

Dynamics of earthworm taxonomic and functional diversity in ploughed and no-tilled cropping systems



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ABSTRACT

No-till has been proposed to limit the negative impacts of intensive agriculture. Soil organisms such as earthworms are good indicators of soil tillage effects. The aim of this study was to assess the dynamics of both taxonomic and functional diversity of earthworm communities after switching from ploughing i.e. deep tillage at 25–30 cm depth inducing soil inversion in this paper, to no-till. We assumed (i) that this transition led to increased diversity and (ii) that both taxonomic and functional indices indicated changes in tillage practices. Earthworms were sampled at three experimental sites in France on a Cambisol, a Luvisol, and a Fluvisol over several years (from 1995 to 2011), comparing both tillage systems. Standardized mean differences (Cohen's indices) were calculated on several taxonomic and functional indices to quantify the influence of tillage practices within each site. We generally found a neutral or positive effect of the no-till on taxonomic and functional indices. The temporal responses of earthworm diversity were stronger in earliest stages (less than 6 years) than in oldest ones (more than 8 years) revealing transitory effects on diversity. In site III, for instance, a positive effect of no-till was observed on species and functional richness during the first 5 years but a negative effect was shown in year 6. Thus, no clear continuous increase of taxonomic and functional diversity was found in no-tilled fields, but positive and negative effects according to sites and years. More marked differences were found for taxonomic than for functional indices, suggesting that individuals settling the fields shared a similar combination of functional traits to those previously present. As transitory effects have been observed, this study highlighted that long-term trials are needed to assess the effects of cropping systems on earthworm biodiversity.

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1. Introduction

To limit the harmful effects of intensive agriculture which is based on increased agricultural production and characterized by a high rate of human interventions and use of inputs, alternative agricultural and management practices have been proposed since the 1980s (Altieri, 1983). Some of them, like ploughing abandonment, may benefit soil organisms (Hole et al., 2005; Holland,

2004). According to several authors, switching from a conventional to an alternative system involves a transition period of several years, during which the system moves towards a new state of equilibrium (Dumanski et al., 1998; Tebrügge and Düring, 1999). For instance, West and Post (2002) showed that after a change from conventional tillage to no-till, 15–20 years were necessary for carbon sequestration rates to reach a new equilibrium.

Soil organisms can be influenced by evolving soil chemical, physical and biological properties. Among soil organisms, earthworms are recognized as indicators of soil quality and of the impacts of agricultural practices such as soil tillage and pesticide use (Cluzeau et al., 1987; Paoletti, 1999; Pelosi et al., 2013). Some alternative agricultural practices are known to increase earthworm

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abundance, biomass and taxonomic diversity (Fraser, 1994; Riley et al., 2008) e.g. cover cropping (Peigné et al., 2009), tillage abandonment (Hubbard et al., 1999), inclusion of legumes and temporary meadows in agricultural rotations (Schmidt and Curry, 2001; Schmidt et al., 2003; van Eekeren et al., 2008), decrease in pesticide use (Bengtsson et al., 2005; Pelosi et al., 2013). Some of these alternative practices, such as tillage abandonment, may result in a rapid response by earthworm communities (e.g. 2–5 years in grassland, according to van Eekeren et al. (2008) or Decaëns et al. (2011)). Unfortunately, most studies assess earthworm communities at one date, and do not study the trials or fields over time (but see Pelosi et al., 2015). Thus, there is a need to assess the dynamics of earthworm communities over a long period after changing agricultural practices, as this will enable the magnitude of any changes to be quantified. Many short-term responses can be atypical.

Taxonomic indices or functional groups defined *a priori*, such as eco-morphological groups of earthworm (Bouché, 1972) are commonly used to assess the impacts of anthropic activities on soil organisms (Bengtsson et al., 2005; Freemark, 1995). Although widespread and useful, some drawbacks are associated with such approaches. In taxonomic indices such as species richness, each species has an identical weight in the analysis. Otherwise, using *a priori* functional groups implies (i) discrete functional differences between taxa, which are usually continuous (Fonseca and Ganade, 2001; Gitay and Noble, 1997) and (ii) non-robust results that depend on the definition of the functional group (Wright et al., 2006). The functional trait-based approach is currently used to identify organisms' response to environmental disturbances (e.g. plant ecology) (Archaimbault et al., 2010; Garnier and Navas, 2012; Lavorel and Garnier, 2002; Violle et al., 2007). Functional traits are properties of individuals that govern their responses to their environment (Statzner et al., 2001; Violle et al., 2007). This approach deals with previously described drawbacks by drawing causal relationships between individual properties and environmental gradient (Pey et al., 2014). According to Díaz et al. (2007),

the functional diversity of communities is defined as the value, range and relative abundance of traits found in a given community. This approach is growingly used in soil ecology, and trait-based approaches have been suggested by several authors as relevant to reveal earthworm responses to environmental perturbations (Fournier et al., 2012) or the response of soil invertebrates to agricultural activities (Hedde et al., 2012; Pelosi et al., 2014; Pérès et al., 2011).

The aim of the present paper is to assess the dynamics of earthworm taxonomic and functional diversity in ploughed and no-tilled cropping systems. To do this, we worked on temporal data at three experimental sites to test two hypotheses: (i) that the transition from ploughing to no-till leads to increased diversity and (ii) that both taxonomic and functional diversity indices can indicate changes in tillage practice.

2. Materials and methods

2.1. Sites and cropping systems

Field data were collected on agricultural fields receiving different tillage (Table 1) at three different localities in France (Table 2). All the trials are arranged in a randomized complete block design. All the treatments were ploughed (moldboard ploughing) at 25–30 cm depth before the establishment of the trials. Climates are continental with an oceanic influence that was more or less marked depending on the site. Temperatures and precipitation for the years preceding the sampling are shown in Table 2. According to the FAO classification, soils were Cambisol on site I, Luvisol on site II, and Fluvisol on site III (Table 3a). Physico-chemical characteristics of the soils at 0–25 cm depth are shown in Table 3. Soils were silty or sandy, with water pH ranging from 6.0 to 8.3. Organic matter content and C/N ratio ranged from 16.6 to 37.3 g kg⁻¹ and from 8.6 to 11.0, respectively, depending on the site, and the system (Table 3b). They did not statistically vary with time in the different sites.

Table 1

Crop management, i.e. pesticide use, crop rotation, soil tillage, harrowing and fertilization, in the three agricultural sites. For the plot name, I, II or III refers to the site name, P or NT refers to ploughing or no-till, and 1 or 2 refers to the number of fields under this treatment. Scientific names for wheat, soybean, alfalfa, maize, rape, oat and rye are *Triticum aestivus*, *Glycine max*, *Medicago sativa*, *Zea mays*, *Brassica napus*, *Avena sativa* and *Secale cereal*, respectively.

Site name	Farming method	Pesticides	Crop rotation	Soil tillage	Name of machinery (for direct seeding)	Mean frequency (per year) and season for the harrowing	Fertilisation	Treatment name
I		Mineral	(Kerguehenec)		Conventional farming	Herbicides, fungicides, molluscicides (rarely)	Maize, wheat, rape, wheat	Ploughing (25–30 cm depth)
			I-P1			No	Organic: poultry manure	I-P2
			No insecticides	No-till	SD 3000, Khun		Mineral	I-NT1
						Organic: poultry manure	I-NT2	
II (Versailles)	Conventional farming	Herbicides, fungicides, molluscicides (rarely). No insecticides	Oilseed rape, wheat, pea, wheat	Ploughing (25–30 cm depth)		2, in autumn	Mineral	II-P
			Pea, wheat, maize, wheat	No-till	Semeato	No		
III (Thil)	Organic farming	No pesticides	Alfalfa, maize/oat, soybean, wheat/rye, soybean, wheat/alfalfa	Ploughing (25–30 cm depth)		1.5, at 5 cm depth, in spring or autumn, depending on the crop	Organic: pig bristles	III-P
				No-till	Amazon for cereals and Monosem for maize and soybean	1.8, at 5 cm depth, in autumn		III-NT

Table 2
Localization and climate in the three agricultural sites during the years preceding the samplings.

Site name	Localization	Time since trial set up	Minimal annual temperature (°C)	Maximal annual temperature (°C)	Mean annual precipitation (mm)
Site I: Kerguehenec	47°52'N, 02°46'W	1	-0.9	24.8	1111.0
		5	-1.7	23.7	731.0
		7	-1	25.8	993.0
Site II: Versailles	48°48'N, 2°08'E	8	-9.1	33.0	506.0
		9	-7.3	36.1	533.6
		10	-19.9	32.1	738.9
		14	-9.7	35.6	547.0
Site III: Thil	45°49'N, 5°20'E	1	-4.1	29.7	809.4
		2	-4.0	30.3	710.8
		3	-3.7	30.3	646.0
		4	-5.1	27.1	912.3
		5	-5.1	27.1	971.1
		6	-4.8	29.7	665.4

Sites compared different treatments involving two different types of tillage: ploughing or no-till. In all sites ploughing (moldboard ploughing) involved soil inversion to 25–30 cm depth and use of a combined drill. No-till involved mechanical disturbance in the top 3 cm, without soil inversion, on the whole area in sites I and III and limited to the sowing line in site II. Crop management i.e. pesticide use, crop rotation, soil tillage, harrowing and fertilization, in the three agricultural sites are presented in Table 1.

2.2. Earthworm sampling methods

Details of earthworm sampling at each site are given in Table 4. All studies were carried out during autumn (November) or early spring (March–April), when most earthworm species are particularly active (Bouché, 1972). In a given site, samples were taken at the same time (in spring or autumn). Samplings were mostly done on winter wheat (*Triticum aestivum*) crops, but some were done on soybean (*Glycine max*) and maize (*Zea mays*) residues or wheat/alfalfa (*Medicago sativa*) crop associations (site III). At all sites, the sampling method combined chemical extraction and hand-sorting (Table 4). Sampling was done from 1995 to 2011, i.e. 1–10 years since the trial's establishment, depending on the site. Sampling points were randomly chosen in the fields, at a minimum distance of 10 m from each other and from the field edge.

2.3. Calculation of functional trait profiles

Because direct measurements of biological and ecological processes such as growth, reproduction, and competitive ability are often impractical, we focused on easily-measured or well-known features that may act as surrogates for such processes. Nine traits were selected for their perceived relevance to tillage effect, five being morphological (i.e. body length, epithelium type, cocoon length, pigmentation, and body wall thickness), three being ecological (i.e. carbon requirement, habitat and microhabitat), and one being behavioral (i.e. vertical distribution within soil). Body length, epithelium type, cocoon length, and body wall thickness were selected because it is often claimed that the largest and the most fragile organisms may be most affected by intensive tillage (Boström, 1995; Chan, 2001). We made the assumption that apigmented species are more eaten by predators during soil inversion. We used carbon requirements given in Bouché (1972) for testing earthworm preference for higher concentrations in soil carbon in unploughed treatments. We assumed that the number and type of habitats (i.e. arable, cave, costal wetland, forest, grassland, inland wetland, no vegetation, shrub/heatland, urban green areas) or microhabitats (i.e. faeces, herb, litter, mineral surfaces, moss, under rock, soil, decaying trunk) in which an earthworm can potentially be found (i.e. habitat plasticity) is indicative of its adaptability to live in disturbed habitats (for

Table 3
Soil characteristics (0–25 cm depth) at the three agricultural sites: (a) soil type, texture, water pH, calcium carbonate (CaCO₃) and cation exchange capacity (CEC) at the beginning of the trial establishment and (b) mean of organic matter and C/N ratio since the trial establishment. For the plot name, I, II or III refers to the site name and P or NT refers to ploughing or no-till.

(a)							
Site name	Soil type (FAO classification)	Sand (g kg ⁻¹)	Silt (g kg ⁻¹)	Clay (g kg ⁻¹)	Water pH	CaCO ₃ (g kg ⁻¹)	CEC
Site I: Kerguehenec	Cambisol	411	423	166	6.0	<1	9.6
Site II: Versailles	Luvisol	271	562	167	7.4	<1	9.4
Site III: Thil	Fluvisol	580	270	150	8.3	221	6.1
(b)							
Site name	Soil tillage	Organic matter (g kg ⁻¹)				C/N ratio	
Site I: Kerguehenec	P	36.7				10.7	
	NT	37.1				10.9	
Site II: Versailles	P	17.4				10.6	
	NT	16.6				10.2	
Site IV: Thil	P	18.1				8.6	
	NT	19.2				8.6	

Table 4
Earthworm sampling methods and size of the fields in the three agricultural sites. AITC means allyl isothiocyanate.

Site name	I (Kerguehenec)	II (Versailles)	III (Thil)
Sampling period	Spring	Autumn	Autumn/spring (2007, 09 and 10)
Sampling method	Formalin, hand-sorting	AITC, hand-sorting	Formalin, hand-sorting
Reference for the method	Cluzeau et al. (1999)	Pelosi et al. (2009)	Peigné et al. (2009)
Size of sampling unit (m ²)	1	0.16	1
Size of the sampled fields (m ²)	300	5000	960
Number of replicates per treatment	1 for years 1, 5 and 3 for year 7	2	3 for years 1, 2, 5 and 2 for years 3, 4, 6
Number of sampling points per replicate	3	5	1 for years 1, 2, 5 and 2 for years 3, 4, 6

instance, a high capability to colonize soil after physical perturbations (Caro et al., 2013; Eijsackers, 2011). Finally, earthworm species' vertical distribution may affect the response of species since the more an individual lives in the ploughed layer, the more it may suffer from ploughing. Morphological and ecological traits were obtained from Bouché (1972), Sims and Gerard (1999) and Csuzdi and Zicsi (2003). The latter reference was used only for morphological traits. Habitat and microhabitats were determined using the three cited books. Bouché (1972) gave soil organic carbon values for each earthworm sampling point. We estimated the carbon requirements of species according to their frequency distribution on the soil organic carbon gradient. Earthworm vertical distribution was based on the authors' expertise and literature data (Gerard, 1967; Lavelle, 1998; Rundgren, 1975). Given the heterogeneity of data, we homogenized trait information by the fuzzy coding method to describe the affinity of a species for different trait classes (Chevenet et al., 1994). We followed the procedure described by Hedde et al. (2012). Briefly, information on each trait was coded by an affinity score ranging from 0 to 3 for each trait class, and affinities were summed to build the trait profile (e.g. the distribution of affinities within classes). Trait profiles were standardized so that their sum for a given taxon and a given trait equaled 100%. The list of functional traits for the different species is presented in Appendix 1.

2.4. Community parameters and associated statistical analyses

We assessed taxonomic and functional diversity of earthworm communities for each individual field. Taxonomic diversity was estimated by the species richness (i.e. the number of identified species), the Shannon–Wiener index and the Pielou's evenness index. The Shannon–Wiener index was calculated as follows (Lacoste and Salanon, 2005):

$$H' = - \sum_{i=1}^S p_i \log_2 p_i$$

where $p_i = n_i/N$ is the proportional abundance of each species, and S is the total number of species. The Shannon–Wiener index is commonly used to characterize species diversity in a community since it accounts for both abundance and dominance of species. It can vary from 0.5 (low diversity) to 5 (high diversity) (Lacoste and Salanon, 2005). The Pielou's evenness index was calculated as follows (Lacoste and Salanon, 2005):

$J' = H'/H'_{\max}$, where H'_{\max} is the \log_2 of S . This index can range from 0 to 1; it is minimum when a large proportion of the total community is represented by a small number of species.

Functional diversity was estimated by the functional richness (FRic), evenness (FEve), and divergence (FDiv) (Villéger et al., 2008). All these indices were calculated from a multi-dimensional

functional space computed from the matrix of trait data (Gerisch et al., 2012; Mouchet et al., 2010; Mouillot et al., 2011; Pakeman, 2011; Schleuter et al., 2010). Functional richness expresses the functional space filled by the community. It corresponds to the smallest volume which includes all the species of a community in the functional space. Functional richness increases when the species on the boundaries of the functional volume become distant from each other. Functional evenness describes the evenness of abundance distribution in the functional space. It is based on the smallest path to link all the species in the functional space (minimum spanning tree), weighted by species abundances. For instance, provided that species number and proportions of species abundances remain stable, functional evenness increases when the minimum spanning tree increases, i.e. species are better distributed in the functional space. Finally, functional divergence describes how species abundance is spread compared with the center of gravity of the functional volume. Briefly, the mean distance of species positions to the center of gravity in the functional space was calculated. Then, the difference between each species position and the mean distance are computed and weighted by species abundance. For instance, provided that the volume, the species number and the proportions of species abundances remain stable, functional divergence increases when some species become more distant from the center of gravity.

Standardized mean difference (Cohen's d) effect sizes were calculated based on average differences between earthworm diversity under no-till and ploughing (Cohen, 1988). Cohen's d allows correcting for small sample size bias and difference in number of replicates for each individual study. Cohen's d effect size was calculated for all the six diversity indices, for each site, each year after the trial establishment, and represented on a graph. For this, we collected the number of replicates, the mean and the standard deviation characterizing each community.

All statistical analyses were performed with the R statistical software (R Development Core Team, 2011). The species richness, the Shannon–Wiener index and the Pielou's evenness index were computed using the “vegan” package and FRic, FEve and FDiv were computed using the “FD” package (Laliberté et al., 2014). Differences in diversity indices between tillage types and years at each site were tested using parametric (t -test or ANOVA followed by a Tukey test) or non-parametric tests (Wilcoxon Mann–Whitney or Kruskal–Wallis followed by a non-parametric Kruskal–Wallis post hoc test using the “pgirmess” package) when the normality and the homoscedasticity of variance were violated.

3. Results

Thirteen species were found in the three agricultural sites: *Lumbricus castaneus* (Savigny, 1826), *Lumbricus rubellus*

(Hoffmeister, 1843), *Satchellius mammalis* (Savigny, 1826), *Lumbricus terrestris* (Linné, 1758), *Aporrectodea nocturna* (Evans, 1946), *Aporrectodea longa* (Ude, 1885), *Aporrectodea giardi* (Ribaucourt, 1901), *Aporrectodea icterica* (Savigny, 1826), *Aporrectodea caliginosa* (Savigny, 1826), *Aporrectodea rosea* (Savigny, 1826), *Allolobophora chlorotica* (green morph) (Savigny, 1826), *Proctodrilus antipai* (Michaelsen, 1891) and *Octolasion cyaneum* (Savigny, 1826). As experimental sites were in different locations in France, they hosted different species of earthworms, although the dominant species were almost the same in the three trials. In site I, dominant species densities were *A. caliginosa* and *A. icterica* in ploughed fields and *A. caliginosa*, *A. icterica* and *L. terrestris* in no-till. In site II, they were *A. caliginosa* and *A. chlorotica* in ploughed fields and *A. caliginosa*, *L. terrestris* and *A. giardi* in no-tilled fields. Finally, in site III, *A. nocturna*, *A. caliginosa* and then *L. castaneus* and *L. terrestris* were mostly found in the no-tilled fields. In ploughed fields, *A. nocturna* and *A. caliginosa* and then *L. castaneus* and *A. icterica* were the dominant species.

3.1. Effects of tillage on earthworm diversity

We generally found a neutral or positive effect of the no-till on taxonomic and functional indices, depending on the site (Fig. 1). The majority of the points were indeed close to zero (no effect of tillage), or within the upper part of the graphs (positive effect of the no-till). In site II, the effects were mostly neutral. In sites I and III, the effects were more variable. Some points showed a negative effect of the no-till but these effects are low, between 0 and -1 , and even mostly between 0 and -0.5 (Fig. 1). Contrarily, the positive effects were generally stronger, up to 3, especially for taxonomic indices. Overall, taxonomic indices highlighted more important differences between the different tillage than functional indices.

3.2. Dynamics of the effects of tillage on earthworm diversity

The temporal pattern of the response of earthworm diversity to a modification in tillage was different between experimental sites. In site II that compared systems aged of at least 8 years, there was no effect of the no-till over time, either for taxonomic or functional indices. In sites I and III, where the dynamics had been studied since the first year after the ploughing abandonment, we observed a positive effect on the species richness and the functional richness (except for functional richness for I-P1/I-DS1) after only one year but this effect then disappeared (Fig. 1A and D). Overall transient positive effects were then observed, except in site I at 5 years (I-P2/I-DS2) and in site III at 6 years where it was a transitory negative effect (Fig. 1A and D). In site I, for all the indices, we found a positive or negative effect that was maximum at 5 years. In site III, considering all the indices, we generally observed an increase in taxonomic indices between 3 and 5 years, followed by a decrease at 6 years. The functional indices displayed lower variations over time than taxonomic indices. For instance, in site III, taxonomic indices increased from year 2 to 5 in no tilled compared to ploughed fields whereas functional diversity indices present no difference and even decrease at the same period in no tilled fields (Fig. 1). So, once again, more marked differences were found for taxonomic than for functional indices.

4. Discussion

The positive or neutral effect of ploughing abandonment over time on earthworm diversity found in this study had already been reported (Boström, 1995; Chan, 2001; Holland, 2004; Pelosi et al., 2009, 2014) but not concerning earthworm taxonomic and functional diversity simultaneously. Contrarily to our first

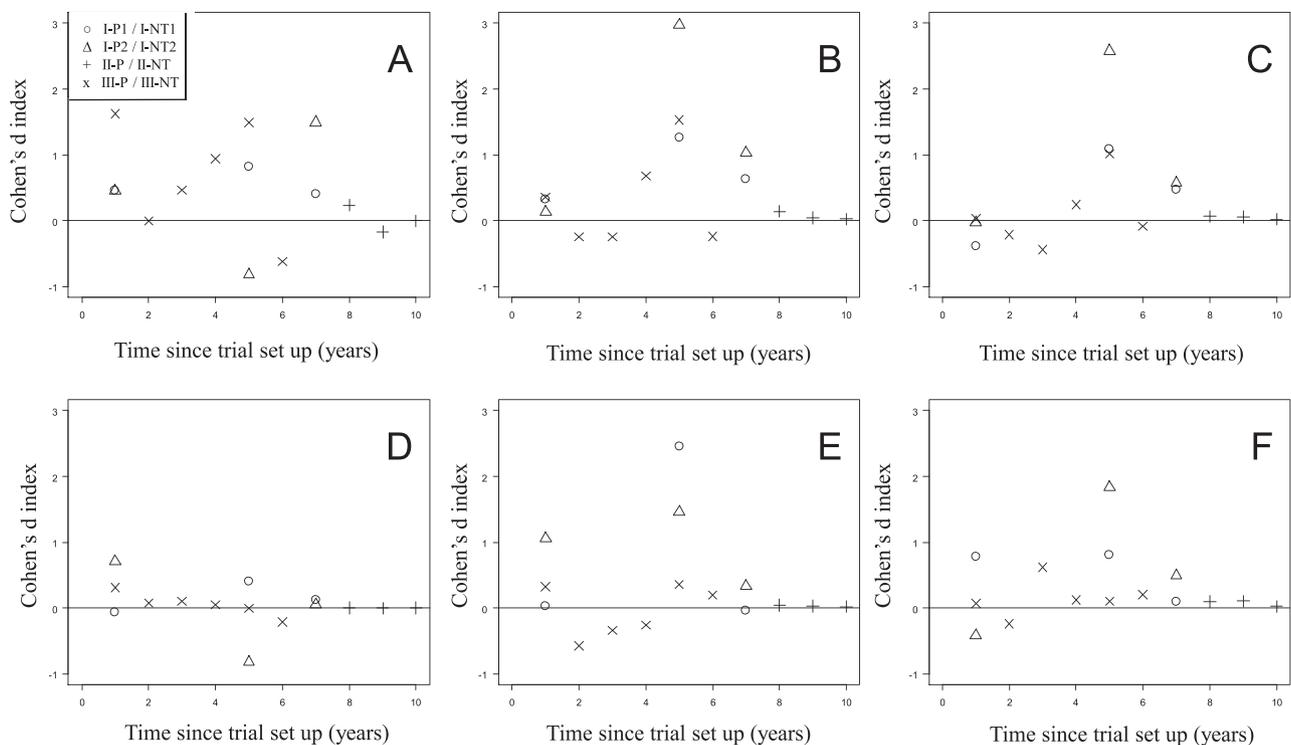


Fig. 1. Dynamics of effect size (Cohen's d index) of soil tillage (no-till vs ploughing) on six indices of the diversity of earthworm communities. Taxonomic diversity indices are represented in A: Species richness (S); B: Shannon–Wiener diversity index (H'); C: Pielou's evenness index (J'). Functional diversity indices are represented in D: Functional richness (FRic); E: Functional evenness (FEve); F: Functional divergence (FDiv). I, II or III refers to the site name, P or DS refers to ploughing or no-till, and 1 or 2 refers to the number of fields under this treatment.

assumption i.e. that both types of diversity indices would increase with time due to conservation practices, we observed transient positive or negative effects in the youngest experimental sites. The experimental site II did not reveal any difference of diversity between the two types of tillage whatever the year of sampling. However, the effects on taxonomic and functional diversity in sites I and III appeared more marked than in site II, with for instance positive effect of no-till compared with ploughing in site III during the first 5 years, although negative effects were also shown in year 6. Thus, no clear continuous increase of taxonomic and functional diversity was found in no-tilled fields, but positive and negative effects according to years. In site I, this variability could be partly due to the quality of the organic matter i.e. poultry manure, which is yearly used in the fields receiving organic fertilizers. In the fields with mineral fertilization, the variability was less important. In site III, the assumption to explain negative effects of no-till could be the harrowing frequency that was on average higher in no-tilled than in ploughed fields. Given that the trial was under organic farming, mechanical weeding was required to control the weeds. Chan (2001) reported a potential negative effect of harrowing on earthworms but, according to Eriksen-Hamel et al. (2009), harrowing “fragment and incorporate crop residues in the soil profile, which may speed residue decomposition”, promoting earthworm growth. Thus, although the studied systems varied mainly according to tillage and while functional traits were selected so that they had a link with a modification in tillage, other management like fertilization or crop rotations may influence the response of earthworm communities to decreasing tillage intensity. Moreover, the observed differences between sites may be due to the different agricultural practices, soils and climates.

Regarding our second assumption, taxonomic and functional diversity indices did not indicate changes in tillage in every site and year. This study highlighted a quite stable absence of effect of tillage abandonment on diversity indices over time in site II. However, variations with time were observed in sites I and III, particularly for taxonomic indices. In both sites, a maximum was attained 5 years after the trial establishment for the Shannon–Wiener index, the Pielou’s evenness index, the functional evenness, and the functional divergence which then decreased. Earthworm taxonomic diversity was reported by some authors to evolve during the transition from ploughing to no-till (Chan, 2001; Tebbrügge and Düring, 1999). However, these indices may also stay constant (Pelosi et al., 2009) because of compensation between species for instance i.e. some species appear while others disappear. The changing pattern of earthworm species assemblages following a switch from one management system to another has already been described by Decaëns et al. (2011). The consequence may be stagnation or even a decrease of taxonomic and functional diversity.

Consideration of taxonomic and functional indices allows us to infer some mechanisms of species assemblage and interactions. Since species’ functional traits can be regarded as links between diversity and ecosystem functioning, trait-based indices also complement taxonomical measures of diversity by providing indirect information on soil ecological functioning (Pey et al., 2014). We found that the taxonomic structure of communities (assessed by species richness and H indices) changed with time, while little if any modifications of functional structure were noticed. For instance, taxonomic indices such as species richness and H' indices increased continually from year 2 to year 5 in no tilled compared to ploughed fields in site III whereas, on the opposite, functional diversity indices presented no difference and even decrease at the same period in no tilled fields. This may signify that when species are added to a community, they are placed inside the functional volume (few change in $FRic$) and without changes in species abundance distribution in the

functional space (few change in $FDiv$ and $FEve$). So considering the studied traits combination, species that were added to already present communities are functionally redundant. Moreover, the fact that modification of the Pielou’s evenness did not influence functional indices reveals compensation between functionally similar species. Such results reveal limited habitat species pools: the pressures linked to the agricultural land use and management limit the habitat species pool (Belyea and Lancaster, 1999). Thus, the species that settle in the fields have a trait combination that is not different from that of already present species. Also, interactions between organisms (and with the environment) probably led to changes in species dominance, but without altering abundance distribution in the functional trait space. Thus, while the functional indices tended to remain stable between no-tilled and ploughed fields, we observed an overall positive effect of ploughing abandonment on taxonomic indices, involving an increase in functional redundancy that would permit a higher resistance of earthworm communities to additional disturbance (Díaz and Cabido, 2001).

This study also highlighted that long-term trials are needed to assess the effects of cropping systems on soil biodiversity since the observed effects may be transitory. In site II, ploughed and no-tilled fields were compared for at least 8 years after trial establishment while in the other two sites, the last sampling was done at most 7 years after the trial establishment. Thus long-term monitoring is needed before conclusions can be drawn. Chemical, physical and biological changes due to agricultural practices may affect earthworm communities over various timescales, from short-term (e.g. a sudden physical, deleterious disturbance) to long-term (e.g. a change in the location, quantity and nature of resources). We conclude that it could be preferable to determine temporal patterns of community change rather than comparing different systems at a fixed point in time. The importance of long-term trials to study the effects of alternative cropping systems on biodiversity was also emphasized by Tebrügge and Düring (1999) and Irmiler (2010) who deplores the fact that most studies are restricted to short investigation periods.

5. Conclusions

To limit harmful effects of conventional agriculture, no-tilled practices are more and more promoted especially for soil preservation. The aim of this study was to assess the dynamics of the diversity of earthworm communities in ploughed and no-tilled soils. We found no clear continuous increase of diversity with time due to no-tilled practices in every experimental site. Temporal pattern of the response of earthworm diversity to a modification in soil tillage was different between experimental sites, being more marked in youngest sites. In these sites, a transitory positive or negative effect was observed, with maximum differences 5 years after the trial establishment. In the site aged 8–10 years, there was no diversity difference between tillage practices over time; earthworm diversity tends to be stabilized after several years of no-tilled practices. In youngest sites, changes in ploughing practices influenced taxonomic diversity while a lower influence on functional diversity indices was observed. The information provided by both categories of indices may indicate a redundant functional profile of the earthworm species within the studied communities in no-tilled fields: more earthworms’ species but equal and even less functional diversity. In conclusion, this study revealed that the beneficial effect of the tillage abandonment could be transitory, highlighting the importance of long-term trials and different sampling times to assess the effects of cropping systems on soil biodiversity. Taxonomic and functional diversity indices are complementary to reveal effects of a modification in agricultural practices or cropping systems on earthworm community.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.still.2015.07.016>.

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