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Reducing tillage in cultivated fields increases earthworm functional diversity

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ABSTRACT

Alternative cropping systems such as conservation agriculture have been implemented to limit the harmful effects of intensive conventional cropping systems. Conservation agriculture is known to modify the structural diversity of earthworm communities, but no data have been reported so far on their functional diversity. Structural and functional indices of community were used to study the effects of different soil tillage intensity on earthworm diversity in arable soils.

Field data were collected in four agricultural trials across France representing different soiland climatic conditions. Three types of soil tillage were assessed: plowing, superficial tillage and direct seeding. Earthworm abundance, species richness and ecomorphological group abundance were investigated. Seven functional traits, i.e. body length, body mass/length ratio, epithelium type, cocoon diameter, typhlosolis type, carbon preferences and vertical distribution, were selected according to their hypothesized link with mechanisms of tillage impact. Functional diversity indices were then computed. Soil tillage intensity decreased functional diversity and modified the functional trait profile within the earthworm community whereas neither structural diversity (species number) nor abundance changed with tillage intensity. Differences between plowing and direct seeding were significant in each trial, and superficial tillage often showed intermediate trait values. Regarding ecomorphological groups, anecic abundance was positively influenced by a decrease in soil tillage, contrary to epigeic and endogeic earthworms that showed no response. Tillage acts as an environmental filter, and decreasing its intensity caused a lesser convergence of traits and thus higher functional trait diversity. We demonstrated that a trait-based approach better permitted comparisons of community responses across sites than species number or abundance.

1. Introduction

Agricultural intensification has reduced soil biodiversity in cultivated fields. Many authors have reported negative impacts of plowing, pesticide use, simplification of crop rotations and land use management on several soil invertebrate communities (Bengtsson et al., 2005; Hubbard et al., 1999; Doran and Zeiss, 2000). Earthworms, which represent a large proportion of soil biomass, i.e. up to 80% (Yasmin and D'Souza, 2010), are highly sensitive to soil tillage (Chan, 2001; Hubbard et al., 1999). They have important agro-ecological functions (Edwards and Bohlen, 1996; Sims and Gerard, 1999) and are well-known ecosystem engineers (Jones et al., 1994) and bioindicators of soil biological functioning (Paoletti, 1999). Reduced or non-inversion tillage cropping systems are thought to be beneficial to these soil organisms (Bengtsson et al., 2005; Pelosi et al., 2009). Among them, conservation agriculture was first proposed to limit soil erosion and thus ensure the sustainability of some farming systems. It combines minimum tillage, diversified crop rotations and permanent cover crops to manage weeds and pests and to reduce erosion (FAO). The development of these alternative cropping systems, with reduced mechanical disturbance, influences earthworm community structure (Fonte et al., 2009; Pelosi et al., 2009) and thus the associated ecological services (Capowiez et al., 2009).

Functional diversity of a community can be measured by several approaches (Bernhardt-Röermann et al., 2008), including (i) the diversity of *a priori* functional groups, (ii) the diversity of

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mathematically determined functional groups, and (iii) synthetic indices based on functional traits. Functional trait concepts have emerged as a promising way for understanding the mechanisms that drive organism responses to environmental disturbances (e.g. the habitat templet theory; Southwood, 1977). Functional traits concern species properties that affect individual fitness and govern species' responses to their environment (Violle et al., 2007). Trait-based approaches are currently used in different fields of ecology, e.g. plant or stream invertebrate ecology (Archaimbault et al., 2010; Lavorel and Garnier, 2002). They have been less studied in soil ecology, although functional trait profiles have been stressed to be a consistent way to reveal earthworm responses to environmental perturbations (Fournier et al., 2012; Hedde et al., 2012; Pérès et al., 2011). Traits have to be selected for their perceived relevance to tested environmental drivers. Ideally, considerations of biological and ecological functions would be related directly to purely functional traits such as growth, reproduction, and competitive ability. However, direct measurements of biological and ecological properties and processes are often impractical. We therefore focused on easily measured or well-known features that may act as surrogates for such properties and processes. Morphological traits can be surrogates for growth/maintenance (e.g. body length, body mass/length ratio, presence/size of a typhlosolis, i.e. a mid-dorsal invagination of the earthworm midgut that may be involved in nutrient uptake efficiency, Stevens and Hume, 1995), protection (e.g. epithelium type) or investment in reproduction (e.g. cocoon diameter). Behavioral traits, like earthworm species' vertical distribution, may also reflect the response of individuals, notably in term of exposure to disturbance. Finally, ecological preference like carbon content preferences can also be used to test earthworm responses to modification in soil properties and functioning (in terms e.g. of pH or organic matter content).

Up to now, earthworm functional diversity has been characterized using *a priori* functional groups, i.e. the ecomorphological groups defined by Bouché (1972). Anecics are generally less abundant or even absent in plowed fields (Chan, 2001). The direct (mechanical damage and exposure to predation) or the indirect deleterious impacts of plowing (changes in soil environment, including destruction of burrows, burying of surface organic matter and changes in soil physical conditions such as water content and temperature) may explain these results (Chan, 2001; Edwards and Bohlen, 1996). The lack of an organic layer in plowed systems strongly constrains the survival of epigeic species in these systems. The endogeic species, living in the top 20 cm of soil, may be reduced (De Oliveira et al., 2012) or favored by plowing (Nuutinen, 1992; Pelosi et al., 2009; Wyss and Glasstetter, 1992) since they could take advantage of crop residues in the soil made available to them through incorporation (Chan, 2001).

The present work aims at studying the effects of different soil mechanical disturbances on earthworm communities in arable soils. We used data from several trials testing different types of tillage, i.e. plowing, superficial tillage, and direct seeding. To establish the generality of results (soil and climate independency), data were collected in agricultural trials in four sites across France. We tested the effect of a decrease of tillage intensity on different descriptors of earthworm communities (total abundance, species richness, ecomorphological group abundance and functional trait diversity) and compared them. We hypothesized that a decrease in soil tillage leads to an increase of the carrying capacity of soil (earthworm density), of species richness and of functional trait diversity due to less harsh conditions. First, concerning ecomorphological groups, we hypothesized that (1) mechanical de-intensification changes their distribution, favoring anecics, as well as the species living in the topsoil, mostly epigeics, due to the progressive establishment of an organic layer. Second, tillage acts as an environmental filter, hence (2) functional traits converge to a narrower range of values with increasing of intensity of tillage. Regarding the diversity of traits, four sub-hypotheses are considered: (3.1) the largest and the most fragile (with a supple epithelium) organisms are most affected by intensive tillage. (3.2) More earthworms with a larger feather typhlosolis are found in plots with lower nutrient availability, i.e. the plowed plots. This hypothesis is based on Stevens and Hume (1995) who found that a larger feather typhlosolis is associated with higher nutrient uptake efficiency. (3.3) As a consequence, a higher proportion of earthworms with high soil carbon content requirement is found in unplowed plots. Finally, (3.4) the more an individual lives in the topsoil, the more it suffers from plowing.

2. Materials and methods

2.1. Sites and cropping systems

Field data were collected from agricultural trials in four different localities in France (Table 1). According to the FAO classification, soils were Cambisol on trial A, Luvisols on trials B and C, and Fluvisol on trial D. Climatic conditions are temperate and presented a variable oceanic influence, from oceanic (trial A–C) to continental (trial D) climates (Table 1). Trials compared at least two different types of soil tillage: plowing, superficial tillage and direct seeding (Table 2). Plowing involved soil inversion to 25–30 cm depth. Superficial tillage involved mechanical disturbance to less than 8 cm depth, without soil inversion. Direct seeding involved mechanical disturbance in the upper 3 cm of soil in the sowing furrows, without soil inversion. The number of replicated plots per tillage type in each individual trial was 6 for trial A, 2 for trial B, 3 for trial C, 2 or 3 for trial D. Information on crop rotations, pesticide use and fertilization is given in Table 2.

Physico-chemical characteristics of soils are detailed in Table 1. Soils were loamy (trials B and C) to sandy (trial D) textured. Soil texture differed between tillage type within trial C and, to a lesser extent, trial D. Soil pH values were associated with bedrocks, from granite in trial A (pH–H_2O = 6.2) to aerial loess deposits in trials B and C (pH–H_2O = 7.0–7.6) and carbonated alluvium deposits in trial D (pH–H_2O = 7.8–7.9). Similarly, $CaCO_3$ content reflected the bedrock nature of each site but no differences existed within plots of the same site. Organic matter content was higher in soils of trial A than in the other soils (35 and 14–21 g kg^{-1} respectively). No differences occurred between tillage types in trial A whereas soil organic matter content was increased when conservation agriculture had been adopted in the other three trials. The gain ranged from +6% to +25% in trial D (plowing vs surface tillage) and B (plowing vs direct seeding) respectively.

2.2. Earthworm sampling methods

The main characteristics of the sampling design of each study are given in Table 3. All studies were carried out during autumn (November) or early spring (March–April), when most earthworm species are particularly active (Bouché, 1972). Samplings were mostly done on winter wheat crops, but some were done on flax or sugar beet (trial C) and on soybean residues or wheat/alfalfa crop associations (trial D). In all the trials, the sampling method combined chemical extraction (using different chemicals) and hand-sorting (Table 3). The number of replicates per plot was 2 in trial D, 3 in trial A, 4 in trial C and 5 in trial B. Depending on the trial, sampling was done from 1995 to 2011. As the number of years since the trial establishment ranged from 3 to 14, and because of the year-to-year weather variation, we incorporated the between-year differences by computing median values of earthworm species densities at the plot level. Despite differences in sampling design