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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]. Functional traits of species are variously defined but essentially concern characteristics that

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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 (AD-soils)	Wheat	207	255	17	1.4	12	7.7	6.2	21.4	1.7	66	20	20	333	9	212	5
	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 (UW-soils)	Wheat	94	781	53	2.2	25	7.6	17.2	15.6	4.5	69	201	39	590	14	376	3
	Miscanthus	99	761	51	2.1	24	7.6	21.2	15.2	4.5	72	184	46	578	12	369	2