) of collembolan communities can be used as an indicator of land use, as demonstrated for earthworms (Pérès et al. 2011). Life form could be related to vertical distribution, which is the main gradient along which collembolan are distributed (Ponge 2000). Moreover, this kind of indicator is important for the development of soil biological indicators because this approach limits effort and reliance on expert knowledge, and can be used as a surrogate of species richness in extensive monitoring schemes (Reis et al. 2016).

Our objective was to investigate the characteristics of microarthropod communities across various land uses, including urban and industrial land uses, in order to (i) evaluate the effect of land use on biodiversity, (ii) define biodiversity baseline values for each land use and (iii) to determine whether bio-indicators of soil quality follow those on the basis of physicochemical characteristics. The resulting implications for the development of biological soil quality indicators and for the management of French soils according to land use are discussed.

2. Material and methods

The data pertains exclusively to microarthropod communities in topsoils to a depth of 5 cm and does not concern the deeper layers of the soil profiles. Likewise, as in the study of soil chemical properties (Joimel et al. 2016), the SUITMA group comprises soils used by the mining industry, solid and liquid waste dumping, as well as habitation and road construction. Sites are, for example, waste deposit sites of factories, urban and industrial wasteland. It should also be mentioned that here, urban vegetable garden soils are excluded from the SUITMA category and constitute a separate type of land use. Indeed, there is no consensus about urban garden soils (e.g. McDonald and Balasko, 2003) and the study of chemical properties (Joimel et al. 2016) highlights its intermediate characteristics between agricultural and urban soils. Chemical properties also differ according to agricultural land use (Joimel et al. 2016) and as the effects of these different land uses on soil biodiversity are recognised (Cluzeau et al. 2012), we have chosen to separate the different agricultural land uses into three categories: grassland, arable land and vineyards.

The proposed land use refers to the following types: forest, grassland, arable land, vineyard, urban vegetable garden, SUITMA (urban, industrial, traffic, mining and military areas). A dataset of 3096 replicates from 758 sites (Table 1), was built by gathering together data from different research programmes carried out with different sampling strategies, but always with the same sampling method. In each site, sampling points were either randomly chosen or equidistant. Furthermore, we did not consider habitat type at all in order to choose the sampling points. The selection of sampling plots in SUITMA is done similarly to other land uses.

2.1. Microarthropod extraction methods and community parameters

Microarthropods were extracted, according to the ISO 23611-2 method, for one week from intact soil cores (5 cm depth, 6 cm diameter), using a high-gradient Macfadyen extractor (Petersen et al. 2003). A temperature gradient is created between the lower part of the system (where the collecting flasks are placed) and the upper part (where the samples are). The collecting flasks are immersed in a cooling water bath at +4 °C. The upper part is heated from 35 °C to 60 °C with intermediate phases at 40 °C and 50 °C. Each temperature phase lasts 48h. Between 3 and 6 soil cores were sampled from each site, according to land uses and project. Microarthropods were identified and sorted into Acari, collembolan or 'other microarthropods' using a dissecting stereomicroscope (Cortet et al. 2007). Collembola were identified to the species level using the dichotomous keys available (Dunger 1999; Dunger and Schlitt 2011; Gisin 1943; Hopkin 2007; Jordana 2012; Potapow 2001; Thibaud et al., 2004; Zimdars 1994). Acari were identified to the suborder level: Prostigmata (previously called Actinedida), Gamasida, Oribatida or Acaridida (Krantz and Walter, 2009; Walter and Proctor 2013).

Furthermore, we assigned each of the collembolan species to one of three ecomorphological types, corresponding to the life-forms defined by Gisin (1943) describing their habitat preferences combined with morphological properties: (i) epedaphic, very mobile and living mainly in litter and topsoil; (ii) euedaphic, poorly mobile and living in soil macropores and (iii) hemiedaphic, an intermediate group. Classification of collembolan species between these three groups are related to morphological characteristics and expert knowledge (Annex 1). Epedaphics are pigmented, with 8 ocelli and antenna, with well-developed furca and legs. Sometimes, long setae and scales were present. Euedaphics are unpigmented, without ocelli with poorly-developed legs and furca. Hemiedaphics present intermediate characteristics.