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Modeling water and isoproturon dynamics in a heterogeneous soil profile under different urban waste compost applications

Vilim Filipović [a,b,c,*], Yves Coquet [b], Valérie Pot [c], Sabine Houot [c], Pierre Benoit [c]

[a] Department of Soil Amelioration, Faculty of Agriculture, University of Zagreb, Svetošimunska 25, 10000 Zagreb, Croatia
[b] Université d'Orléans, ISTO, UMR 7327, 45071, Orléans, France; CNRS/INSU, ISTO, UMR 7327, 45071 Orléans, France; BRGM, ISTO, UMR 7327, BP 36009, 45060 Orléans, France
[c] UMR ECOSYS, INRA, AgroParisTech, Université Paris-Saclay, 78850 Thiverval-Grignon, France

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ABSTRACT

Compost amendments and tillage practices can modify soil structure and create heterogeneities at the local scale. Tillage affects soil physical properties and consequently water and solute transport in soil, while compost addition to soil influences pesticide sorption and degradation processes. Based on the long-term field experiment QualiAgro (a INRA–Veolia partnership), a modeling study was carried out using HYDRUS-2D to evaluate how two different compost types combined with the presence of heterogeneities due to tillage affect water and isoproturon dynamics in soil compared to a control plot. A municipal solid waste compost (MSW) and a co-compost of sewage sludge and green wastes (SGW) have been applied to experimental plots. In each plot, wick lysimeters, TDR probes, and tensiometers were installed to monitor water and solute dynamics. In the plowed layer, four zones differing in their structure were identified: compacted clods, non-compacted soil, interfurrows, and the plow pan. From 2004 to 2010, the unamended control (CONT) plot had the largest cumulative water outflow (1388 mm) compared to the MSW plot (962 mm) and SGW plot (979 mm). After calibration, the model was able to describe cumulative water outflow for the whole 2004–2010 period with a model efficiency value of 0.99 for all three plots. The CONT plot had the largest isoproturon cumulated leaching (21.31 μg) while similar cumulated isoproturon leaching was measured in the SGW (0.663 μg) and MSW (0.245 μg) plots. The model was able to simulate isoproturon leaching patterns except for the large preferential flow events that were observed in the MSW and CONT plots. The timing of these preferential flow events could be reproduced by the model but not their magnitude. Modeling results indicate that spatial and temporal variations in pesticide degradation rate due to tillage and compost application play a major role in the dynamics of isoproturon leaching. Both types of compost were found to reduce isoproturon leaching on the 6 year duration of the experiment.

1. Introduction

Compost application to soils is getting more importance due to its benefits in improving crop productivity and soil quality. It has been accepted as an ecological method for the disposal of organic wastes, while maintaining or increasing soil fertility at the same time (Diacono and Montemurro, 2010). Many types of compost made from municipal solid waste, sewage sludge or farmyard manure are applied nowadays to agricultural soils. These various compost ingredients can be mixed together in different amounts and may generate different impacts on agroecosystems. Compost addition to soil tends to affect soil physical properties by increasing soil aggregate stability (Annabi et al., 2011), plant available water and soil porosity (Curtis and Claassen, 2005), and by decreasing bulk density in the same time (Wong et al., 1999). In European conventional agriculture, compost is incorporated to soil by moldboard plowing. In addition to compost application, tillage can also affect soil hydraulic properties (Strudley et al., 2008; Alletto et al., 2010). Schneider et al. (2009) found that tillage had greater influence on soil saturated hydraulic conductivity than urban waste compost addition. Combining compost addition with moldboard plowing can create compacted soil zones next to non-compacted soil zones containing large amounts of organic material. Large differences in soil hydraulic properties can be expected between these different soil zones, which can have significant effects on water and solute distribution within as well as beneath the tilled layer (Coquet et al., 2005a).

In addition to their effects on soil hydraulic properties, compost amendments have been shown to impact pesticide transport in soil. Pesticide mobility in soil can be decreased by increased sorption on compost material (Filipe et al., 2010) depending on pesticide properties and compost type. According to other authors (Yang et al., 2005; Cabrera et al., 2007), pesticide mobility can be increased due to the higher content of dissolved organic carbon caused by soil organic matter addition.

* Corresponding author at: Department of Soil Amelioration, Faculty of Agriculture, University of Zagreb, Svetošimunska 25, 10000 Zagreb, Croatia.
E-mail address: vfilipovic@agr.hr (V. Filipović).

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Dolaptsoglou et al. (2007) showed that addition of poultry compost and urban sewage sludge in a clay loam soil reduces terbuthylazine degradation compared to non-amended soils, while the addition of corn straw did not modify it. Kodešová et al. (2012) found that chlortoluron mobility in a Luvic Chernozem soil decreased up to a compost content in soil of 6%, and then increased with larger compost contents (7% and 8%).

Pesticide fate in soil is controlled by sorption and degradation processes that can have large spatial variability in soil at the field scale (Beck et al., 1996; Benoit et al., 1999). One of the most frequently used herbicides in European agriculture is isoproturon (IPU) [3-(4-isopropylphenyl)-1,1-dimethylurea] which is used to control weeds in cereal crops (such as wheat and barley) and is one of the most detected herbicides in surface and ground waters, especially in France (SOeS, 2012). Consequently, its dynamics and fate in soil need to be clarified through laboratory and more importantly field experiments. Vieublé-Gonod et al. (2009) conducted a research on the spatial and temporal heterogeneity of IPU biodegradation at the decimetric scale in relation to the spatial distribution of organic matter originating from urban waste compost application. Data showed that the interfurrows resulting from the incorporation of stubble and compost into the soil by plowing and located between the furrows created by the plow constituted a special local environment with the highest level of IPU mineralization. Isoproturon mineralization in the interfurrows depended on the amendment type: it was more pronounced for municipal solid waste compost than for a sewage sludge and green waste co-compost, while the control plot had the lowest mineralization rate (Vieublé-Gonod et al., 2009).

Numerical models can be used to study the effect of compost incorporation on pesticide fate in soil. Coquet et al. (2005b) used HYDRUS-2D to simulate water flow and bromide transport in a soil profile that contained compacted and non-compacted soil zones. Filipović et al. (2014) used a similar method for simulating water flow and isoproturon dynamics in a heterogeneous soil profile receiving a co-compost of sewage sludge and green wastes during a multiannual period. After calibration of the soil hydraulic parameters and optimization of the isoproturon degradation rate on a limited period of time (9 months), HYDRUS-2D was able to successfully reproduce water and isoproturon dynamics during the whole 6-year period of study.

The objective of our work was to evaluate how the application of two different types of urban compost – a municipal solid waste compost (MSW) and a sewage sludge and green waste co-compost (SGW) – to a plowed soil impacts water flow and isoproturon dynamics during a 6 year time period. The HYDRUS-2D model was used to simulate water flow and isoproturon fate in plots receiving each of these two composts and in a control plot (CONT) without compost addition.

2. Materials and methods

2.1. Site and compost characteristics

The field experiment was set up in Feucherolles (Yvelines, France) as part of the QualiAgro long-term study (Houot et al., 2002). The soil is an Albeluvisol (World Reference Base classification, IUSS, 2014) containing 19% clay, 75% silt, and 6% sand on average in its tilled layer. The soil profile was composed of five horizons which were determined on the field site: a tilled loamy LA horizon, an eluviated silt loam E horizon, an illuviated silty clay loam BT horizon, a transitional silty clay loam BT/IC horizon, and a silty loam structure-less decarbonated loess IC horizon, with some small variations in thickness of the soil horizons depending on the plot. The basic soil characteristics are presented in Table 1. The field has been cultivated since 1998 with a biannual rotation of winter wheat (*Triticum spp.*) and maize (*Zea mays L.*). Exception was made in 2006/07 when barley (*Hordeum vulgare* L.) was grown due to corn rootworm (*Diabrotica virgifera virgifera* L.) infestation. Urban waste composts were applied over wheat or barley stubble and disking was immediately carried out to incorporate composts and stubbles within the upper soil layer (first 25 cm). A four-furrow moldboard plow was used for tillage every autumn to a depth of 28 cm (plowing width of 40 cm). A detailed calendar of agronomic practices can be found in Filipović et al. (2014). The field had been divided into 40 experimental plots (45 × 10 m) with five treatments replicated four times in a randomized complete block design (Fig. 1a). Four different organic amendments have been applied: a municipal solid waste compost (MSW) made from residual municipal wastes after the selective collection of dry and clean packaging a biowaste compost (BIO) made from the selectively collected fermentable fractions of municipal wastes co-composted with green wastes; a compost resulting from the co-composting of sewage sludge and green wastes (SGW); and a farmyard manure (FYM) obtained from a dairy farm. These four organic treatments were compared to a control treatment (CONT) that did not receive compost amendment. The composts have been applied every second year (a supplementary compost application was made in September 2007 after the barley crop) starting 1998 in an amount of 4 t of organic carbon per ha.

Table 1
Average soil properties for the SGW, MSW and CONT plots (mean of 4 replicate plots)[a].

Treatment	Depth of soil horizon	C org	C/N	pH	Clay	Silt	Sand	CEC
	(cm)	g kg^{-1}			%			mol kg^{-1}
SGW	LA horizon 0–28	15.14	10.7	6.86	13.5	79.5	7.0	0.999
	Plow pan 28–38	11.23	9.8	6.94	15.5	78.1	6.4	0.877
	E horizon 38–50	4.78	8.2	7.15	21.6	73.5	4.9	0.991
	BT horizon 50–90	3.20	7.1	7.29	29.4	67.1	3.5	1.425
MSW	LA horizon 0–28	13.53	11.6	7.51	14.1	78.9	7.0	1.019
	Plow pan 28–38	11.22	10.2	7.64	15.9	78.0	6.1	0.936
	E horizon 38–50	4.78	8.4	7.63	19.8	74.2	6.0	1.003
	BT horizon 50–90	2.91	6.8	7.67	29.6	67.4	3.0	1.476
CONT	LA horizon 0–32	10.12	10.7	6.63	14.5	79.0	6.5	0.738
	Plow pan 32–43	9.20	9.8	6.84	17.5	76.2	6.3	0.773
	E horizon 43–50	4.40	7.9	7.03	20.5	73.8	5.7	0.828
	BT horizon 50–90	2.87	6.8	7.27	30.1	66.6	3.3	1.075

[a] The plow layer of each of the 20 plots of the field experiment (5 treatments × 4 repetitions — see Fig. 1a) has been sampled after the experiment in March 2010. A campaign had been dedicated to sub-layers from the 28 to 90 cm depth, with a similar objective, i.e., one representative sample per plot, prepared from about 30 drillings.

For this modeling study three plots have been selected: one plot receiving the MSW compost (average analytical characteristics for the 1998–2009 period corresponding to seven compost applications: $pH_{MSW} = 7.4 \pm 0.4$, $OM_{MSW} = 562 \pm 99$ g kg^{-1}, $C/N_{MSW} = 16.0 \pm 2.8$), one plot receiving the SGW compost ($pH_{SGW} = 7.6 \pm 0.7$, $OM_{SGW} = 454 \pm 65$ g kg^{-1}, $C/N_{SGW} = 10.8 \pm 2.3$), and a control plot. The three plots were selected close to one another (Fig. 1) for monitoring water and pesticide transport. The soil physical and chemical properties in the plowed layer (0–28 cm) were measured at the beginning of the agronomic experiment in 1998 (Table 2) and confirmed the homogeneity of the field site. In addition, an electrical resistivity prospection has been performed in 2004 (Fig. 1b) and showed that the field site was homogeneous and that the largest variations of apparent electrical resistivity were found at the edges of the field. The selected plots had similar ranges of electrical resistivity variation.

In December 2004 large soil pits (45 cm deep and 2 m wide) were dug in each of the three plots and were described according to Manichon's (1982) method (Fig. 2). This method is used to describe the soil structure of the tilled layer of agricultural fields. It is based on the visual observation of soil macroscopic features on the vertical face of a large soil pit oriented perpendicular to the tillage direction (Coutadeur et al., 2002; Roger-Estrade et al., 2000). The soil profile was divided into vertical and horizontal compartments according to the effects of the tillage implements and the internal structure of each of these compartments. Three types of compartments were distinguished in the tilled layer (Fig. 2):

– The furrows — correspond to the soil which has been cut and rotated by the moldboard plow. Macroporous soil zones, noted Γ, and