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The impact of agricultural practices on soil biota: A regional study

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ABSTRACT

A gradient of agricultural intensification (from permanent meadows to permanent crops, with rotation crops and meadows as intermediary steps) was studied in the course of the RMQS-Biodiv program, covering a regular grid of 109 sites spread over the whole area of French Brittany. Soil biota (earthworms, other macrofauna, microarthropods, nematodes, microorganisms) were sampled according to a standardized procedure, together with visual assessment of a Humus Index. We hypothesized that soil animal and microbial communities were increasingly disturbed along this gradient, resulting in decreasing species richness and decreasing abundance of most sensitive species groups. We also hypothesized that the application of organic matter could compensate for the negative effects of agricultural intensity by increasing the abundance of fauna relying directly on soil organic matter for their food requirements, i.e. saprophagous invertebrates. We show that studied animal and microbial groups, with the exception of epigeic springtails, are negatively affected by the intensity of agriculture, meadows and crops in rotation exhibiting features similar to their permanent counterparts. The latter result was interpreted as a rapid adaptation of soil biotic communities to periodic changes in land use provided the agricultural landscape remains stable. The application of pig and chicken slurry, of current practice in the study region, alone or in complement to mineral fertilization, proves to be favorable to saprophagous macrofauna and bacterivorous nematodes. A composite biotic index is proposed to synthesize our results, based on a selection of animals groups which responded the most to agricultural intensification or organic matter application: anecic earthworms, endogeic earthworms, macrofauna other than earthworms (macroarthropods and mollusks), saprophagous macrofauna other than earthworms (macroarthropods and mollusks), epigeic springtails, phytoparasitic nematodes, bacterivorous nematodes and microbial biomass. This composite index allowed scoring land uses and agricultural practices on the base of simple morphological traits of soil animals without identification at species level.

1. Introduction

Soil biota are a major component of agroecosystems, playing a decisive role in ecosystem services such as, among many others, nutrient capture and cycling (Carpenter et al., 2007; Van der Heijden et al., 2008; Murray et al., 2009), building and control of soil organic matter (SOM) or soil physical structure (Wolters, 2000; Jégou et al., 2001; Jouquet et al., 2006), and vegetation dynamics (De Deyn et al., 2003; Mitschunas et al., 2006; Forey et al., 2011), with synergistic effects on crop production (Ingham et al., 1985; Eisenhauer et al., 2010). Studies on plant-soil feedbacks mediated

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by soil biota showed that soil animals and microbes are also involved in signaling processes which contribute to the integrity of agroecosystems and which sustain crop production (Blouin et al., 2005; Sanon et al., 2009; Endlweber et al., 2011).

Soil biotic communities were included in soil quality monitoring programs in Europe, an initiative stimulated by adoption of the Thematic Strategy for Soil Protection by the European Union (EC, 2006), and sets of biological indicators of soil quality were proposed, based on national programs (Black et al., 2003; Rutgers et al., 2009; Keith et al., 2012). In France, the ADEME ("Agence de l'Environnement et de la Maîtrise de l'Énergie") urged scientists to develop tools for monitoring soil quality from a biological point of view and initiated and financially supported the RMQS-BioDiv program in French Brittany, a western peninsula mostly covered with agricultural land. The national RMQS ("Réseau de Mesures de la Qualité des Sols") network (2200 sites, distant of 16 km) is devoted to the monitoring of physical–chemical properties of soils (Arrouays et al., 2002; Saby et al., 2011) but with future prospects in soil microbiology (Ranjard et al., 2010). The French Brittany part of this network was selected for the assessment of soil biotic communities and the search for a biotic index of soil quality in agricultural land (Cluzeau et al., 2009, 2012; Villenave et al., 2013).

Earthworms, macroinvertebrates other than earthworms, microarthropods, nematodes, and microbial communities were selected as a set of indicator groups proposed at European level (Bispo et al., 2009). All of them are known for their sensitivity to disturbances associated to agriculture, among others tillage (Cortet et al., 2002b; Krogh et al., 2007; Lagomarsino et al., 2009), fertilizer addition (Cole et al., 2005; Van der Wal et al., 2009), pesticide treatment (Frampton, 1997; Rebecchi et al., 2000; Cortet et al., 2002a), disappearance or simplification of ground cover (Filser, 1995; Loranger–Merciris et al., 2006), soil compaction (Cluzeau et al., 1992; Heisler and Kaiser, 1995), and heavy metal contamination (Bruce et al., 1999; Hedde et al., 2012).

Apart from species richness and diversity/evenness indices, widely used at community level, some indices based on species traits directly relevant to disturbance levels were identified for nematodes, such as the Maturity Index (Ettema and Bongers, 1993). Similar indices have been proposed for some other invertebrate groups (Parisi et al., 2005) and for the whole faunal community (Yan et al., 2012). Direct extraction of DNA and other standardized microbiological methods also allow estimating parameters of soil biological (mainly microbial) activity (Harris, 2003; Petric et al., 2011). To the study of these taxonomic groups was added a Humus Index, derived from the assessment of biological activity through the identification of humus forms in forest soils (Ponge and Chevalier, 2006), specially adapted to agricultural soils on the base of previous results on the influence of farming systems on soil structure (Topoliantz et al., 2000).

Meadows, meadows in rotation, crop fields in rotation and permanent crop fields can be considered as forming a gradient of increasing intensity of agricultural practices (Burel et al., 1998; Stoate et al., 2001; Decaëns et al., 2008). Our first hypothesis is that increasing disturbance in soil animal and microbial communities can be observed along this gradient, which could be revealed by decreasing species richness and decreasing abundance of more sensitive species groups (Eggleton et al., 2005; Osler and Murphy, 2005).

Some agricultural practices aim at restoring soil fertility, compensating for the exportation of nutrients through herbage and food crop production. Among fertilizing practices, those increasing soil organic matter content, i.e. the application of manure, compost and organic-rich waste products of animal husbandry such as chicken droppings or pig slurry, are known to improve soil quality and crop yield but also lead to uncontrolled N losses (Cox et al., 2001; Antil et al., 2009; Chirinda et al., 2010). Slurry application may thus compensate for the negative effects of agricultural intensity, in particular for those species relying on soil organic matter (SOM) for food requirements, i.e. saprophages: this is our second hypothesis.

Spatiotemporal influences on the distribution of soil biota (Winkler and Kamplicher, 2000; Decaëns, 2010; Jangid et al., 2011), as well as the effects of geology and related soil features (Kováč, 1994; Popovici and Ciobanu, 2000; Fierer and Jackson, 2006) will be taken into account in our regional scale census of the impact of agricultural practices on soil biotic communities.

2. Materials and methods

2.1. Study sites

A total of 109 sites, distant of 16 km on a regular grid, among which 99 in agricultural land (53 crop fields, 46 meadows), were selected for the present study. All these sites pertain to the national RMQS network. They were characterized by geographical position, parent rock and soil type, land use and farming system (Appendix 1). The climate is typically Atlantic but there is a west-east gradient of increasing seasonal contrast and a north-south gradient of increasing temperature and decreasing rainfall due to mainland effect and Gulf Stream influence, respectively. In French Brittany, most frequent geological substrates are hard rocks such as granite and hard sandstone.

At the time of sampling (2006 and 2007) crop fields were mostly permanent (42 among 53, i.e. 79%), while half of the meadows (23 among 46) were included in rotations with crops (Appendix 1). Mineral fertilization was widely used in the studied region (84 sites among 99), alone (20 sites) or more often combined with cattle manure (32 sites), pig and chicken slurry (19 sites) or both (11 sites).

Permanent meadows, meadows in rotation, crops in rotation and permanent crops formed a gradient of agricultural intensity according to increasing use of plowing, fertilizer and pesticide application:

- Permanent meadows: no plowing/tillage or only occasional (when sawn), no or only occasional pesticide application, no fertilizers or varied organic and/or mineral fertilizers, permanent plant cover
- Meadows in rotation: same as above but alternating with crops
- Crops in rotation: same as below but alternating with meadows
- Permanent crops: plowing/tillage each year (one to three/four times per year), various levels and types of pesticide and fertilizer use, seasonal plant cover

Given the complexity of measuring the impact of pesticides, which may vary in quantity and variety, frequency of application, and ecotoxicity (Sattler et al., 2007), we decided for the present study to note only whether pesticides were used or not, without trying to separate them into categories nor defining any scale of intensity of pesticide use.

2.2. Sampling procedure

Sampling took place in 2006 (30 sites) and 2007 (69 sites). With the exception of non-earthworm macroinvertebrates, sampling was done by the same team, previously trained to the different sampling methods in use. Sampling campaigns took place between 15 February and 25 April, the most favorable period in French Brittany agricultural land. Site descriptors were coded and recorded in the DONESOL database (Jolivet et al., 2006a,b).