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Temporal differentiation of soil communities in response to arable crop management strategies

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ABSTRACT

Promoting diverse and functioning biological communities is an important objective of agroecology, with increasing attention given to the important role of soil biodiversity. In an experimental study conducted under field conditions, we followed over four years the dynamic of soil organisms from various sizes and trophic niches in four variants of a cropping system which are differentiated by soil tillage, residue management and N fertilization rate. Differentiation in overall family diversity, as well as in the abundance and diversity of the multiple trophic groups was evaluated every two years.

Our study demonstrated a delayed but effective differentiation in soil biota diversity following implementation of the agricultural practices. Soil biodiversity varied throughout time with some groups responding more readily than others, thereby highlighting differences related to trophic position and body size. The visualization of diversity profiles revealed an increasing impact of agricultural practices on group diversity towards higher trophic levels. While tillage appeared a main factor of influence, surprisingly little impact of residue management and nitrogen fertilization could be observed.

Predicting the response of the soil biota to anthropogenic influence calls for an understanding of complex interactions between soil organisms in heterogeneous soil microhabitats. Through its multi-taxonomic approach, the present study increases our understanding of the dynamic of soil communities in agricultural cropping systems and helps identify possible consequences for soil functioning.

1. Introduction

Achieving sustainability is a worldwide current concern in agriculture that brings important challenges but also opportunities for rethinking agroecosystem management (Delong et al., 2015; Tittonell, 2014). The necessity of integrating ecological processes within food production systems has become the corner stone of agroecology (Wezel et al., 2014). Particularly, increasing consideration is given to soil biodiversity, whose role has long been underestimated in cropping systems, but whose preservation in now recognized as key for maintaining or improving soil functioning capabilities, such as litter decomposition and nutrient cycling (De Graaff et al., 2015; Kassam et al., 2013; Kibblewhite et al., 2008; Zhang et al., 2015).

Soil communities are highly diverse and encompass a wealth of organisms with sizes ranging from the micro- to the macroscale that are embedded in a close network of direct and indirect interactions with each other and their environment (Giller, 1996; Moore et al., 2003). However, in agroecosystems soil community networks are often highly reduced compared to natural ecosystems and are greatly influenced by agricultural practices that modulate the habitat structure and the quantity, quality and location of resources for soil organisms (Roger-Estrade et al., 2010;

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Turmel et al., 2015). Besides the spatio-temporal distribution of crops, driving factors include tillage intensity, residue management and fertilization regimes; all of them can be conjointly modulated to meet the purposes of agroecology (Wezel et al., 2014). Previous studies have shown similarities but also substantial variations and contradictions in the response of soil organism groups to a given agricultural practice, depending on their taxonomic identity and resource acquisition strategies (Cole et al., 2008; Holland, 2004; Postma-Blaauw et al., 2010; Roger-Estrade et al., 2010; Van Capelle et al., 2012).

Full-inversion tillage practices that bury crop residues into the soil have been related to relatively homogeneous soil communities, dominated by bacteria, bacteria-feeding protozoa and nematodes and rapidly reproducing invertebrates, such as small euedaphic predatory mites (Koehler, 1999; Wardle, 1995). Previous studies have found that decreasing soil disturbance, for example by adopting conservation tillage, can benefit soil organisms in several ways including reduction in mechanical injuries, improved habitat structure and lower exposure to predators (Brussaard et al., 2007; Pelosi et al., 2015; Roger-Estrade et al., 2010; Wardle, 1995). Leaving residues at the soil surface has been viewed as positive for sustaining diverse soil communities because residues foster microorganism activity and provide favorable structural and microclimatic habitat conditions for a range of taxa (Chan, 2001; Cochran et al., 1994; Govaerts et al., 2007; Kladivko, 2001; Landis et al., 2000). Particularly, the resulting long-standing layer of organic matter in the upper soil should favor the presence of detritivores and their predators (Goncharov and Tiunov, 2014; Kladivko, 2001; Stinner and House, 1990), and enable the expansion of fungal populations, an important trophic resource for many microbi-detritivore arthropods, such as Collembola and oribatid mites (Cochran et al., 1994; Hendrix et al., 1986). Reducing mineral fertilization is as well generally encouraged in the context of agroecology as a more sustainable practice (Gliessman, 2007). Mineral nitrogen (N) input may have indirect effect throughout the soil communities by affecting the abundance and diversity of microorganisms (Fierer et al., 2012; Geisseler and Scow, 2014) and has been shown to indirectly enhance densities of microarthropods in grasslands (Cole et al., 2008). However, little evidence exists that reducing N fertilization affects soil invertebrates in arable systems (Kanal, 2004; Verhoef and Brussaard, 1990).

In view of the existing literature, adopting new agricultural management strategies should lead to changes in taxonomic diversity, as well as in the size and trophic constitution of soil communities. Nonetheless, few studies have assessed and compared the temporal dynamics of soil communities across a range of trophic groups in cropping systems after shifts in agricultural practices (Thiele-Bruhn et al., 2012). In the present study, we addressed this knowledge gap by tracking the short-term effects of shifts in agricultural management strategies under field conditions on the dynamics of an extensive soil community. Specifically, we investigated how the abundance and diversity of several trophic groups have differentiated over time in a rotation of annual crops, in which changes in soil tillage, residue management and N fertilization regime were introduced at the start of the experiment. We expected to observe the largest temporal differentiation in overall taxonomic diversity, because of different sensitivity of various taxa to soil disturbance and resource availability. We also expected to observe various responses depending on the size and trophic position of the studied organisms. For example, small size taxa with high reproductive rates such as microbivores may be less affected by changes in agricultural practices compared to larger-size species. Species at the top of the food-web might show a stronger response because of their dependence on the lower trophic levels and generally higher mobility.

2. Material and methods

2.1. Experimental site

The study was conducted at the long-term experiment SOERE ACBB (Systèmes d'Observation et d'Expérimentation pour la Recherche en Environnement Agrosystèmes Cycles Biogéochimiques et Biodiversité) “arable crops”, located at Estrées-Mons, Northern France (49.873 N, 3.032 E). The experiment was established on an 8 ha field, which had been cropped with annual crops for many years before the onset of the experiment. In 2010, after 2 years of complete homogenization with the same crop (wheat in 2008, then barley in 2009) and same conventional management, a six-year rotation was initiated, composed of spring pea (*Pisum sativum*, L.), winter wheat (*Triticum aestivum*, L.), rapeseed (*Brassica napus*, L.), spring barley (*Hordeum vulgare*, L.), maize (*Zea mays*, L.) and winter wheat. The experiment started in March 2010 (called T0) at pea sowing and six treatments were set up with 4 replicates within a randomized block design. Four of these treatments were investigated in the present study: CONV (conventional) with full-inversion ploughing, reference N fertilization rate and crop residues recycled to soil; RT (reduced tillage) i.e. same treatment but with shallow tillage; RT-RR (reduced tillage and residues removal) i.e. shallow tillage, reference N fertilization and crop residues removal; RN (reduced N fertilization) i.e. full-inversion ploughing, N fertilization rate reduced by ~70% and crop residues recycled (Table 1).

In the RT-RR treatment, crop residues were removed after harvest using a hay baler after cereal crops and a silage harvester for maize. In the other treatments, crop residues were incorporated in soil using disk ploughing in the RT treatment and mouldboard ploughing in the CONV and RN treatments. Tillage depth was about 25 cm in the ploughed treatments and 8 cm in the shallow tillage treatments. Crop residues were returned to soil every year except in the RT-RR treatment. Consequently the mean amount of C returned through aerial residues during the studied period was 1.6 t C ha^{-1} yr^{-1} in the RT-RR treatment and 3.2 t C ha^{-1} yr^{-1} in the three other treatments. Over the full rotation, the mean fertilization rate was 134 kg N ha^{-1} yr^{-1} except for the RN treatment which received only 43 kg N ha^{-1} yr^{-1}.

Initial soil physico-chemical parameters and their spatial variability were measured in January 2010. Within each plot, 8 locations selected on a regular grid were sampled using a tubular gauge (Humax, 8 cm diameter) down to 60 cm. Soil cores were divided into several layers (0–20, 20–35, 35–40, 40–60 cm) and analyzed individually for organic carbon and total nitrogen

Table 1
Description of the investigated treatments of SOERE ACBB for arable crops.

Code	Treatment	Soil tillage	Crop residue management	N fertilization rate
CONV	Conventional	Full-inversion tillage	Returned	Reference[a]
RT	Reduced tillage	Shallow tillage	Returned	Reference
RT-RR	Reduced tillage and residue removal	Shallow tillage	Exported	Reference
RN	Reduced nitrogen	Full-inversion tillage	Returned	32% of Reference

[a] The reference rate was calculated for each crop each year, according to a N balance-sheet method.