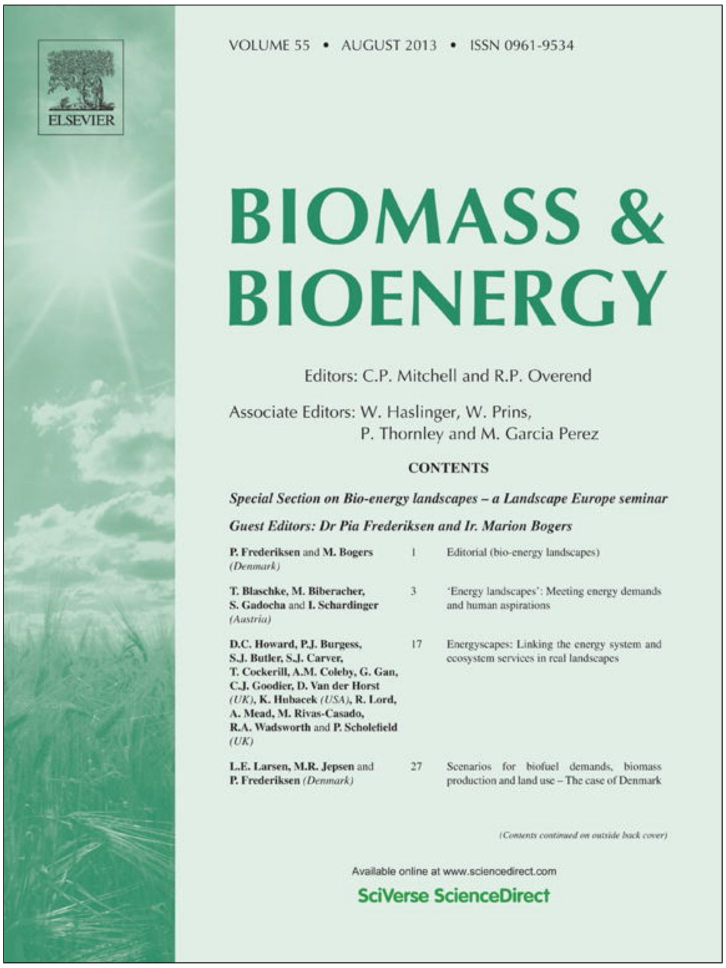
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Responses of soil macroinvertebrate communities to Miscanthus cropping in different trace metal contaminated soils

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ABSTRACT

Nowadays, the influence of biomass plantations in polluted soils as a remediation strategy has mainly been considered in the view of phytoextraction, but little of soil biodiversity. Our objective was to assess the impact of *Miscanthus* × *giganteus* plantations on soil macroinvertebrates in trace metal contaminated soils. We hypothesized (1) that miscanthus plantations host more numerous and diverse communities than comparable annual crop soils and (2) that functional traits permit to decrypt the biological strategies underlying invertebrate community response. We selected fields on sandy and loamy-clay soils contaminated either by urban wastewater or atmospheric deposition, respectively. Our results showed that in comparison to annual cropping systems, miscanthus plantation enhanced higher densities and diversity of soil invertebrates but not of ground-dwelling invertebrates. Miscanthus cropping led to an increase in the proportion of resident, detritivores and rhizophages species, and a trend was revealed for larger invertebrates. Thus, the use of a trait-based approach provided fine opportunities to elucidate invertebrate responses to land use changes in contaminated areas.

1. Introduction

Plants with high biomass are increasingly cultivated in the world for energy or biotechnology. Their impacts on soil have been mainly addressed with regard to the input of carbon in soil, the cycle of nitrogen and other nutrients, and the role of the root system in plant nutrition [1–3]. Yet, contaminated agricultural soils are still potentially cultivable for non-food items, provided that cultivation does not favor an increased damage of micro-contaminants to different compartments of ecosystems. Nowadays, the role of biomass crops in trace metal polluted soils was mainly considered from a perspective of phytoextraction, with short-term coppices (willow or poplar) [4]. Only recently, the impacts of biomass crops on soil biodiversity were questioned [5,6]. The establishment of perenial biomass plantations modifies life conditions of soil biota *via* the absence of tillage, the reduced (if any) use of pesticide and the development of a litter layer at the soil's surface [5,6].

Currently, soil biodiversity is mainly evaluated through indicators related to its structural and compositional dimensions [7]. Although useful, such indicators do not satisfactorily inform on the mechanisms by which biota responds to environmental stress. Moreover, due to confounding factors, the validity of results may be limited or misinterpreted. The use of functional traits of soil organisms can improve our understanding of soil biota response to environmental stress [8].

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Functional traits of species are variously defined but essentially concern characteristics that affect individual fitness of animals and govern their impacts and responses to their environment [9]. Functional traits permit to define causal relationships between environmental stress and response of biota.

The objective of the present work was to assess the impact of a biomass crop, *Miscanthus* × *giganteus*, on invertebrate communities in contaminated agricultural soils. We hypothesized that perennial, miscanthus growing on soils polluted with trace metals hosted more numerous and diverse invertebrate communities in comparison to annual cropping on such polluted soils. In addition, we postulated that invertebrate functional traits are useful tools to disentangle the complex responses of organisms. For this, we selected two agricultural counties, offering contrasting soil textures (sandy vs clayey silt) and a different origin of trace metal pollution (airborne metal deposition vs waste-water irrigation), in order to examine the generic applicability of the functional trait approach.

2. Material and methods

2.1. Contaminated agrosystems

We selected cultivated agricultural fields on sandy soils in the Paris region or on loamy-clay textured soils in northern France. Both agricultural lands are representative of different ways of metal pollution dissemination. All selected fields were located in large agricultural counties with fairly high landscape homogeneity, in order to diminish differences in invertebrate recolonization sources and dynamics between sampling sites. In both agricultural lands, we compared biomass plantations and annual crops. At the time of the sampling, all biomass plantations were 3-yrs old *Miscanthus* × *giganteus* (hereafter referred to as miscanthus) crops; annual crops were wheat. In northern France, silt to clayey silt textured agricultural soils, mainly Cambisols, under two biomass plantations (called thereafter Misc1 and Misc2) and an annual crop were selected, located in the vicinity of the former Metaleurop Nord metal smelter (50°25′ N; 2°49′ E). The Metaleurop Nord plant was the only producer of primary lead in France and one of the largest in Europe [10]. After more than a century of pyro-metallurgical activity, which generated large quantities of atmospheric metal dust (AD), the smelter closed in 2003. Various loads of airborne metal deposition have been incorporated in soils, hereafter referred to as AD-soils. In this agricultural land, contamination in the surface layer was shown to reach levels as high as 1132 mg kg^{-1} of Pb, 21 mg kg^{-1} of Cd and 2167 mg kg^{-1} of Zn [10].

In the Paris region, a biomass plantation and an annual crop were selected at Pierrelaye (49°01′ N; 2°10′ E), in a 12 km^2 agricultural land area used for more than one century for spreading of raw wastewater of the Paris urban center. As a result of such massive urban wastewater (UW) irrigation, the surface horizons of theses soils accumulated large amounts of organic matter, dissolved salts (carbonates, phosphates) and metal pollutants (mainly Zn, Pb, Cu, and Cd) [11,12]. These soils, hereafter referred to as UW-soils are mainly Orthic and Albic Luvisols [13]. They are sandy textured in the A and E horizons, and sandy-clay textured in the Bt horizon [12]. In UW-soils, large values of soil metal contents were recorded, up to about 1.3 g Zn kg^{-1}, 750 mg Pb kg^{-1}, 350 mg Cu kg^{-1} and 13 mg Cd kg^{-1}.

2.2. Soil sampling and analyses

In all fields, four sampling sites of 0.5 m^2, distant by 10 m were designed along a transect of 30 m. At the corners of each sampling site, 0–10 cm soil cores were taken using a stainless steel auger and pooled for analyses. We determined granulometry [14], pH [15], phosphorus [16], total organic C and N [17] and total Fe, Ca, Zn, Pb, Cu, and Cd concentrations with inductively coupled plasma mass spectroscopy performed after tri-acid HF–HCl–HNO_3 digestion [18]. All soils analyses were made by the 'Laboratoire d'Analyse des Sols' (INRA, Arras, France) applying standardized methods and quality assurance procedures. Selected physicochemical soil characteristics are presented in Table 1. Soil texture, an intrinsic characteristic of the parent material of the soils showed little variation within each agricultural land. Soil pH was varied from 7.7 to 8.3 for AD-soils but was 7.6 for UW-soils. Absence of pH variation for UW-soils was ascribed to the buffering action of large amounts of organic matter of urban origin, in spite of the presence of secondary carbonates added by wastewater irrigation. By contrast, the soil organic C content was clearly different between the two agricultural lands, and illustrated the different origin of metal contamination, i.e. wastewater irrigation vs atmospheric deposition, with values in UW-soils being 2–3-fold higher (>50 g kg^{-1}) than in AD-soils (17–25 g kg^{-1}). The C/N ratio presented a similar trend displaying 2-fold higher values in UW-soils.

Within each agricultural land, the soils showed only little differences in total metal concentrations but large differences were recorded between UW and AD soils, except for Cr and Cd. Concentrations in Zn, Pb, Cu, Co and Ni were higher in UW than in AD soils. Except for data on soil texture, all other selected physicochemical parameters presented in Table 1 are strongly dependent on the origin of trace metal dissemination.

Table 1 – Selected physicochemical characteristics of the 5 studied soil samples in the two agricultural areas (0–30 cm).

Area	Crop	Clay	Sand	Corg	N tot	C/N	pH	Ca	Fe	P_2O_5	Cr	Cu	Ni	Zn	Co	Pb	Cd
		g kg^{-1}						g kg^{-1}			mg kg^{-1}						
MetalEurop	Wheat	207	255	17	1.4	12	7.7	6.2	21.4	1.7	66	20	20	333	9	212	5
(AD-soils)	Miscanthus1	230	274	17	1.3	13	8.1	7.1	23.9	1.5	66	20	22	326	10	201	4
	Miscanthus2	250	50	25	1.7	15	8.3	24.3	21.1	1.7	66	19	32	129	9	62	1
Pierrelaye	Wheat	94	781	53	2.2	25	7.6	17.2	15.6	4.5	69	201	39	590	14	376	3
(UW-soils)	Miscanthus	99	761	51	2.1	24	7.6	21.2	15.2	4.5	72	184	46	578	12	369	2

2.3. Invertebrate sampling

In the first two weeks of April 2010, two invertebrate habitats were sampled by a combination of standard methods in each agricultural land on the center of the 0.5 m^2 sampling sites. Ground-dwelling macroinvertebrates, such as carabid beetles or much of spiders, were sampled using pitfall traps. The traps were made from 7-cm diameter plastic cups, inserted into the soil with their top flushing the soil's surface. They were sheltered from rain by plastic cup lids over the traps using support sticks, raised to about 2 cm above the soil. The traps were partly filled with vinegar used as a preservative medium. Traps were left for 1 week and the collected contents preserved in ethanol (70°) for ulterior identification. On the same sampling sites, soil-dwelling macroinvertebrates were hand sorted from a 25 × 25 × 20 cm monolith of soil. Yet, since preliminary work highlighted a very low abundance of invertebrates in UW soils [8], sampling volumes on this site were enlarged to 50 × 50 × 20 cm.

At laboratory, we aimed at identifying invertebrates at least to the family level. In addition, earthworms, woodlice, centipedes, ground beetles (Carabidae), scarab beetles (Scarabaeidae), clown beetles (Histeridae) were identified to the species level according to [19–24]. Spiders were identified at genus level except for Linyphiidae, Theridiidae and some Gnaphosidae [25]. Larvae were attributed to morphological groups, i.e. campodeiform, elateriform and melolonthoïd larvae. Other invertebrates were determined as precisely as possible. We used [26] as standard for invertebrate taxonomy.

2.4. Descriptive variables of invertebrate communities

We calculated three indices of invertebrate community structure. The density of soil-dwelling invertebrates, expressed as individuals per m^{-2}, was obtained by weighting observed abundance per sampling surface. The activity of invertebrate at the soil's surface, expressed as individuals per trap, corresponded to the number of ground-dwelling individuals collected by traps. The number of identified taxonomic units (OTU) per sample was calculated as a measure of community diversity for soil- and ground-dwelling datasets [8]. Otherwise, special attention was given to earthworms and carabid beetles since these taxa are currently used as bioindicators [27,28].

Table 2 lists hypothesized mechanisms by which the main driving factors, i.e. the soil pollution, the phenology and growth of miscanthus and the agricultural practices, would impact distribution of functional traits within invertebrate communities. The null hypothesis corresponded to no differences occurring between annual crops and miscanthus plantation, it means that soil pollution masked any impact of modification of land use. We focused on three functional traits: body size, food and dispersal ability. We examined four

Table 2 – Proposed causal relationships between driving factors, mechanisms of changes under miscanthus plantation and modification of proportion of functional trait attributes.

Driving factors	Mechanisms in annual crops	Changes under Miscanthus		Category impacted	Functional trait
Agricultural practices (plant residue management)	Shredding and burying plant residue into the soil	Leaf litter accumulates at soil' surface → creation of a new habitat	+	Apterous (resident)	Wing morphology
Agricultural practices (tillage)	Physical stress on soil invertebrates (soil is maintained in a 'pionneer stage')	No till	+		
Agricultural practices (pesticide use)	Chemical stress on targeted & non-targeted invertebrates	Reduced chemical stress	+		
Trace metal contamination	Metal contamination affects life history parameters of organisms	No expected changes	–		
Agricultural practices (tillage)	Direct, deleterious effects on large anim;	No till	+	(Intermediate to) large	Body size
Trace metal contamination	Metal contamination affects life history parameters of organisms	No expected changes	–		
Miscanthus phenology and growth	Rootstock development of Miscanthus	Increase of trophic resource for root-eating organisms	+	Rhizophagous	Food
Miscanthus phenology and growth	Shredding and burying plant residue into the soil	Increase of topsoil SOM content → trophic resource for detritivores	+	Saprophagous	
Agricultural practices (pesticides use)	Pesticides negative effects on targeted invertebrates	Reduced chemical stress	+	Phytophagous	
Agricultural practices (tillage)	Soil organic matter (SOM) mineralisatior	Increase of topsoil SOM content → trophic resource for detritivores	+	Geophagous	
Trace metal contamination	Metal contamination affects life history parameters of organisms	No expected changes	–	Geophagous	

possible scenarios when changing land use from annual crop to perennial, miscanthus plantation: (i) a shift from small-body dominated to large-body dominated invertebrate communities, (ii) an increase in the proportion of soil- and litter-eating invertebrates, (iii) an increase in the proportion of resident invertebrates, (iv) an increase in the proportion of root-feeding invertebrates. Food was divided in 8 attributes (animal feeding on soil, plant detritus, feces, dead animals, living animals, aerial plant material, roots or fungi), body size in 4 attributes (<5 mm, 5–10 mm, 10–20 mm and >20 mm) and wing morphology in 3 attributes (apterous = wingless invertebrates; brachypterous = invertebrates with reduced or unfunctional wings; macropterous = invertebrates with fully functional wings).

Information on functional traits derived from about 130 sources from West-European studies, giving access to the fundamental trait profile of each taxa (cf. the list of references in Supplementary Material). Information was pursued, as possible, at the most precise taxonomic resolution. All information was stored in a database called "Biological & Ecological functional Traits of Soil Invertebrates" (BETSI). For analysis of this abundant information, qualitative, semiquantitative or quantitative data were implemented in a single numerical format by fuzzy coding [29]. Each variable was expressed in different attributes, and the affinity of each taxon to each attribute was indicated using scores. To give the same weight to each taxon and each biological trait in further analyses, affinity scores were standardized so that their sum for a given taxon and a given trait equals one (or 100%). Note that a trait score 'zero' for all attributes of a trait signifies that information was currently unavailable. In such a case, taxa took the mean trait profile of all other taxa in subsequent trait analyses (i.e. such a taxon did not contribute to potential patterns of that given trait). We thus obtained a dataset of 86 taxa × 15 attributes, with a global filling rate about 95% (cf. Table 1 of Supplementary Material). We also calculated the relative abundance dataset by pooling hand sorted and trapped invertebrate datasets. We obtained a dataset including 86 columns (taxa) and 20 rows (sampling points). Finally, we calculated the community weighted mean (CWM) for each attribute, as the sum of species affinity for a trait attribute weighted by species relative abundance (log transformed) in the community [9].

2.5. *Statistical analysis*

Differences in calculated indices for miscanthus plantation and respective annual crop were tested using Student's *t*-test. All statistical analyses were performed at the significant level of $\alpha = 0.05$. Indices computing, statistical analyses and figures were made with 'vegan' and 'FD' libraries for R Software [30].

3. Results and discussion

3.1. *Structure and diversity of invertebrate communities*

A total of 959 individuals have been collected, 562 by pitfall trapping (376 in AD sites and 186 in UW sites) and 397 by hand sorting (256 in AD sites and 141 in UW sites). In average, about 65% of trapped invertebrates belonged to three taxonomic groups, i.e. Araneae, Carabidae and Staphylinidae (respectively 28%, 21% and 20% in AD-soils and 36%, 16% and 8% in UW-soils). Similarly, three groups represented about 70% of hand sorted invertebrates, i.e. Lumbricidae, Myriapoda and insect larva (respectively 21%, 19% and 27% in AD-soils and 2%, 12% and 69% in UW-soils).

3.2. *Density of soil macroinvertebrates*

The density of soil-dwelling macroinvertebrates was significantly higher under miscanthus plantation than under wheat cropping, for both agricultural lands (Fig. 1-A). In AD-soils, densities were 3-fold higher, with median values of 432 (Misc1), 512 (Misc2) and 144 individuals per m^{-2} (wheat). In UW-soils, beneficial effects of miscanthus cropping were greater, with a median value 7-fold higher (84 vs 12 individuals per m^{-2}, respectively). No statistical differences in earthworm and woodlouse densities were found in UW-soils, and very low densities were recorded (<4 individuals per m^{-2}). At the contrary, miscanthus plantation in AD-soils hosted higher densities of earthworms and woodlice when comparing to AD-soils under annual cropping (70–32 and 16–0 individuals per m^{-2}, respectively). The taxonomic diversity (OTU) identified within soil-dwelling macroinvertebrates was significantly higher under miscanthus plantation, for both agricultural lands (Fig. 1-B). The number of OTU was 3.0 and 2.4 fold higher in AD-soils and 2.6 fold higher in UW-soils. The number of earthworm species recorded in AD and UW-soils varied from 5 to 1, respectively. Local earthworm species richness was low, 0–0.8 species per point in UW-soils (annual and miscanthus crop respectively) and 0.8–2 species per point in AD-soils. No differences were found in earthworm diversity in soils under miscanthus or annual cropping.

Miscanthus plantation enhanced by 3–7-fold the density of soil-dwelling macroinvertebrates when comparing to annual cropping in both agricultural lands. However, in UW-soils, densities observed under miscanthus plantation were still low, a 2-fold smaller than values recorded in the forest soils of Pierrelaye agricultural land (~250 individuals per m^{-2}; Hedde, personal communication). Impacts of miscanthus plantation on earthworm density were found site-specific. Earthworm density doubled in AD-soils but did not vary in UW-soils. In UW-soils, we identified in a previous study a threshold metal content constrained earthworm densities. Hence, no earthworm were found in UW-soils containing Cd with more than 2.3 mg kg^{-1} (or e.g. Zn with more than 400 mg kg^{-1} since total concentrations of metal pollutants are closely correlated, please see Ref. [8] for more details). In that case, soil contamination probably still limited earthworm recolonization under miscanthus.

Regarding impacts on taxonomic diversity, it has been reported that biomass plantations generally hosted a larger species number of birds, butterflies or small mammals than comparable arable land [5,31]. Our results on soil macroinvertebrate community are consistent with such a trend, corroborating current knowledge on impacts of biomass cropping on soil invertebrates. It is generally stressed that biomass plantations have longer rotation periods, low fertilizer and pesticide requirements which provide an improved soil protection and a greater richness of spatial structures.

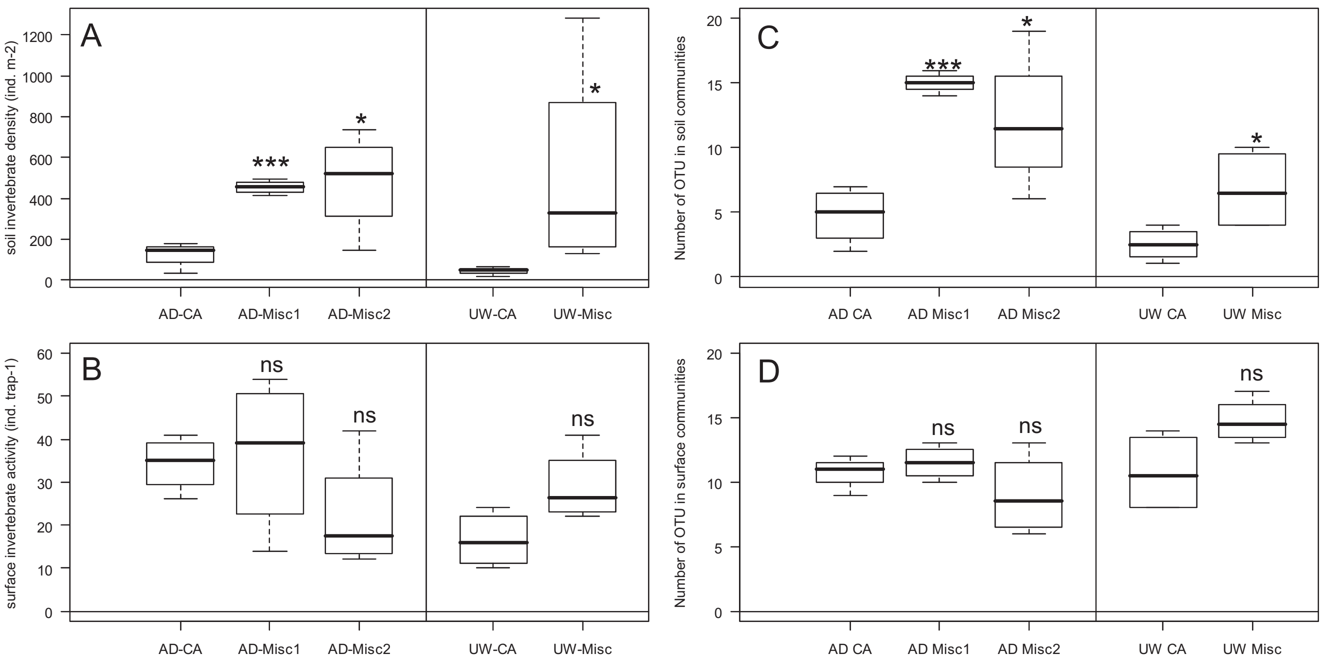

Fig. 1 – Effect (boxplot and whiskers) of miscanthus plantation on macroinvertebrate communities of two agricultural lands contaminated by trace metal (AD and UW) compared to annual crop (CA). Density (A) and taxonomic diversity (B) of soil-dwelling invertebrates; activity (C) and taxonomic diversity (D) of ground-dwelling invertebrates. Asterisks indicate significant differences between miscanthus and annual crop of each agricultural land.

Furthermore, harvesting is carried out in winter causing less impacts [6].

3.3. *Activity of ground surface' macroinvertebrates*

Miscanthus cropping did not significantly influence surface activity or diversity of invertebrate in both agricultural lands (Fig. 1-C). In clayey-silt textured AD-soils, the median was about 38 individuals per trap. A trend was revealed in UW-soils ($p = 0.059$), with an activity about 1.6-fold higher under miscanthus cropping (median values of 17 and 27 individuals per m^{-2}). Similar results have been recorded for ground beetles, that were 2-fold numerous in traps of the AD-soils than in UW-soils (6.7 and 3.3 individuals per trap, respectively). Taxonomic diversity at the soil's surface in both agricultural lands presented median values ranging from 8 to 11 (Fig. 1-D). Regarding ground beetles species diversity, no differences were found for UW-soils. In average, the species richness per point was 3.5 species and a total of 7 and 6 species were present in soils under miscanthus and annual cropping, respectively. By contrast, miscanthus grown on AD-soils hosted more (Misc1) or less (Misc2) ground beetle species than annual cropping (6.5, 2.0 and 3.5 species per point, respectively). A total of 8 species was found for Misc1 and annual cropping while 5 species were recorded in Misc2 site.

Our results showed that, whatever the site, miscanthus cropping led to neutral effects on activity or on taxonomic diversity of communities at the soil's surface. However, we observed contrasting results on ground beetles, for which miscanthus growing had positive, neutral or negative effects. Such findings are consistent with other studies indicating that biomass cropping may enhance [32] or decrease carabid diversity [33,34]. Moreover Ref. [32], showed carabid abundance to be highly variable between years.

3.4. *Functional traits distribution*

3.4.1. *Response to annual cropping*

Our results showed that annual crops of both agricultural lands displayed similar profiles in CWM of wing morphology, body size and food attributes. Macropterous and apterous individuals dominated (with CWM values about 40%) (Table 3). Very small (<5 mm) and small invertebrates (5–10 mm) represented 23% and 41–45% of the communities, respectively. Pooling the two other attributes together led to rather similar proportions of larger invertebrates (31–35%). Communities were dominated by invertebrates that preferentially feed on aerial plant material and living animals (28–33% and 47–50%, respectively) (Table 3). Congruence in trait profiles of both annual crops of the two sites is highly interesting considering agricultural land differences in terms of soil texture (sandy vs clayey silt), pollution origin (atmospheric deposition vs irrigation) and soil organic matter status (contents and C/N). Such findings suggest that a trait-based approach permits to capture the functional response hidden behind the structural response of communities. Annual cropping and moderate metal pollution can be viewed as sieves selecting macroinvertebrates according to their traits. These two environmental sieves limited or prevented the presence of large animals, of detritivore and rhizophage animals but promoted mobile, macropterous invertebrates. The domination of consumers (phytophages and predators) to the detriment of

Table 3 – Mean CWM for food, body size and wing morphology attributes in the invertebrate communities of the 5 studied soils. (Food) f1: roots, f2: aerial tissues of plants, f3: dead animals; f4: living animals; f5: plant detritus; f6: soil, f7: feces; f8: fungi; (Body size) bs1 < 5 mm, bs2 5–10 mm, bs3 10–20 mm, bs4 > 20 mm; (Wing morphology) wm1 apterous; wm2 brachypterous; wm3 macropterous. $, *, **, *** differed from corresponding annual crop for $p < 0.100$, $p < 0.050$, $p < 0.010$ and $p < 0.001$, respectively.

Areas	Crop	f1	f2	f3	f4	f5	f6	f7	f8	bs1	bs2	bs3	bs4	wm1	wm2	wm3
MetalEurop	Wheat	2.4 (1.2)	28.3 (4.5)	3.0 (2.2)	50 (6.0)	14 (1.7)	1.9 (0.1)	0.1 (0.1)	0.3 (0.1)	23.5 (4.2)	41.5 (3.9)	18.0 (2.4)	17 (2.2)	40.8 (5.4)	15.5 (3.4)	43.7 (6.7)
(AD-soils)	Miscanthus1	5.5 (0.8)$	**17.7 (0.7)***	0.6 (0.2)	55.8 (1.0)	18 (1.5)$	1.8 (0.3)	0.1 (0.0)	0.6 (0.2)	23 (0.9)	33.7 (1.1)$	**33.1 (1.8)*****	10.2 (2.1)$	**63.2 (3.1)***	11.0 (0.5)	**25.9 (3.0)***
	Miscanthus2	8.5 (2.4)$	**16 (1.8)***	1.1 (0.4)	42.6 (2.0)	15.4 (2.7)	**14.9 (1.6)*****	0.2 (0.0)	1.1 (0.4)	21.7 (2.2)	**25 (2.4)***	**26.2 (2.9)***	**27.1 (1.4)***	**73.9 (3.8)***	9.1 (1.3)	**17.0 (4.1)***
Pierrelaye	Wheat	0.1 (0.1)	33 (2.3)	3 (0.3)	47.4 (4.4)	7.1 (2.6)	0.3 (0.2)	6.1 (0.7)	3.0 (0.3)	23.7 (2.4)	45.3 (3.3)	28.8 (3.6)	2.2 (1.9)	43.1 (2.2)	15.2 (1.4)	41.6 (3.5)
(UW-soils)	Miscanthus	0.1 0.0	**21.2 (1.2)****	**1.9 (0.2)***	59.5 (4.0)	13.6 (2.8)$	0.9 (0.3)$	**0.0 (0.0)*****	2.8 (0.7)	24.8 (2.2)	46 (3.1)	24.5 (1.9)	4.7 (2.0)	**68.3 (1.4)*****	**9.0 (1.0)***	**22.7 (2.1)*****

Bold values are significant at $p < 0.050$.

saprophages and geophages illustrated simplified food-webs. Community indices based on nematoda food preferences have been used to highlight similar reduced food-webs in annual crops [35]. In spite of the low number of situations studied that restricts genericity of results, similarities shared by crops differing in soil texture and contamination origin suggest new hypotheses on contamination assessment in agroecosystems. Obviously, this result has to be reinforced by future studies with a larger set of plots.

3.4.2. *Changes induced by miscanthus plantation*

Under miscanthus plantation, the CWM of apterous individuals was significantly increased, reaching up to 74% and 68% of community in AD- and UW-soils respectively (1.85 and 1.6 fold higher than in annual crop). Such an increase was linked to a subsequent decrease in the CWM of macropterous individual (17–26%). Miscanthus plantation significantly changed body size distribution only in AD-soils. It increased the CWM of >20 mm animals in Misc2 plot (27%) and of 10–20 mm animals in both miscanthus plantations (26–33%) when compared with annual crop (17% and 18%, respectively). In UW-soils, no changes were recorded. Miscanthus plantation differs from annual crops by no-tillage management and a reduced use of inputs [36]. It can be hypothesized that such decreasing agricultural pressure under miscanthus plantation permitted the establishment of higher proportions of apterous (=resident) and of larger invertebrates (in AD-soils). Body size and dispersal ability are related to components of ecosystem functioning such as energy flow and population dynamics. Body size generally interacts with other correlated traits [37]. For instance, in water streams, large body size was associated with long life span and less than one reproductive cycle per year were reported as an indication for relatively stable habitats with a low frequency and intensity of disturbances [38]. Large carabid beetles are known to be more sensitive than smaller species because of their lower dispersal ability [28]. Similarly, large, anecic earthworms are sensible to soil physical disturbance [39,40]. Conversely, traits conferring rapid population growth, and thus resilience to disturbances, should be especially favored in disturbed habitats. For example Ref. [41], reported that the relative abundance of small-sized individuals should increase for many types of disturbances in water streams. In our work, the UW-soil environment seems to counterbalance the positive effects of miscanthus cropping since only a slight decrease in small invertebrate proportion was observed.

Under miscanthus plantations, a substantial decrease in animal feeding on aerial part of plants (either vegetative or reproductive) was recorded. This probably reflected canopy closing and a low number of advantices. However, it does not agree with [32] who argued that adventice seed availability at miscanthus floor favors plant (seed) eating carabid beetles. In our study, miscanthus cropping tended to an increase in root-feeding invertebrate proportion in AD-soils. Miscanthus induced an increase of saprophages and geophages in UW-soil ($p < 0.1$) and of saprophages (Misc1) and geophages (Misc2). Miscanthus cropping led to a new habitat resulting from the development of a litter layer at soil' surface and the development of an important root system. Soil organic matter accumulation in topsoil layers is often documented after conversion to no-till practices (e.g Ref. [42].). These modifications have enhanced the proportion of geo- and saprophages that, in turn, can relate to change in cycling of major elements and incorporation of organic matter [43].

Although community assembly theories have been successfully applied for many years in aquatic ecology or plant ecology [44,45], there is a little knowledge on soil invertebrate functional responses to environmental constraints (but see Ref. [46] for earthworms [47], for carabid beetles [8], for total soil macrofauna). Extensive studies are now needed for a better understanding of anthropic disturbance impacts on soil biodiversity in functional point of view.

4. Conclusion

In this study, we demonstrated that 3 years after establishment of *Miscanthus* $\times$ *giganteus* in trace metal contaminated soils, higher densities and diversity of soil-dwelling invertebrates were observed in comparison to annual crops on trace metal contaminated soils, but not of invertebrates highly mobile at soil' surface. A functional trait-based approach was used that highlighted the biological strategies involved in macroinvertebrate presence. Miscanthus plantations had higher proportion of resident (apterous), detritivores (saprophages and geophages) and rhizophages species. Moreover our approach revealed a trend of decreasing proportions of smallest individuals. The present work aims at promoting the potentiality of a trait-based approach in elucidating invertebrate responses to environmental constraints in complex media such as soils.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.biombioe.2013.01.016.

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