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Impact of spatial distribution of exogenous organic matter on C mineralization and isoproturon fate in soil

Laure Vieublé Gonod [a,*], Achouak El Arfaoui [b], Pierre Benoit [b]

[a] AgroParisTech, UMR 1402 ECOSYS (Ecologie Fonctionnelle et Ecotoxicologie des Agroécosystèmes), Av. L. Brétignières, 78850 Thiverval Grignon, France
[b] INRA, UMR 1402 ECOSYS (Ecologie Fonctionnelle et Ecotoxicologie des Agroécosystèmes), Av. L. Brétignières, 78850 Thiverval Grignon, France

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ABSTRACT

Organic matter (OM) is known to affect the behaviour of pesticides in soil (transfer, degradation, retention). In cultivated soils, crops residues and compost incorporation by ploughing results in a heterogeneous OM distribution in soil with the formation of spots with a mm to dm size. This study aimed to compare the impact of OM (straw and compost) addition and its spatial distribution in soil on the total mineralization and the fate of isoproturon (IPU) in cm repacked soil cores. OM was homogeneously or heterogeneously (in small spots or in a larger spot) distributed in the soil cores. ^{14}C IPU was uniformly added at the regular agronomic dose to the soil and OM. We followed total carbon mineralization, ^{14}C IPU mineralization, and extractable and non-extractable ^{14}C residues during a 43-days incubation. We analysed the fate of ^{14}C at the core scale, and characterised what happened separately on soil and spots of OM after their separation. The results showed that i) the addition of exogenous OM stimulated microbial respiration, but the effect was similar regardless of the spatial distribution of OM in soil (13.9%–19.5% of the total organic carbon); ii) IPU degradation was negligible in OM but was significantly stimulated when OM was added to soil (compared to soil incubated alone) up to a factor of 2; iii) the fate of IPU was impacted by the OM spatial distribution in soil locally and at the core scale and degradation and mineralization was maximal when compost was homogeneously distributed in soil; and iv) these effects were different for maize straw and compost. The nature of OM and its spatial distribution that can be impacted by agricultural practices seem to be important factors to be considered to better understand the fate of pesticides in soil and their transfer to superficial or underground water.

1. Introduction

Conventional agriculture uses large amounts of pesticides and some of them, such as isoproturon (IPU), are frequently found in natural waters at concentrations exceeding the European regulatory limit for drinking water of 0.1 $\mu g\ l^{-1}$. Leaching through soils has been identified as a major source of pesticide contamination of aquifers (Barbash et al., 2001; Gaw et al., 2008). The risk of groundwater being polluted depends on the soil capacity to degrade and/or retain pesticides (Ana'Yeva et al., 1986). The fate of a pesticide in soil is affected by many factors (e.g., soil constituents, microorganisms, moisture status, etc). Among these, organic matter (OM) is considered to be of major importance because of its implication in several processes (Pieuchot et al., 1996). Thus OM in soil was shown to promote the retention and immobilisation of pesticides in soil (Barriuso et al., 1997; Benoit and Preston, 2000) or alternatively stimulate their biodegradation (Sorensen and Aamand, 2001). These contrasted effects are related not only to the pesticides properties but also to the nature of OM. For example, Dolaptsoglou et al. (2007) observed that the addition of poultry compost and urban sewage sludge delayed the degradation of terbuthylazine, whereas the addition of corn straw did not significantly alter its degradation.

Applying organic amendments is a current agricultural practice which gets more importance due to its benefits in maintaining soil fertility and its potential to substitute mineral fertilizers. However, their incorporation in soil by ploughing creates a spatially heterogeneous distribution of OM. Vieublé-Gonod et al. (2009) noted that, when characterising soil profiles at a decimetre scale after the addition of different organic amendments in a cultivated soil, different zones that were more or less enriched with OM could be discerned. They showed that interfurrows constituted a particular

* Corresponding author. Tel.: +33 130815269.
E-mail address: lvieuble@grignon.inra.fr (L. Vieublé Gonod).

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environment with the highest content of the C incorporated by the mouldboard plough, as well as the highest level of microbial biomass and microbial activity. This heterogeneity may persist several months after compost or stubble burying, depending on the nature of the added OM (Vieublé-Gonod et al., 2009). In the same study, Vieublé-Gonod et al. (2009) showed that IPU degradation was stimulated in interfurrows enriched with OM, such as crop residues or compost. These results were obtained with field samples that were destructured and homogenised before laboratory incubation experiments. In field conditions, OM may be concentrated in spots (even in interfurrows). These spots are likely to create specific local conditions with high microbial activity, and it can be assumed that they may also affect the fate of pesticides. When pesticides are transported in soil pores, they may encounter either OM or other soil constituents in function of the size and the localization of these organic hot spots in soil.

A few studies have considered the impact of the localization of crop residues in soil on their decomposition (e.g., Abiven and Recous, 2007), but to our knowledge, none of them have addressed the impact of the spatial distribution of OM on the fate of pesticides in soil.

Consequently, the objectives of this study were to investigate the impact of different spatial distributions of OM on widespread and specific microbial activities in repacked soil cores. Homogeneous and heterogeneous distributions were considered at the cm scale for two different types of organic materials typically incorporated in the field: maize straw and municipal solid waste compost. More specifically, we aimed to determine whether the addition and spatial distribution of exogenous OM had an effect on the overall C mineralization and the fate of IPU, and whether these effects depended on the quality of the buried OM.

2. Materials and methods

2.1. Soil, straw and compost

Soil was sampled in January 2006 in the ploughed layer (0–20 cm) of a fertilised control plot cropped with a biannual rotation winter wheat-maize (*Triticum* spp.-*Zea mays L.*). This plot belongs to an experimental field located at Feucherolles (Yvelines, France) that is used since 1998 to investigate the long-term effects of repeated applications of urban waste composts on soil fertility and the dynamics of mineral and organic pollutants either present in the soil or added with composts. The soil is a silt loam Albeluvisol (FAO classification) and contains on average 19% clay, 75% silt and 6% sand in the ploughed layer. The soil characteristics are presented in Table 1. The soil was sieved moist, and only aggregates with a diameter ranging from 2 to 3.15 mm were kept.

Two types of OM were used for the experiments: a maize straw collected from the surface of a soil after harvest in October 2005 and composted municipal solid waste (MSW) that is used at the experimental site of Feucherolles. The MSW compost came from the composting platform of Murianette (38, France) and has been prepared from kitchen waste (25%), cardboard (24%), green wastes (17%), glass (14%), plastics (6%) and others materials (14%). The maize straw was in a similar state of decomposition than the crop residues buried by ploughing at the field site. The straw was cut before sieving to 5 mm. The compost was also sieved to 5 mm. The characteristics of the organic amendments are presented in Table 1.

2.2. Soil, OM and soil-OM cores construction

The quantities of straw and compost (8 mg of straw and 17 mg of compost per g of dry soil) added to the soil-OM cores were adjusted according to the carbon contents measured in the interfurrows of the control plot (that received only crop residues) and the plot amended with the MSW compost for 7 years (Vieublé-Gonod et al., 2009). The final C contents in the soil-OM cores were 12.8 and 14.4 g of C kg^{-1} of dry material for the soil-straw and soil-compost cores, respectively.

We worked with an aqueous solution of ^{14}C-ring labelled IPU (International Isotope, 847.3 MBq $mmol^{-1}$, purity > 90%). Two solutions were prepared; one was used to amend the soil (5.1 mg l^{-1}), and another one was used to treat the OM (3.6 mg l^{1}). The final water content of soil and OM corresponded to 80% of the maximum water holding capacity (Table 1). The IPU concentration, identical in the soil and OM, was 0.29 mg kg^{-1} (1.17 kBq g^{-1}). Such a concentration represents approximately the agronomic dose of 1.2 kg ha^{-1}. Immediately after the IPU application, soil, OM and soil-OM cores were prepared.

Cores were progressively prepared in plexiglas rings (before being demoulded) by adding 7 successive layers containing OM, soil or soil and OM, according to five different spatial distributions as shown in Fig. 1: i) microcosms with organic matter alone (OM controls) to evaluate microbial processes associated to straw and compost; ii) control cores containing only soil (soil controls); iii) cores with a homogenous distribution of OM in the soil (called H). The soil and OM were separately treated with IPU and then mixed before the construction of the cores; iv) cores with a heterogeneous spatial distribution of OM in the soil: the OM was concentrated in a large spot of 12 × 12 × 18 mm in the central part of the core (named 1S in the following). v) cores with a heterogeneous spatial distribution of OM in the soil: the OM was distributed in 12 small spots of 6 × 6 × 6 mm that were localized in 3 non-consecutive layers (4 spots per soil layer) (named MS in the following).

The cores were consistently compacted to obtain a final dry bulk density of 1.20 ± 0.05 g cm^{-3}, a density commonly observed in the ploughed layer of cultivated soil (Défossez et al., 2003). The use of aggregates in the 2–3.15 mm size class range resulted in cores with a total porosity of approximately 50%, creating favourable conditions for microbial activity. The final cores measured 3-cm in height and 5-cm diameter. The dry mass of the final cores was 76.6 g. Nine replicates per spatial distribution (3 per date) were carried out. The OM, soil and soil-OM cores were incubated in 1 L airtight jars under laboratory-controlled conditions (28 °C, 80% of maximum water holding capacity) for 43 days. The air exchange to ensure aerobic conditions was achieved by opening jars regularly over time when changing NaOH used to trap the evolved CO_2.

2.3. Total organic carbon and IPU mineralization at the core scale

The total organic carbon mineralization was measured in all of the microcosms throughout the incubation. The evolved CO_2 was trapped in 20 ml of 0.5 N NaOH that was changed after 3, 7, 14, 21,

Table 1
Soil, compost and straw characteristics.

	W_{MWHC} (g water 100 g^{-1} dry material)	C (g kg^{-1} dry material)	N (g kg^{-1} dry material)	C/N	pH
Soil	27.8	9.7	1.0	9.7	6.9
Compost	57.3	294.2	19.3	15.2	
Straw	257.5	403.6	9.2	44.0	

W_{MWHC}: maximum water holding capacity.