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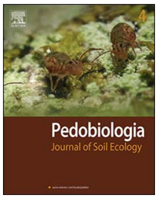

Responses of soil biota to non-inversion tillage and organic amendments: An analysis on European multiyear field experiments

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ABSTRACT

Over the last two decades, there has been growing interest on the effects of agricultural practices on soil biology in Europe. As soil biota are known to fluctuate throughout the season and as agro-environmental conditions may influence the effect of agricultural practices on soil organisms, conclusions cannot be drawn from a single study. Therefore, integrating the results of many studies in order to identify general trends is required. The main objective of this study was to investigate how soil biota are affected by repeated applications of organic amendments (i.e. compost, farmyard manure and slurry) or reduced tillage (i.e. non-inversion tillage and no till) under European conditions, as measured in multiyear field experiments. Moreover, we investigated to what extent the effects on soil biota are controlled by soil texture, sampling depth, climate and duration of agricultural practice. Experimental data on earthworm and nematode abundance, microbial biomass carbon and bacterial and fungal communities from more than 60 European multiyear field experiments, comprising different climatic zones and soil texture classes, were extracted from literature. From our survey, we can conclude that adopting no tillage or non-inversion tillage practices and increasing organic matter inputs by organic fertilization were accompanied by larger earthworm numbers (an increase between 56 and 125% and between 63 and 151% for tillage and organic amendments, respectively) and biomass (an increase between 108 and 416% and between 66 and 196% for tillage and organic amendments, respectively), a higher microbial biomass carbon content (an increase between 10 and 30% and between 25 and 31% for tillage and organic amendments, respectively), a marked increase in bacterivorous nematodes (an increase between 19 and 282% for organic amendment) and bacterial phospholipid-derived fatty acids (PLFA; an increase between 31 and 38% for organic amendment). Results were rarely influenced by soil texture, climate and duration of practice.

1. Introduction

Soil biology is recognized as being a crucial part of soil quality and is becoming increasingly important in modern agriculture. After all, recent tendencies to reduce the use of external inputs in European agriculture implies a greater reliance on the self-regulating processes of the soil (Brussaard et al., 2007). Soil biota play an important role in these processes and in the associated provision of various ecosystem services, such as supply of nutrients to plants, maintenance of soil structure, water regulation, disease suppressiveness and crop yield (Kibblewhite et al., 2008a). Furthermore, unlike physical and chemical soil properties which tend to alter rather slowly, biological soil properties are sensitive to the slight modifications that the soil can undergo in response to a change in soil management (Bastida et al., 2008; Yao et al., 2013). In spite of the above, indicators related to soil biodiversity are measured very rarely (Morvan et al., 2008). Soil biota include both

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invertebrates (e.g. nematodes, earthworms, mites) and microorganisms (e.g. protists, bacteria, fungi) which are closely interlinked through the soil food web. The soil microbial biomass, one of the soil biota indicators used most frequently in soil quality studies and mainly formed by fungi and bacteria, governs nutrient supply via degradation of organic matter and the subsequent nutrient mineralization and immobilization (Sicardi et al., 2004). Moreover, bacteria and fungi affect soil aggregation by means of polysaccharides and fungal hyphae (Preston et al., 2001). Next to the soil microbial biomass, nematodes can also be regarded as important indicators of soil condition (Bongers, 1990; Neher, 2001). After all, nematodes represent a central position in the soil food web and correlate with ecological processes such as nitrogen cycling and plant growth (Ferris et al., 2012; Gebremikael et al., 2016). Further, several studies indicate that the abundance and composition of free-living nematodes (especially bacterivorous and fungivorous nematodes) can provide additional information about the microbial community and processes (e.g. Ferris et al., 2004). Invertebrates and more specifically earthworms, are crucial for the initial comminution and mixing of residues into the soil and hence, making organic matter more accessible to micro-organisms (Kostina et al., 2011). Furthermore, earthworms enhance root growth, water flow and infiltration and gas exchange in soil by building a system of macro (bio) pores and by increasing the stability of soil aggregates (Bossuyt et al., 2006; Lavelle et al., 2006). The EU FP6 project ENVASSO (Environmental Assessment of Soil for Monitoring) aimed to design a set of EU-wide indicators to provide the basis for a soil and land information system for monitoring in Europe. Based on a literature review and an inventory of national monitoring programs, abundance, biomass and species diversity of earthworms was selected as a key indicator for monitoring soil biodiversity (Kibblewhite et al., 2008b; Bispo et al., 2009).

Management practices that enhance soil biological functioning are cornerstones of sustainable agriculture (Malezieux et al., 2009). Bunemann et al. (2006) concluded that any practice that increases the amount of soil organic matter will also increase soil biological activity. This assumption was endorsed by several reviews on the (long-term) effects of organic amendments on soil biology. Thoden et al. (2011) on (free-living) nematodes, Bertrand et al. (2015) on earthworms and Diacono and Montemurro (2010) on bacteria and fungi reported a direct positive effect of organic amendments such as composts, animal slurry or farmyard manure. In addition, soil tillage represents one of the main agricultural management practices affecting soil biodiversity (van Capelle et al., 2012). Tillage practices change the soil water content, temperature, aeration and the degree of mixing crop residues within the soil matrix (Kladivko, 2001). In general, both the abundance and diversity of soil communities increase with decreasing tillage intensity (Briones and Schmidt, 2017). However, in a review with a focus on German data by van Capelle et al. (2012), it was shown that impacts of tillage intensity on soil organisms may differ considerably depending on body size, ability to burrow, habitat demands and food preferences

As soil biological indicators are known to fluctuate throughout the season and as agro-environmental conditions may influence the effect of agricultural management on soil organisms, conclusions cannot be drawn from a single study. Therefore, integrating the results of as many studies as possible in order to identify general trends is required. Previous attempts have typically either focused on one group of organisms (e.g. Thoden et al., 2011) or on one region in Europe (e.g. van Capelle et al., 2012).

Therefore, the main objective of this study was to quantify the expected magnitude of the effects of the repeated application of organic amendments and reduced tillage on soil biota (integrating four key functional groups of the soil food web, including fungi, bacteria, earthworms and nematodes) as measured in European multiyear field experiments. We hypothesized that both organic amendments and reduced tillage would positively affect the different soil biota indicators (**H1**). A secondary objective was to investigate to what extent the effects on soil biota differ across geographically contrasting locations in Europe thereby including different climatic zones and soil types. We hypothesized that the effect of a change in soil management (i.e. reduced tillage and applying organic amendments) on soil biota would be controlled by site-dependent differences in soil texture and climate (**H2**).

2. Material and methods

2.1. Collection of data

A dataset comparing soil biota in different tillage and organic fertilizer treatments in European multiyear field experiments was compiled based on data reported in scientific literature and research reports. We focused on four key functional groups of the soil food web: earthworms, nematodes, bacteria and fungi. In total, more than 60 peer-reviewed papers, (national) project reports and PhD theses were selected for evaluation. The main selection criteria were: (i) the presence of a control treatment (i.e. conventional (mouldboard) ploughing (P) in tillage studies and standard (mineral) fertilization (MIN) in studies on the use of organic amendments), (ii) effects of tillage intensity and organic amendments could be distinguished from other treatment effects, (iii) original data on the relevant parameters describing invertebrates or microorganisms were obtained from European multiyear field experiments (no data from pot or incubation trials were used in our survey), (iv) each field experiment contained at least two replicates and (v) all other factors (e.g. crop rotation) were kept as constant as possible.

Identification of earthworms and nematodes till species level were rarely reported for European field experiments. Therefore, only earthworm and nematode number (individuals m^{-2} or individuals per 100 ml soil) and earthworm biomass ($g\,m^{-2}$) were used in our study. Both the amount of plant-parasitic and free-living nematodes were included, although the free-living nematodes were mainly bacterivorous and fungivorous nematodes as in most cases the abundance of omnivorous and predator nematodes was low and no clear trends or differences owing to different treatments could be observed. Microbial biomass content (i.e., microbial biomass carbon, estimated by using methods such as substrate-induced respiration or fumigation-extraction) was also taken into account in this study. However, a given organic amendment or tillage practice may change the composition of the microbial community (e.g. shifts from bacterial-dominated to fungal-dominated food webs) without changing total amount or activities. The microbial community was incorporated in this review by means of PLFA (Phospholipid fatty acid) analysis (bacterial PLFA and fungal PLFA), although most studies focused on soil microbial biomass only, as the central pool in nutrient cycling.

A large variety of non-inversion tillage techniques was found in European literature. We distinguished three tillage classes based on tillage depth: no tillage (NT), shallow non-inversion tillage (SNIT) comprising all tillage practices with a maximum working depth of 15 cm and deep non-inversion tillage (DNIT) with a working depth greater than 15 cm. Further, in the selected field experiments, the non-inversion tillage practices were applied every year and no mouldboard plough was used. The organic amendments covered in this analysis were slurry (S; all types of animal slurry), farmyard manure (FYM) and compost (COMP; comprising all types of composts such as green waste compost, municipal solid waste compost, farm compost, etc.) and were applied on a yearly basis. In the field experiments on organic amendments that were included in our study, it was not a prerequisite that there would be no mineral fertilizer applied on top of the organic amendment nor that the supply of nutrients in both the control (i.e. standard mineral fertilization) and the treatments that received organic amendments would be equal.

To compare data of the same indicator from different field experiments, the indicator value of a given non inversion tillage technique or organic amendment (a) was expressed relative to the indicator value of