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Spatial and temporal heterogeneity of soil microorganisms and isoproturon degrading activity in a tilled soil amended with urban waste composts

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A B S T R A C T

Organic wastes addition may impact the pesticide behaviour in soils. Furthermore the incorporation of crop residues or organic amendments by ploughing can induce a heterogeneous spatial distribution of the added organic matter in the tilled layer. Spatial and temporal heterogeneity of soil microorganisms and isoproturon biodegradation was investigated at the decimetric scale in relation to the spatial distribution of organic matter originating from urban waste composts from 1 to 19 months after their incorporation through ploughing. We compared one control plot without compost addition and two plots receiving either municipal solid waste (MSW) compost or green waste co-composted with sewage sludge (SGW) every two years. According to morphological description, the ploughed layer was divided into four zones: the interfurrows, containing important quantities of fresh organic matter, the plough pan and two types of clods, the Δ clods (with no visible structural porosity) and the Γ clods (with visible macropores). Total organic carbon (C) and microbial and fungal biomasses were measured on homogeneous samples taken from each zone. Total C and isoproturon mineralization were monitored for two months at 2 sampling dates. At the end of incubation, samples were extracted to evaluate the nature and availability of isoproturon residues. The results showed that interfurrows constituted a special local environment with the highest level of microbial biomass and the highest isoproturon mineralizing capacities and respiration levels. The presence of compost in the interfurrows stimulated isoproturon biodegradation relative to controls. This effect was more pronounced for the MSW compost than for the SGW compost. Heterogeneity may persist several months after compost or stubble hiding depending on the nature of added organic matter.

1. Introduction

The biological treatment of organic wastes of urban origin (green waste, sewage sludge, municipal waste,...) via composting and compost application on cultivated soils has received increasing attention in France and more generally in Europe. Composts can be used as an organic amendment or fertilizer, thus overcoming, in the short term, loss of organic matter by erosion or leaching (Han et al., 2000; Parnaudeau et al., 2004) and reducing the use of artificial products. In parallel, this practice offers an alternative to the landfilling or incineration of organic wastes.

The impact of organic wastes addition on the pesticide behaviour in soils has been recently assessed (Albarran et al., 2004; Blacksaw et al., 2005). Indeed the important quantity of organic matter incorporated into the soil after organic waste application plays a major role in the transformation, sorption and transport of many organic pollutants (Albarran et al., 2004). Thus compost application may modify the efficiency, the persistence and the mobility of some pesticides (Worrall et al., 2001), but contrasting results have been reported in the literature (Briceno et al., 2007).

Organic matter application may affect the biodegradation of pesticides applied to cultures by i) stimulating the indigenous microflora (Abdelhafid et al., 2000) or by introducing exogenous microorganisms into the soil (Benoit and Barriuso, 1997), ii) altering pesticide mobility (Cox et al., 2001; Schneider et al., 2009) and thus contact probabilities with degrading microorganisms, iii) modifying local conditions that can be more or less favourable to microbial activities (Saison et al., 2006). Adding organic matter to soil may also impact pesticide sorption and so their bioavailability (Barriuso et al., 1997; Celis et al., 1998). Increased immobilization after compost application can slow down pesticide biodegradation (Barriuso et al., 1997). The stability and the degree of maturity of compost is an important factor of the modifications of pesticide sorption in amended soils (Pedra et al., 2007). Compared to precursor materials, compost organic matter generally presents a reduction in the water-soluble organic matter fraction and

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a larger aromaticity (Sluszny et al., 1999) due to humification. Aromaticity generally enhances the sorption of organic pollutants (Ahmad et al., 2001; Benoit et al., 2008). However, poorly-decomposed organic matter especially present in coarse fractions, i.e. particulate organic matter, may also represent reactive and accessible sorption sites (Benoit et al., 2008). Consequently, organic matter application could favour either degradation or immobilization of pesticides. The fate of pesticides in soil after compost application will depend on both quantity and nature of the added organic matter.

Another important controlling factor of pesticide fate could be the location of the added organic matter in soil. In agricultural fields, the spatial variability of pesticide degradation has been investigated to assess the persistence and the potential risk of contamination of ground and surface waters (Beck et al., 1996; Bending et al., 2001). These studies showed that pesticide degradation displays high spatial variability. For example, Beck et al. (1996) found that the time required for 50% reduction in the concentration of isoproturon ranged from 31 to 483 d in 25 different sampling areas (1 m^2) within an agricultural field. Vieublé Gonod et al. (2003, 2006) also showed that spatial variability of 2,4-D mineralization was important and increased from field to micro-habitat scale. But factors responsible for this heterogeneity are unknown. The relations between the fate of pesticides and the location of organic matter could be an interesting hypothesis to check. Indeed, the incorporation of crop residues or organic amendments by ploughing can induce a heterogeneous spatial distribution of the added organic matter in the tilled layer. However, to our knowledge, the impacts of this spatial variation on the fate of pesticides have not been assessed in details. Similarly, not much is known about the impact of the heterogeneous distribution of organic matter in tilled layers on the distribution of soil microorganisms and their activities. In this context, the objectives of this research were to study the spatial and temporal heterogeneity of soil microorganisms and their potential to degrade isoproturon, a herbicide largely used in winter cereals, in relation to organic matter localization in a ploughed soil. More specifically, the aims were to determine if i) the different zones identified according to morphological features in the tilled layer created by farming (Roger-Estrade et al., 2004) constituted different ecological niches for soil microorganisms, ii) the microbial characteristics (abundance and respiration activity) and the potential of isoproturon degradation in the defined zones changed with compost applications and with the type of compost and iii) heterogeneity changed with time.

2. Material and methods

2.1. Field site

The study was conducted at an experimental field located at Feucherolles (Yvelines, France). This field experiment was started in 1998 to investigate the long-term effects of repeated applications of urban waste composts on the soil fertility and the dynamics of mineral and organic pollutants either present in the soil or added with the compost. The soil is a silt loam Glossic Luvisol and contains on average 19% clay, 75% silt and 6% sand in the ploughed layer. It is cropped with a biannual rotation winter wheat-maize, where isoproturon is the main herbicide used on the wheat crop. Two composts have been applied in September once every two years between 1998 and 2006: a co-compost of sewage sludge and green waste (SGW) and a municipal solid waste (MSW) compost. Compost characteristics (before their application to soil) are presented in Table 1. Each compost application represented an addition of 4 tons of organic C per ha. To compare, in the control plot that does not receive compost, C inputs by the stubble alone were estimated to 1 ton of organic C per ha (Mary and Recous, 1994). Since 1998, compost application has increased soil organic C content relatively to the control plot (Schneider et al., 2009). Between 1998 and 2006, soil organic carbon contents increased from 10.5 ± 1.0 to 12.4 ± 1.1 g kg^{-1} soil for the SGW plot and from 10.3 ± 0.7 to 11.3 ± 0.8 g kg^{-1} soil for the MSW plot. On the contrary, carbon content remained constant in the control plot: 10.6 ± 0.2 in 1998 and 9.8 ± 0.6 g kg^{-1} soil in 2006. No difference was found for the total N content (Schneider et al., 2009).

Table 1
Characteristics of the co-compost of sewage sludge and green waste (SGW) and the municipal solid waste (MSW) compost. Average and standard errors (numbers in parentheses) were calculated from compost analyses in 1998, 2000, 2002, 2004 and 2006.

	SGW compost	MSW compost
C (g kg^{-1} dry matter)	282 (69)	289 (23)
N (g kg^{-1} dry matter)	22.8 (4.2)	18.5 (2.2)
C/N	12.5 (2.9)	15.7 (0.8)
pH_{water}	7.7 (0.9)	7.4 (0.5)
Bacteria[a] (CFU g^{-1} dry soil)	16.10^6 (3.10^6)	8.10^6 (2.10^6)
Fungi[a] (CFU g^{-1} dry soil)	$1200 \cdot 10^3$ ($120 \cdot 10^3$)	$291 \cdot 10^3$ ($32 \cdot 10^3$)

[a] Analyses carried out on the SGW and MSW composts in 2002.

2.2. Field observations and soil sampling

The three plots studied were two compost-treated plots receiving either SGW or MSW compost, and a control plot without compost application. In the different plots (450 m^2 each), stubble disking (10–15 cm depth) was performed one day after compost application in early September 2004 and 2006. Two months after compost application, the soil was ploughed (28 cm depth) using a four-body mouldboard plough (ploughing width of 40 cm). In the following spring (April) maize seedbed was prepared using a tine cultivator (depth ranged from 0 to 10–15 cm) before maize implantation. Maize was harvested in October 2005. The soil was ploughed again in November 2005 just before wheat sowing. Wheat harvest occurred in August 2006 (Fig. 1).

Soil structure description in the ploughed layer was based on the visual observation of soil macroscopic features on a vertical face of a soil pit (45 cm deep and 2 m wide) perpendicular to the tillage direction (Gautronneau and Manichon, 1987). The soil structure was described in each plot at different dates: January 2005, 2 months after ploughing, March 2005, 4 months after ploughing, May 2005, after seedbed preparation and maize sowing, April 2006, 5 months after ploughing and October 2006 few days after stubble disking but before mouldboard ploughing. This last operation incorporated and mixed the freshly added compost to the wheat stubble in the 0–10 cm layer. Regarding to the anteriority of compost amendments, the different sampling dates corresponded to 1 (October 2006), 4 (January 2005), 6 (March 2005), 8 (May 2005) and 19 (April 2006) months after compost application.

Four soil compartments were identified: interfurrow that corresponds to the ancient stubble disked layer before inversion by the plough and contains a large quantity of compost and/or crop residues from the preceding crop; the ploughed pan at the base of the ploughed layer; two types of clods called Δ (compacted clods) and Γ (well structured clods with visible macropores) (Fig. 2). Samples were taken horizontally from each soil observation face using cylinders of 2.5 cm diameter and 4 cm length. At each date and in each plot, 10–15 samples from each observed soil compartment were collected and pooled to constitute a representative mean sample after homogenization by sieving at 3.95 mm.